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Domain knowledge, ability, and the principal's authority relations

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I consider how different managerial traits affect the authority relation between a principal and his agent. An increase in the principal's domain knowledge—which enhances his capability to verify the agent's recommendations—leads to an increase in the proportion of the agent's recommendations that are approved, an increase in the agent's initiative, and is unambiguously beneficial to the principal and to the agent. In contrast, an increase in the principal's general ability to explore additional alternatives on his own leads to the principal making a larger proportion of the decisions. This discourages the agent's initiative and can adversely affect the principal.

1. Introduction

■ A substantial body of empirical evidence shows that the career experience of senior managers has a significant effect on their behavior and on the characteristics of their organizations. For example, Barker and Mueller (2002) find that firms headed by CEOs who spent most of their careers in marketing or engineering/R&D groups tend to spend significantly more on R&D whereas Xuan (2009) shows that a CEO's job history has a significant effect on the capital allocation decisions in multidivisional firms. From a practical perspective, understanding the significance of such managerial firm- or industry-specific knowledge should help determine the criteria for choosing among candidates for the CEO and other senior managerial positions.[1] A firm may debate whether to limit the search to a narrow pool of internal candidates with abundant firm-specific knowledge, or to expand the search to include candidates from outside the firm, who may lack such knowledge but may possess superior general managerial abilities.

Although evidence on the significance of managerial characteristics is abundant, very little theoretical analysis of these issues can be found. In this article, I consider the effect of the principal's characteristics on his authority relations with his subordinates. I investigate which characteristics are more likely to lead him to decentralize decision-making authority

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[1] Similar questions arise also in other contexts, such as deciding on the qualifications required of government cabinet ministers. In Israel, a heated public debate has erupted as to whether a politician lacking a military background is qualified to serve as defense minister. See, for example, *Ynet News*, "War Report Scathing for Olmert, Peretz," April 29, 2007.

to his subordinates or to take on more of the decision making himself and consider the effects on the subordinates' initiative, cooperation with the principal, and the overall organizational outcomes.

The basic setup, which builds on Aghion and Tirole (1997), considers an agent who evaluates several alternative courses of action, and makes a recommendation to the principal, who then reviews the information presented and decides whether to follow the recommendation or to evaluate other alternatives on his own. This setup is characteristic of many principal-agent relationships, such as those between a CEO and a division manager; a secretary of defense and the army's chief of staff; a university tenure committee and an academic department, etc.

Drawing on research in cognitive psychology reviewed toward the end of this section, I distinguish between two key principal's characteristics: the principal's *domain-specific knowledge* and his *general abilities*. A principal with a rich domain knowledge has a good understanding of the decision at hand, alternative solution routes, and the trade-offs involved with each one of them. He is experienced and may have served in the past in the same position as the agent (e.g., as a division manager in the CEO example). The knowledgeable principal is more capable of disseminating, processing, and verifying the information presented to him by the agent than another principal who is relatively lacking such domain knowledge (e.g., a new CEO from another industry). To put things slightly differently, the extent of the principal's domain knowledge determines the amount of "hard" information that the agent can effectively transmit to him.

Principals also differ in their general managerial abilities and talents. These reflect cognitive abilities, such as intelligence, and possibly also personality traits such as diligence and motivation. The more able is the principal, the easier it is for him to explore other alternatives on his own if he decides not to follow the agent's recommendation. One of the main contributions of this article is to show that these two distinct managerial characteristics have very different implications on the authority relations between the principal and the agent.

The preferences of the principal and the agent regrading the decision at hand are not fully aligned. For example, a division manager wishing to develop a new product may ignore potential adverse effects on the sales of other divisions, realizing that he will be evaluated by the CEO based only on the success of his division. In view of these private benefits, the agent exerts effort in evaluating the alternatives in order to tilt the decision in the direction he favors. However, given the sequential setup, the agent is aware that by presenting the principal with a more favorable recommendation, he may reduce the principal's incentive to exert effort in exploring other alternatives. The agent thus has an incentive to strategically compromise and recommend an alternative which is between his own preferred alternative and the principal's best choice. This aspect of the model distinguishes it from Aghion and Tirole's (1997) setup and allows to study how the outcomes depend on the type of communication that exists between the agent and principal (determined here by the principal's knowledgeability).

The effect of the different principal's characteristics is considered in Section 3. I show that an increase in either of the principal's characteristics (knowledge or ability) induces more compromise from the agent. However, in other respects, the effects of an increase in the two principal's characteristics are markedly different. An increase in knowledge induces the principal to exert less effort and the agent to exert more. Decision making becomes more decentralized: the principal overrules the agent in fewer instances and the agent's real authority–the frequency with which the agent's recommendation is followed–increases. In contrast, an increase in the principal's ability to explore other options often leads to a decrease in the agent's effort, an increase in the principal's effort, and a reduction in the agent's real authority and utility. Due to the dampening effect on the agent's initiative, the overall implications on the principal of an increase in his ability are in general ambiguous and can be negative. In contrast, an increase in the principal's knowledge leads unambiguously to a higher utility for both the principal and the agent.

In Section 4, I consider two extensions of the basic model. In the first, I consider the concept of "managerial style" by endogenizing the principal's choice whether to consult the agent at all.

I show that less knowledgeable managers and higher ability managers are more likely not to consult the agent at all, whereas more knowledgeable managers are more likely to wait and allow the agent to make a recommendation first. In the second extension, I consider two agents who serve under the same principal. Although the two agents are assigned to independent areas, their actions are interdependent because the principal's efforts in the two areas are cost substitutes. I show that an increase in the principal's knowledge in only one of the areas induces both agents to improve their recommendations to the principal. However, the area in which the principal is more knowledgeable becomes "prominent." The principal reduces his effort in this area, which allows him to direct more effort to the other. This encourages the first agent to exert more effort but limits the second agent's real authority and discourages his initiative.

□ **Related literature.** This article is related to a vast literature on the strategic interaction between informed agents and uninformed principals. A seminal contribution is Crawford and Sobel (1982) who consider a pure cheap talk communication environment. The model has multiple equilibria, and the one in which the most accurate information is transmitted is Pareto superior to all other equilibria. Similarly here, both parties benefit when the quality of communication between them improves, but for very different reasons.

A more recent article, Armstrong and Vickers (2010), studies a setup in which an agent observes several projects and chooses one to present to the principal, who can verify its value but does not observe the other projects available to the agent. In contrast to the present analysis, the principal commits to approve only projects that fall within a set which is publicly determined *ex ante* and is unable to independently evaluate projects not presented by the agent. Armstrong and Vickers study the properties of such an optimal "permission set."

More directly, my article relates to a literature in which the acquisition of information by the principal and the agent is endogenous. A seminal contribution is the article by Aghion and Tirole (1997) on authority relations. A key difference with Aghion-Tirole's setup is that they assume that the principal and agent exert effort simultaneously. As the agent's recommendation is only considered when the principal has failed to become informed, it will be followed whether it can be verified or not. Consequently, as long as the parties are sufficiently congruent, the agent always recommends his favorite outcome. In contrast, the agent's recommendation in the sequential setup considered here is strategic, and the agent has an incentive to compromise in order to reduce the principal's incentive to exert effort. Moreover, the degree of compromise is sensitive to the principal's characteristics (knowledge and ability), as these characteristics determine the likelihood that the recommendation would be verified and the likelihood of the principal taking action.

Another closely related article is Rantakari (2012), who establishes a result where a decrease in the principal's cost of effort can lead the agent to recommend a better alternative to the principal. Rantakari's setup is simultaneous and the agent's effort is two dimensional. One dimension determines the value of his idea to the principal, and thus the probability that the agent's idea would be chosen over the principal's, whereas the other determines the agent's private benefits in case his idea is implemented. As a result of a reduction in the principal's cost of effort, the agent exerts less effort toward improving his private benefits. The effect on his effort in the principal's dimension is nonmonotone and depends on the initial probability of his idea being implemented (effort increases if and only if this initial probability is sufficiently high).The key qualitative difference between the models is that here information transmission between the agent and principal is imperfect (whereas in Rantakari's model, the principal is fully informed about the value of the agent's idea). The issue of how the agent's compromise depends on the nature of information transmission thus does not arise.

In Newman and Novoselov (2009) it is the agent who may turn to the principal for help if his own effort to determine the correct action fails. The agent may be reluctant to turn to the principal if following the advice is mandatory, because it is optimal for him to accept the advice only if the principal succeeds to become informed. Newman and Novoselov study how the choice to mandate following the advice affects the agent's and the principal's incentives to exert effort and the agent's motivation to communicate problems to the principal.

Several articles have emphasized the role that the type of communication transmitted between agents and principals (hard vs. soft information) plays. Stein (2002) explores the link between the type of information and the optimal decentralization of decision making. In his analysis of banks' lending practices, he shows that in setups where information is "hard," the centralization of decision making is superior, as it provides powerful incentives to branch managers to research loan applications in order to influence the allocation of capital within the bank. In contrast, when information is "soft," centralization has an adverse effect on the branch managers' incentives, as it increases the risk that capital will be funnelled elsewhere.

In contrast to this article, Stein (2002) analyzes separately the case in which the principal is exerting effort on his own (the soft information case) and the case in which he verifies information transmitted by the agent (the hard information case), whereas in here, the principal engages in both tasks in the same model. Stein's model also does not explore the issue of strategic compromise by the agent, which is at the heart of my model.

Dewatripont and Tirole (2005) show that when communication of hard information is costly, the degree of hard information transmitted is endogenous and is determined by the collaborative efforts of both the receiver and the sender. In contrast, the extent of hard information is exogenous in this article (as it is in Stein, 2002) and is a function of the principal's characteristics. Dewatripont and Tirole study how the equilibrium communication depends on the congruence between the parties, on whether the sender knows the receiver's payoffs (as is assumed here) or not, and on whether hard information is needed for the principal to take action.

Although the empirical literature on managers, traits and the effects on their organizations is extensive, there are very few theoretical articles on the subject. An exception is Rotemberg and Saloner (1993) who investigate how the traits of a CEO affect his ability to motivate his agents to exert effort in search of new ideas. The trait on which they focus is how empathic is the CEO toward his agents. Even though shareholders care only about profits, they may prefer a nonprofit-maximizing CEO as his participatory management style leads to more good ideas being adopted (as well as some bad ones) than the more autocratic style of a profit-maximizing CEO.

□ **Domain knowledge and general abilities: background from the cognitive psychology literature.** Research in cognitive psychology has for long emphasized the importance of *domain-specific knowledge*, acquired through years of training and practice in the domain. Not only the extent of the domain knowledge but, more profoundly, the organization and representation of this knowledge is what distinguish experts from novices. Experts chunk together pieces of information into larger units, which allows more efficient storing of the information and faster access to it. This is manifested by an improved ability to recall accurately information from their domain (as demonstrated, e.g., by Chase and Simon, 1973).[2] Experienced individuals rely on recognition processes and problem schemas to analyze new problems with greater speed and accuracy than novices and often without a need for much conscious and elaborate analysis (Simon, 1990). In many situations, they provide intuitive and accurate judgements based on highly valid cues even without being able to articulate explicitly the reasons.[3] Experts are more able to pick subtle

[2] Chase and Simon find that, when shown board positions taken from actual games, advanced chess players were later able to recall the position of many more pieces than novice players, even though they were not found to possess superior short-term memory or better visual memory. The differences between the groups disappeared when the board position was randomly constructed.

[3] Klein (2003) contains an account of many examples of highly experienced professionals from various domains including firefighters, platoon commanders, and offshore installation managers, who rely heavily on experience to assess intuitively situations that require their intervention. In all of these examples, decision making is based on a recognition of situation prototypes and involved very little comparison of the options. Decision makers were often unable to explain verbally how they reached their decisions.

details, are better able to discriminate between important and less important information,[4] and to recognize what is typical and what is unusual in a given situation. Experts' representations tend to be more abstract and based on general principles and higher-level concepts, whereas novices' representations are more situation- or formula based and tend to overemphasize superficial elements.[5]

In the context of the principal-agent authority relation studied here, the crucial distinction is that the extent of the domain-specific knowledge and the sophistication of the representation of this knowledge are the major determinants of the principal's effectiveness in assessing and verifying proposals made by his agents. A very experienced and knowledgeable principal would be able to gauge almost immediately the credibility of the numerical calculations attached to a specific proposal, the implicit assumptions on which the analysis relies, etc. This rapid assessment can seem almost intuitive, but it is based on a rich storage of similar situations and the principal's ability to instantly access the relevant precedents to help him in his evaluation. Because verification requires very little hard mental work, other cognitive abilities seem to have only a minor effect on it.

In contrast, the task of considering alternatives independently of the agent is much more effort intensive than verification. General cognitive skills are highly important to the principal's effectiveness in this task. As is evident from the discussion above, however, the extent of the principal's domain knowledge plays an important role as well. For highly experienced principals, domain knowledge can be highly operationalized, and they are thus likely to have a lower cost of evaluating different alternatives.

2. The basic model

■ Consider a hierarchy consisting of a principal (P) and an agent (A). A single decision needs to be made and the agent is assigned to evaluate a large number of alternative courses of action. Each alternative yields a payoff v to the principal and utility u to the agent. Denote by $\mathbb{T}$ the set of names of alternatives. Although the payoffs associated with each specific alternative are initially unknown to either the principal or the agent, we assume that the potential payoff possibilities are commonly known.

Specifically, each alternative name $t \in \mathbb{T}$ is mapped onto a payoff pair (v_t, u_t) by some function f. Neither the agent nor the principal can observe f without investing effort (as described below). The image of f, that is, the set of all possible pairs (v, u), is denoted $\Omega = f(\mathbb{T})$, and all functions f are equally likely. The set Ω is known to both players, is convex, and has a differentiable frontier denoted by $u(v)$, defined over some interval $[\underline{v}, \overline{v}]$, where $u' < 0$ and $u'' \leq 0$. Denote by $\underline{u} \equiv u(\overline{v})$ and by $\overline{u} = u(\underline{v})$ the agent's payoffs from the principal's best and worst alternatives on the frontier, respectively. Figure 1 illustrates the set Ω and its frontier $u(v)$.

In addition to the alternatives above, a known default alternative can be chosen, which yields a payoff of zero to both the agent and the principal. We assume that Ω contains numerous outcomes that are significantly worse for the players than the default alternative, such that the parties never choose an alternative randomly. Moreover, the preferences of the principal and the agent are sufficiently congruent such that each would prefer the other party's preferred alternative over the default alternative. That is:

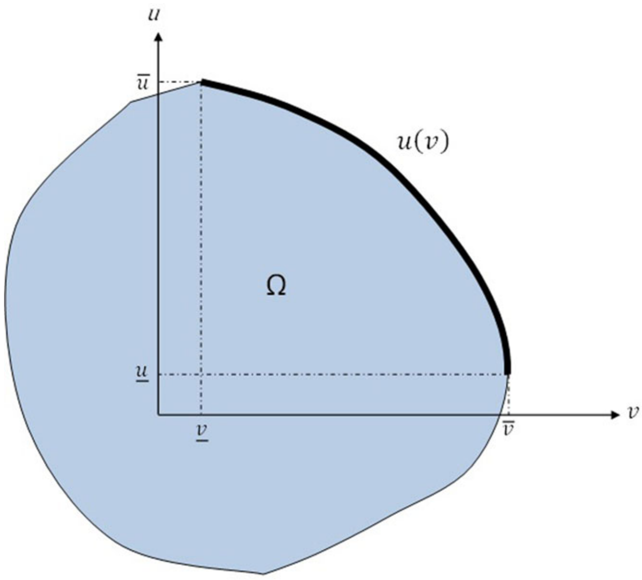
Assumption 1. $\underline{v} \geq 0$ and $\underline{u} \geq 0$.

[4] See, e.g., Lesgold et al.'s (1988) study of the differences between expert and first-year resident radiologists.

[5] These differences have been repeatedly demonstrated in studies in which experts and novices were asked to categorize problems into different groups. In a study of solving physics problems, Chi, Feltovich, and Glaser (1981) find that novices group together problems that contain similar physical objects, such as springs or inclined planes, whereas experts categorize problems by the laws of physics.

FIGURE 1

THE SET Ω AND THE FUNCTION $u(v)$



The principal and agent are risk neutral. However, the payoff to the principal is noncontractible. The principal cannot therefore use monetary incentives to motivate the agent, who is paid a fixed wage (normalized to zero) and invests effort only to the extent that it affects his direct utility.

The timeline is as follows; The agent first invests effort. If successful (i.e., he is now "informed"), the agent learns the values (v_t, u_t) associated with *every* alternative $t \in \mathbb{T}$ both for himself and for the principal (i.e., he learns the mapping f) . Otherwise, the agent learns nothing. The agent succeeds with probability i_a if he invests effort with disutility $c(i_a)$, which is increasing strictly convex and satisfies the Inada conditions[6]: $\lim_{i\to 1} c'(i) = +\infty$ and $c'(0) = 0$ (for brevity, I will often refer to i_a as the agent's effort). The agent's utility, if an alternative with value u is implemented and if investing effort i_a, is

$$u - c(i_a).$$

Based on our assumptions, it immediately follows that if the agent has failed to learn the values of the various alternatives, he will explicitly report this to the principal. If successful, he recommends a single alternative $t \in \mathbb{T}$ to the principal. The principal receives a verification of its worth to him v_t with probability $x \in [0, 1]$ without incurring any cost. The principal is unable to infer anything from the recommendation regarding the payoffs from alternatives that were not presented to him.[7] The principal then decides how much effort to invest in exploring the alternatives on his own. At a disutility of $\mu c(i_p)$, the principal can learn the entire mapping

[6] These conditions are only imposed in order to simplify the exposition and are not essential to the analysis.

[7] This assumption is made for simplicity. A similar assumption is made by Armstrong and Vickers (2010). In reality, it is possible that in some scenarios, the principal would be able to learn from the agent's recommendation on the payoffs of some of the other alternatives, or that observing the hard information attached to the recommendation would reduce his cost of evaluating other alternatives.

f with probability i_p,[8] where $\mu > 0$ is a marginal cost shifter. If an alternative with a value v is implemented, then the principal's utility is:

$$v - \mu c(i_p).$$

If successful, the principal implements his preferred alternative, which is worth $\overline{v}$. Otherwise, the agent's recommendation is implemented.

The principal's characteristics (x, μ) can be naturally related to the discussion at the end of Section 1. A knowledgeable principal is more capable of verifying hard information presented to him in support of a *specific* alternative (i.e., is better at *verification*), and thus the verification probability x is increasing in the principal's domain-specific knowledge. A higher-ability principal finds it easier to explore independently *additional* alternatives that were not presented to him by the agent. Thus, the marginal cost of the principal's effort (the parameter μ) is decreasing in his ability.

The one-to-one association of each one of the principal's characteristics with a single parameter in the model is made for expositional purposes. As discussed in Section 1, whereas cognitive abilities affect mainly the principal's ability to explore alternatives on his own, domain knowledge is likely to have an effect on both tasks. The distinction serves to sharpen the difference between the two characteristics of the principal within the framework of the theoretical model, but one should bear in mind that empirical measures of domain knowledge may have an impact on both dimensions.

3. Analysis

□ **Preliminaries.** Starting from the final stage, consider first the principal's choice of how much effort to invest in exploring alternatives on his own. Denote by $i_p(v)$ the principal's effort, conditional on verifying the agent's recommended alternative's worth v to him. If the principal's effort succeeds, he implements his ideal alternative and gains $\overline{v}$. If not, he approves the agent's recommendation. Therefore,

$$i_p(v) = \arg\max_{i_p} i_p\overline{v} + (1 - i_p)v - \mu c(i_p). \tag{1}$$

If the principal is unable to verify the agent's recommendation (with probability $1 - x$), his choice of effort $i_p(v^*)$ is based on his belief v^* regarding the value of the agent's recommendation. If the agent has failed, the principal's effort is $i_p(0)$.

The first-order condition of the principal's problem is $\overline{v} - v - \mu c'(i_p) = 0$. Let $h = (c')^{-1}$. Then,

$$i_p(v) = h\left(\frac{\overline{v} - v}{\mu}\right). \tag{2}$$

As $c'' \geq 0$, $h' > 0$, and thus $i_p'(v) \leq 0$. In addition, we make the following assumption:

Assumption 2. $h''(z)z + h'(z) > 0$ for all z.

The assumption is satisfied if h is not overly concave, implying that $\partial[i_p'(v)]/\partial\mu \geq 0$, that is, the responsiveness of the principal's effort to the recommendation v is diminishing in his marginal cost of effort μ.[9]

[8] It would make no difference if the principal learned only the first component of f, i.e., only the value v_t to himself associated with every alternative $t \in \mathbb{T}$.

[9] Straightforward derivations from (2) show that

$$\frac{\partial i_p'(v)}{\partial\mu} = \frac{1}{\mu^2}\left[h''\left(\frac{\overline{v} - v}{\mu}\right) \cdot \frac{\overline{v} - v}{\mu} + h'\left(\frac{\overline{v} - v}{\mu}\right)\right].$$

Next, consider the agent's recommendation. If informed, the agent would only recommend an alternative t associated with payoffs (v_t, u_t) which is on the frontier of the set Ω, that is, in $\{(v, u(v))|\ \underline{v} \leq v \leq \overline{v}\}$. To see this, observe that the agent would not recommend an alternative if another exists that yields a higher payoff to himself and at least the same payoff to the principal. Similarly, out of all alternatives that yield a similar value to himself, the agent strictly prefers to recommend the alternative that yields the highest value to the principal, so as to induce him to reduce his effort in exploring other alternatives.

It is intuitive to think of the agent as directly choosing the value v to offer the principal. The agent's maximization problem is:

$$\max_{v \in [\underline{v}, \overline{v}]} \overline{U}(v) = x \cdot [(1 - i_p(v))u(v) + i_p(v)\underline{u}] \ + \ (1 - x) \cdot [(1 - i_p(v^*))u(v) + i_p(v^*)\underline{u}]. \quad (3)$$

$\overline{U}(v)$ denotes the expected gross payoff to the informed agent (without deducting the sunk cost of his effort). The agent's decision takes into account the effect on the principal's subsequent choice of effort in the case that the principal verifies the value of the recommendation (with probability x) and the principal's belief v^* in the case that he fails to do so. Under rational expectations, the principal's belief is identical to the agent's choice v^* in that case.

Whether the solution to (3) lies within the interior of $[\underline{v}, \overline{v}]$ or not depends on the parameters. For example, if the probability of verification x is very small, the agent stands very little chance of influencing the principal's choice of effort. He will, therefore, recommend his favorite alternative (with value $\underline{v}$ to the principal). If x is large, however, the agent wishes to raise his recommendation above $\underline{v}$ in order to dissuade the principal from evaluating alternatives too vigorously.

The next condition is sufficient for the agent to benefit from raising his recommendation above $\underline{v}$ (i.e., an interior solution).

Assumption 3. $-x \cdot i_p'(\underline{v})[\overline{u} - \underline{u}] + [1 - i_p(\underline{v})]u'(\underline{v}) > 0$.

Under Assumption 3, the optimal recommendation v^* is in the interior of $[\underline{v}, \overline{v}]$ and is characterized by the first-order condition of (3). This condition can be rearranged as follows:

$$- x \cdot i_p'(v^*)[u(v^*) - \underline{u}] = -(1 - i_p(v^*))u'(v^*). \quad (4)$$

It is worthwhile examining the intuition behind this key equation. The agent faces a trade-off: on the one hand, a more favorable recommendation to the principal (with a higher v) results in a lower payoff to the agent if the principal's own investigation fails (whether the principal was able to verify the recommendation or not). This occurs with probability $1 - i_p(v^*)$. The expected marginal utility loss from a small increase in the recommendation is the term on the right of (4). On the other hand, a higher recommendation also entices the principal to lower his effort if he is able to verify its value (with probability x). The term on the left-hand side is the expected marginal benefit to the agent of such compromise. As the principal invests less effort, there are more instances (by $-i_p'(v)$) in which the principal is uninformed and the agent's recommendation is implemented. In these cases, the agent gains additional $u(v) - \underline{u}$ units of utility. The recommendation is increased until the marginal benefit just equals the marginal loss.

To assure that the solution is uniquely defined by the first-order condition above, we assume:

Assumption 4. $\overline{U}(v)$ is strictly concave.[10]

It follows from Assumption 2 that $\partial \left[i_p'(v)\right] / \partial \mu > 0$. This assumption holds, e.g., for the parametric family of cost functions $c(i) = i^k / k$ for $k > 1$. As $c'(i) = i^{k-1}$, $h(z) = z^{\frac{1}{k-1}}$. Therefore, $h'' \cdot z + h' = (z^{\frac{1}{k-1} - 1}) / (k - 1)^2 > 0$.

[10] Straightforward derivations show that $\overline{U}''(v) = x[h'' \cdot \frac{u(\overline{v}) - u(v)}{\mu u'(v)} + 2h']u'(v) + (1 - h)u''(v)$. Thus, a sufficient condition for concavity is for the term in square brackets to be positive. Essentially, this requires h'' to be either positive or moderately negative.

As the principal's level of effort is $i_p(v^*)$ whether he verified the recommendation or not, the informed agent's gross payoff in equilibrium can be written as follows:

$$\overline{U} \equiv \overline{U}(v^*) = [1 - i_p(v^*)]u(v^*) + i_p(v^*) \cdot \underline{u}. \tag{5}$$

Finally, the agent's effort choice i_a^* in the first stage is determined as follows:

$$i_a^* = \arg\max_{i_a} i_a \overline{U} + (1 - i_a) \cdot i_p(0)\underline{u} - c\,(i_a)\,. \tag{6}$$

The agent's choice of effort anticipates his own subsequent recommendation if successful and the principal's effort choice conditional on the recommendation.

□ **The effect of the principal's characteristics.** We now turn to investigate the effects of the principal's characteristics on the effort levels and on the decentralization of decision making within the hierarchy, as measured by the proportion of times in which the agent's recommendation is followed (the agent's *real authority*).

The effects of the different principal's characteristics are considered in turn, beginning with the effect of an increase in the principal's domain knowledge, represented in the model by an increase in the probability of verification x of a specific alternative presented to him. The proof of the next proposition and all other proofs not appearing in the text can be found in Appendix B.

Proposition 1 (*an increase in principal's domain knowledge*). Suppose that the probability of principal's verification (x) increases. Then,

(i) the value to the principal v^* from the alternative recommended by the agent increases.
(ii) the principal's effort $i_p(v^*)$ decreases and he overrules the agent in fewer cases.
(iii) the agent's effort i_a^* increases.
(iv) the utilities of both the principal and the agent increase.

Proposition 1 shows that when the organization is headed by a more knowledgeable principal (holding ability fixed) the outcomes are *superior for both the principal and the agent*. Observe from (4) that the marginal return to the agent of compromising and making his recommendation more favorable to the principal increases with the probability of verification x, as the principal gets to see the agent's actual recommendation in more cases. Because verification is more likely the more knowledgeable is the principal, the agent's recommendation is more favorable in that case. In equilibrium, the principal correctly anticipates the agent's behavior and his effort is lower, whether he is able to verify the agent's recommendation or not. Consequently, the principal is more often uninformed and the agent's real authority is greater. The agent is better off serving under a knowledgeable principal, even though he compromises more. The logic is as follows: instead of his equilibrium strategy, the agent could have alternatively delivered the same recommendation he presents to a less knowledgeable principal. His payoff, however, would have been higher as, per part (ii), the knowledgeable principal exerts less effort when unable to verify the recommendation. As the agent nonetheless chooses to compromise more, such strategy necessarily yields yet a higher payoff.

We now turn to the effect of an increase in the principal's ability to explore alternatives on his own, as measured by a reduction in the marginal cost of the principal's effort μ.

Proposition 2 (*an increase in the principal's general ability*). When the cost to the principal of exploring alternatives on his own decreases (μ is lower):

(i) for any given recommendation value v, the principal's effort $i_p(v)$ increases.
(ii) the value v^* of the alternative recommended by the agent is strictly higher.

(iii) the agent's effort i_a^* diminishes and his utility decreases provided either: (a) x is sufficiently large or (b) the principal's effort $i_p(v^*)$ does not decrease.
(iv) the effect on the principal's utility is ambiguous in general and can be negative.

As with verification ability, an increase in the principal's ability to explore alternatives independently increases the value of compromise for the agent. As the principal's effort is higher for any given v (part (i)), it is less likely that he will remain uninformed and thus the marginal cost of the agent compromising and recommending a higher v, is lower. In addition, the principal's choice of effort is more responsive to the agent's recommendation. Consequently, when informed, the agent is more "disciplined" and delivers a recommendation with a higher payoff to the principal in order to dissuade him from exploring other alternatives too vigorously.

The key difference from Proposition 1 is that in the case of an increase in the principal's ability to explore independently, the principal's effort may go up, in which case he would be less likely to follow the agent's recommendation. Consequentially, the agent's real authority is diminished and his incentives to exert effort are weakened. The principal's effort thus "crowds out" the agent's effort in this case.

Specifically, the probability that the principal overrules the agent and decides on the course of action on his own is $i_p(v^*)$. The complement $1 - i_p(v^*)$ measures the agent's real authority. As μ decreases, the change in the rate of overruling is thus:

$$-\,d[i_p(v^*)]/d\mu = -\partial i_p(v^*)/\partial\mu - i_p'(v^*)\cdot \partial v^*/\partial\mu. \tag{7}$$

Two opposing effects are at work: the direct effect results in the principal exerting more effort (given the same recommendation) and accordingly a higher rate of overruling. However, the agent takes this into account and improves his recommendation. This strategic effect induces the principal to reduce his effort. In general, it is difficult to determine which of the effects dominate. Appendix A presents two parametric examples: in the first, the direct effect dominates and the principal overrules the agent in more cases when he is more capable of exploring alternatives himself. In the second, the two effects exactly offset one another and $i_p(v^*)$ is invariant in μ.

Conditional on his recommendation being verified, the agent's utility decreases in the principal's ability, as the principal's effort is higher. For the agent's overall utility to decrease it is thus sufficient that either the verification probability is sufficiently high, or that the principal's effort increases also when not verifying the recommendation. In such a case, the return on the agent's investment and his effort unambiguously declines. The agent's contribution to the hierarchy is "marginalized" twice: he is less active in evaluating alternatives and, if informed, his recommendations are followed less often.

It is possible for both the principal and the agent to be adversely affected as a result of an increase in the principal's ability (an example is given in Appendix A). This stands in sharp contrast to Proposition 1, which shows that both the principal and the agent unambiguously benefit from an increase in the principal's knowledge. The principal's (*ex ante*) utility is

$$V = i_a^*\overline{V}(v^*) + (1 - i_a^*)\overline{V}(0),$$

where $\overline{V}(v) = \max_{i_p} i_p\overline{v} + (1 - i_p)v - \mu c(i_p)$ is the principal's (interim) utility, conditional on the agent's recommendation. A decrease in μ changes the principal's utility by

$$-\frac{dV}{d\mu} = -\frac{\partial i_a^*}{\partial\mu}[\overline{V}(v^*) - \overline{V}(0)] - i_a^*\overline{V}'(v^*)\frac{\partial v^*}{\partial\mu} - i_a^*\frac{\partial\overline{V}(v^*)}{\partial\mu} - (1 - i_a^*)\frac{\partial\overline{V}(0)}{\partial\mu}.$$

Applying the Envelope Theorem and substituting for $\overline{V}'(v^*)$, $\partial\overline{V}(v^*)/\partial\mu$, and $\partial\overline{V}(0)/\partial\mu$ we obtain

$$-\frac{dV}{d\mu} = -\frac{\partial i_a^*}{\partial\mu}[\overline{V}(v^*) - \overline{V}(0)] - i_a^*\cdot(1 - i_p(v^*))\frac{\partial v^*}{\partial\mu} + i_a^*\cdot c(i_p(v^*)) + (1 - i_a^*)\cdot c(i_p(0)). \tag{8}$$

The third and fourth terms are the direct positive effects of a decrease in the principal's cost of effort. The second term is the increase in the principal's utility due to the agent compromising more. The first term is the indirect effect due to the change in the agent's incentives to exert effort. This effect is negative whenever $\partial i_a^* / \partial \mu > 0$. As is shown in the example in Appendix A, this effect can outweigh the other effects, making the total effect negative.

A vast literature on leadership discusses the traits of successful business and nonbusiness leaders. Management writers such as Gosling and Mintzberg (2003) argue that leadership is mainly more about inspiring subordinates: "Leaders don't do most of the things their organization gets done;.... Rather, they help to establish the structures, conditions, and attitudes through which things get done." They also argue that "... they do less controlling, thus allowing other people to be in greater control of their own work."

The results of this section suggest that the ability to lead depends crucially on the manager's knowledgeability and experience within the domain and to a much lesser extent on his ability to create on his own. A knowledgeable manager is successful in our context because he is able to entice his agents to work hard. Moreover, being knowledgeable allows him "to do less controlling," leaving the agents with more real authority over decisions. Additional corroborating evidence for the importance of domain knowledge comes from studies that compare the determinants of manager's success in different setups. Wagner and Sternberg (1985), for example, find that managers' scores in inventories for domain-specific tacit knowledge have a strong positive correlation with managerial success outcomes, including personnel management capability. Correlations with measures of general cognitive ability are far weaker.

Finally, the results of this section can shed light on the potential benefits from organizational practices, such as lateral job rotations, which are used by firms to develop managerial talent and provide future managers with a diverse career experience.[11] Job rotations are designed to enhance potential managers' basic understanding (knowledge) of the various functions within the organization and are typically frequent, short in duration and occur rather early in the employee's career. Consequentially, the exposure gained through them is limited and the acquired knowledge is unlikely to be operational several years ahead, when the employee has advanced into higher management positions.[12] Thus, rotations are likely to have a minor effect on the manager's ability to act independently in these areas in the future. In light of the results derived in Propositions 1 and 2, such career-developing practices can be expected to have a favorable effect on future managers' effectiveness in managing their subordinates and obtaining their cooperation.

4. Discussion and extensions

In this section, I explore several extensions to the basic model.

□ **Principal's characteristics and managerial style.** In this section, I expand the discussion to touch on the concept of "managerial style.“ This rather loose concept has been discussed extensively in the business and management literature but has rarely been formalized. A defining aspect of a managerial style is the degree to which the principal involves his subordinates in the decision-making process. Mintzberg (1994) have described managers with a *committing style* as ones who: "... lead in such a way that everyone on the journey helps shape its course" whereas "those with *calculating style* fix on a destination and calculate what the group must do to get there." Studies of business organization have found great variation in style ranging from an autocratic style to more democratic and participatory styles (Rotemberg and Saloner, 1993). It also has been argued that stark differences in style characterize different levels of management in the hierarchy. An article by Brousseau et al. (2006), for example, considers how managerial decision-making style evolves between junior managerial positions (such as supervisor and

[11] See, for example, the discussion in Campion, Cheraskin, and Stevens (1994).

[12] This is in contrast with examples of highly experienced decisions makers for which knowledge can be very operational that were discussed in the last part of Section 1.

line manager) and middle and senior management. The article suggests that for more senior managers, “decisions styles become more about listening than telling, more about understanding than directing” whereas at lower levels “action is at a premium.” Junior managers, according to the article, tend to take a large share of decisions themselves and without consultation. However as managers move up the organization’s ladder, managers need to learn how to adapt their style to incorporate more information and input from their subordinates in the decision process.

To explore these issues, I analyze a simple extension to the model in which the principal may decide to wait for the agent to exert effort and make a recommendation, or go ahead and try to find the preferred course of action himself, consulting the agent only if need arises (in the basic model, the agent is a first-mover and is always consulted). I consider how the likelihood of consulting the agent is related to the principal’s characteristics (knowledge and ability). I then argue how the evolution of these traits as a manager accumulates experience and rise within the hierarchy can explain some of the observed differences in managerial style within hierarchies.

Formally, there are two periods: 1 and 2. In period 1, the principal and the agent exert effort simultaneously (denoted i_{p1} and i_a, respectively). If the principal is successful, his preferred project $\overline{v}$ is implemented and the agent is not consulted. Otherwise, and if the agent is successful, he makes a recommendation v in period 2 to the principal, who may verify its value in probability x. Depending on the outcome of his verification, the principal may then exert additional effort (i_{p2}) to find his preferred project. The cost of effort i_p by the principal in each one of the periods is $\mu c(i_p)$ and the cost of the agent’s effort is $c(i_a)$.

Denote the expected period 2 payoffs to the principal and the agent, provided the game proceeds there, by V_2 and U_2, respectively, where

$$V_2 = i^*_{p_2}\overline{v} + (1 - i^*_{p_2})v^* - \mu c(i^*_{p_2}),$$
$$U_2 = i^*_{p_2}\underline{u} + (1 - i^*_{p_2})u(v^*)$$

and where $i^*_{p_2} = i_p(v^*)$. The principal’s period 1 effort is a solution to

$$\max_{i_{p_1}} V_1 = i_{p1}\overline{v} + (1 - i_{p1})i_a V_2 - \mu c(i_{p_1}).$$

The agent’s effort maximizes

$$\max_{i_a} U_1 = i_{p1}\underline{u} + (1 - i_{p1})i_a U_2 - c\,(i_a)\,.$$

The period 1’s equilibrium is thus defined by the system of first-order conditions:

$$\frac{\partial V_1}{\partial i_{p_1}} = \overline{v} - i_a V_2 - \mu c'(i_{p1}) = 0, \tag{9}$$

$$\frac{\partial U_1}{\partial i_a} = (1 - i_{p1})U_2 - c'\,(i_a) = 0.$$

Both players’ best responses are downward sloping, as:

$$\frac{\partial i_{p1}}{\partial i_a} = \frac{-V_2}{\mu c''(i_{p1})} < 0,$$
$$\frac{\partial i_a}{\partial i_{p1}} = \frac{-U_2}{c''\,(i_a)} < 0.$$

Thus, the effort choices in the period 1 game are strategic substitutes. In addition, we assume that the equilibrium is stable, which is satisfied under the following assumption:

Assumption 5 (*stability*). $\Delta = \frac{\partial^2 V_1}{\partial (i_{p1})^2}\frac{\partial^2 U_1}{\partial (i_a)^2} - \frac{\partial^2 V_1}{\partial i_{p1}\partial i_a}\frac{\partial^2 U_1}{\partial i_a \partial i_{p1}} > 0.$

Consider next how the principal's choice of effort in period 1 depends on the principal's characteristics x and μ. Consider first the effect of a change in x. Differentiating the system of equations (9) and applying Cramer's law, we obtain:

$$\frac{\partial i_{p1}^*}{\partial x}=\frac{-\frac{\partial^2 V_1}{\partial i_{p1}\partial x}\frac{\partial^2 U_1}{\partial (i_a)^2}+\frac{\partial^2 V_1}{\partial i_{p1}\partial ia}\frac{\partial^2 U_1}{\partial i_a \partial x}}{\Delta}=\frac{-i_a\frac{\partial V_2}{\partial x}c''(i_a)-V_2(1-i_{p1})U_2\frac{\partial U_2}{\partial x}}{\Delta},$$

$$\frac{\partial i_a^*}{\partial x}=\frac{-\frac{\partial^2 V_1}{\partial (i_{p1})^2}\frac{\partial^2 U_1}{\partial i_a\partial x}+\frac{\partial^2 V_1}{\partial i_{p1}\partial x}\frac{\partial^2 U_1}{\partial i_a \partial i_{p1}}}{\Delta}=\frac{\mu c''(i_{p1})(1-i_{p1})\frac{\partial U_2}{\partial x}+i_a\frac{\partial V_2}{\partial x}U_2}{\Delta}.$$

Recall from the proof of Proposition 1 that $\partial V_2/\partial x > 0$ and that $\partial U_2/\partial x > 0$. It thus follows that $\partial i_{p1}^*/\partial x < 0$ and that $\partial i_a^*/\partial x > 0$. As x increases, the principal's period 1 effort decreases and the agent's effort increases. Intuitively, for any level of the agent's effort, the principal's period 1 best-response shifts in, as the principal's payoff in case of failing and the agent succeeding is higher. Similarly, the agent's best response shifts out. Because the efforts are strategic substitutes, the equilibrium level of the agent's effort goes up whereas the principal's goes down. To summarize:

Lemma 1. A more knowledgeable principal (higher x) exerts less effort before consulting the agent and is thus more likely to consult him.

Managers with little domain knowledge (low x) prefer to maintain tight control on the decision process from early on as they correctly perceive they are likely to receive unsatisfactory recommendations from their agents. As a result, they exert a high level of effort from the start and would only consult the agent if they fail to come to a decision by themselves. In contrast, more knowledgeable managers expect to elicit better recommendations from their agents and are thus less likely to exert much effort before consulting their agents and receiving their recommendations.

The effect of an increase in the principal's ability (lower μ) on the principal's period 1 effort is less straightforward. Differentiating (9), we obtain

$$\frac{\partial i_{p1}^*}{\partial \mu}=\frac{-\frac{\partial^2 V_1}{\partial i_{p1}\partial \mu}\frac{\partial^2 U_1}{\partial (i_a)^2}+\frac{\partial^2 V_1}{\partial i_{p1}\partial ia}\frac{\partial^2 U_1}{\partial i_a \partial \mu}}{\Delta}=\frac{-\left[c'(i_{p1})+i_a\frac{\partial V_2}{\partial \mu}\right]c''(i_a)-V_2(1-i_{p1})\frac{\partial U_2}{\partial \mu}}{\Delta},$$

$$\frac{\partial i_a^*}{\partial \mu}=\frac{-\frac{\partial^2 V_1}{\partial (i_{p1})^2}\frac{\partial^2 U_1}{\partial i_a\partial \mu}+\frac{\partial^2 V_1}{\partial i_{p1}\partial \mu}\frac{\partial^2 U_1}{\partial i_a \partial i_{p1}}}{\Delta}$$

$$=\frac{\mu c''(i_{p1})(1-i_{p1})\frac{\partial U_2}{\partial \mu}+\left[c'(i_{p1})(1-i_{p1})+i_a\frac{\partial V_2}{\partial \mu}\right]U_2}{\Delta}.$$

Consider the case where $di_{p_2}^*/d\mu < 0$. It is immediate to verify that $\partial U_2/\partial \mu > 0$ and $\partial V_2/\partial \mu < 0$ in this case. Thus, as result of a decrease in μ, the agent's best-response effort shifts in. The effect on the principal's best response depends on the sign of $c'(i_{p1})+i_a\frac{\partial V_2}{\partial \mu}$. When this term is positive, the direct decrease in the principal's period 1's cost of effort outweighs the increase in his period 2 expected payoff. In this case, the principal's best-response effort in period 1 shifts out. As efforts are strategic substitutes, it follows that the principal's first-period equilibrium effort i_{p1}^* increases, whereas the agent's effort i_a^* decreases. The intuition in this case can be summed as follows: high-ability managers (low μ) expect their agents to be relatively unmotivated and to exert low effort. Because they are also efficient at reaching decisions by themselves, such managers tend to exert more effort themselves in the early stages and thus consult their agents less.

In the complement case where $c'(i_{p1}) + i_a \frac{\partial V_2}{\partial \mu} < 0$, the principal's best-response shifts in as μ decreases. The equilibrium effect on the agent and principal's period 1 efforts is indeterminate in general.

The results of this section shed light on the findings cited above regarding the differences in management styles between different echelons of management. Compared to their junior colleagues, senior managers are likely to be characterized by high values of both x and μ. Throughout his long career, a typical senior manager has accumulated a substantial amount of domain knowledge and developed a complex, refined understanding of the domain. This is reflected by a high value of x. These capabilities are far less developed in junior managers, who tend to be far less experienced.

On the other hand, because junior managers have only recently been promoted from an operator position, their technical skills are at least as good as their subordinates and they are therefore very capable of "doing the work" necessary in order to evaluate the decisions on their own. They also tend to be younger in comparison and thus at the peak of their general cognitive abilities. In contrast, senior managers are on average older and are already several years removed from a field position. Their ability to conduct a rigorous analysis of the alternative courses of action by themselves is thus likely to have diminished, reflected by a high value of μ.[13]

Taken together, the implications of the results obtained in this section seem to fit the findings on the evolution of management style along a manager's career. Junior managers (characterized by low x and μ) take a large part of the decisions themselves and without much consultation with their subordinates, whereas senior managers (high x and μ) are more reliant on their agents, typically consulting their agents first before exerting any effort themselves.

□ **A principal with several agents.** In this section, I examine an environment in which the principal interacts with several agents (e.g., a CEO with several division heads), who are each assigned to a different area (e.g., different products, different geographical markets, etc.). Areas are independent from one another and do not compete for scarce resources. Therefore, any interdependence between the areas stems only from the fact that the principal's efforts in the different areas are cost substitutes.

Specifically, assume that there are two agents (A1 and A2) and a single principal (P). The cost to the principal of investing effort i_{p1} in area 1 and i_{p2} in area 2 is:

$$c_p(i_{p_1}, i_{p_2}) = \frac{\mu_1(i_{p_1})^2}{2} + \delta i_{p_1} i_{p_2} + \frac{\mu_2(i_{p_2})^2}{2}, \qquad \delta \in (0, 1).$$

I also require that δ is sufficiently small compared to μ_1 and μ_2. Specifically, I assume that $\delta < \min\{(1 - x_1)\mu_1, (1 - x_2)\mu_2\}$ where x_i for $i = 1, 2$ are defined below.

Agent 1 is assigned to evaluate and recommend a decision in area 1, whereas agent 2 is assigned to evaluate a decision in area 2. Each decision is characterized as in Section 2 and with identical payoff parameters.

The agents first choose effort levels (i_{a_1}, i_{a_2}). After they have learned (privately) whether their efforts were successful or not, they simultaneously present their recommendations to the principal. If successful, each one of the agents presents an action in his area. Otherwise, he reports that he failed. The principal is able to verify costlessly the value v_i of the recommendation of agent $i = 1, 2$ with probability x_i. Based on the recommendations (v_1, v_2), the principal decides how much effort i_{p1} and i_{p2} to exert exploring by himself alternatives to the agents' recommendations in each of the two areas, respectively.

[13] Studies that employ domain-specific tacit knowledge inventories confirm the importance of domain knowledge for higher-rank managers. In a study of financial auditors, Tan and Libby (1997) have found that proficiency in these inventories is a strong predictor for managerial success in higher-rank managerial positions but not for lower-rank positions. Similar results were found by Hedlund et al. (2003) in a study of military leadership.

We now analyze the game backward. Given (v_1, v_2), the principal's effort allocation problem is:

$$\max_{i_{p_1}, i_{p_2}} i_{p_1}\overline{v} + (1 - i_{p_1})v_1 + i_{p_2}\overline{v} + (1 - i_{p_2})v_2 - c_p(i_{p_1}, i_{p_2}).$$

The solution to this maximization problem is:

$$i_{p_1}(v_1, v_2) = \frac{\mu_2\,(\overline{v} - v_1) - \delta(\overline{v} - v_2)}{\mu_1\mu_2 - \delta^2}, \tag{10}$$

$$i_{p_2}(v_1, v_2) = \frac{\mu_1\,(\overline{v} - v_2) - \delta(\overline{v} - v_1)}{\mu_1\mu_2 - \delta^2}.$$

Certain properties of the solution are worth emphasizing. First, the principal's effort in area i is a function of both recommendations and is *decreasing* in the value of the recommendation made by the agent in area i and *increasing* in the value of the recommendation of the agent in area j. The first effect is identical to that discussed in the single agent case. The second effect is novel and is due to the cost substitutability between the principal's efforts in the two areas. The better is agent i's recommendation, the lower is the principal's return on effort in area i. Consequently, he chooses a lower effort in area i, implying that his marginal cost of effort in area j is reduced.

Consider next the recommendations game. Denote by (v_1^*, v_2^*) the equilibrium recommendations. Let $U_1^{yy}(v_1, v_2)$ denote agent 1's expected payoff, if both agents succeed:

$$\begin{aligned}
U_1^{yy}(v_1, v_2) \equiv\; & x_1x_2 \cdot [(1 - i_{p1}(v_1, v_2)) \cdot u\,(v_1) + i_{p1}(v_1, v_2) \cdot \underline{u}] \\
& + x_1\,(1 - x_2) \cdot [(1 - i_{p1}(v_1, v_2^*)) \cdot u\,(v_1) + i_{p1}(v_1, v_2^*) \cdot \underline{u}] \\
& + (1 - x_1)\,x_2 \cdot [(1 - i_{p1}(v_1^*, v_2)) \cdot u\,(v_1) + i_{p1}(v_1^*, v_2) \cdot \underline{u}] \\
& + (1 - x_1)\,(1 - x_2) \cdot [(1 - i_{p1}(v_1^*, v_2^*)) \cdot u(v_1) + i_{p1}(v_1^*, v_2^*) \cdot \underline{u}].
\end{aligned}$$

Let $U_1^{yn}(v_1)$ denote agent 1's payoff if he succeeds and agent 2 fails:

$$\begin{aligned}
U_1^{yn}\,(v_1) \equiv\; & x_1[(1 - i_{p1}(v_1, 0)) \cdot u(v_1) + i_{p1}(v_1, 0) \cdot \underline{u}] \\
& + (1 - x_1) \cdot [(1 - i_{p1}(v_1^*, 0)) \cdot u(v_1) + i_{p1}(v_1^*, 0) \cdot \underline{u}],
\end{aligned}$$

and let $U_1^{ny}(v_2) \equiv x_2 \cdot i_{p1}(0, v_2^*)\underline{u} + (1 - x_2)i_{p1}(0, v_2^*)\underline{u}$ denote agent 1's payoff if only agent 2 succeeds and $U_1^{nn} = i_{p1}(0, 0)\underline{u}$ his payoff if both agents fail. Similar definitions apply to agent 2. In equilibrium,

$$\begin{aligned}
U_1^{yy} &\equiv U_1^{yy}(v_1^*, v_2^*) = (1 - i_{p1}(v_1^*, v_2^*)) \cdot u(v_1^*) + i_{p1}(v_1^*, v_2^*) \cdot \underline{u} \\
U_1^{yn} &\equiv U_1^{yn}(v_1^*) = (1 - i_{p1}(v_1^*, 0)) \cdot u(v_1^*) + i_{p1}(v_1^*, 0) \cdot \underline{u} \\
U_1^{ny} &\equiv U_1^{ny}(v_2^*) = i_{p1}(0, v_2^*) \cdot \underline{u}.
\end{aligned}$$

If successful, agent 1 is better off if agent 2 fails ($U_1^{yy} < U_1^{yn}$). The principal in this case is inclined to exert more effort in area 2 and thus less effort in area 1. Hence, $i_{p1}(v_1^*, 0) < i_{p1}(v_1^*, v_2^*)$. As a result, agent 1's real authority is increased. In contrast, if he fails, agent 1 is better off if agent 2 succeeds ($U_1^{ny} > U_1^{nn}$), as in this case, the principal's effort in area 1 is higher: $i_{p1}(0, v_2^*) > i_{p1}(0, 0)$. Because $\underline{u}$ is larger than the payoff of the default action (zero), the agent, if fails, wants the principal to exert as much effort as possible.

If informed, agent 1's recommendation maximizes his expected payoff:

$$\max_{v_1} \overline{U}_1(v_1, v_2^*) \equiv i_{a_2}^* U_1^{yy}(v_1, v_2^*) + (1 - i_{a_2}^*)U_1^{yn}\,(v_1),$$

where $i^*_{a_2}$ and v^*_2 are the equilibrium levels of agent 2's effort and recommendation, respectively. Similarly, for agent 2 :

$$\max_{v_2} \overline{U}_2(v^*_1, v_2) \equiv i^*_{a1} U^{yy}_2(v^*_1, v_2) + \left(1 - i^*_{a1}\right) U^{ny}_2(v_2).$$

The fact that both agents serve the same principal creates a strategic dependency between their actions. I first show that agents' *recommendations are strategic complements*. That is, the value to the principal of the recommendation of one agent is increasing in the value of the recommendation the agent anticipates from his peer. The intuition is as follows: an increase in v_2 lowers the return to the principal's effort in area 2. The reduced effort in area 2 effectively lowers the principal's marginal cost of effort in area 1. This induces agent 1 to compromise more and improve his own recommendation v_1, along similar lines to Proposition 2. A similar argument works for agent 2. Formally, let $v^*_1(v_2)$ and $v^*_2(v_1)$ denote the agents' best-response functions in the recommendations game. Then:

Lemma 2. Given initial efforts (i_{a_1}, i_{a_2}), the agents' recommendations are strategic complements: $\partial v^*_1(v_2)/\partial v_2 > 0$ and $\partial v^*_2(v_1)/\partial v_1 > 0$.

The second result concerns the initial choice of efforts (i_{a_1}, i_{a_2}) by the agents. I show that the *agents' efforts are strategic substitutes*: the higher is agent 1's effort, the lower is agent 2's optimal effort.

The intuition is as follows: if informed, an agent is made worse off if the other agent become informed whereas, if uninformed, the agent is better off if the other agent becomes informed. The return on effort—measured by the expectation of the difference in payoffs between being informed and being uninformed—thus shrinks if the other agent is more likely to becomes informed (i.e., if his effort is higher).

Let $i^*_{a_1}(i_{a_2})$ and $i^*_{a_2}(i_{a_1})$ denote the agent's best–response effort functions. Then:

Lemma 3. In the first-stage game, agents' efforts are strategic substitutes: $\partial i^*_{a_1}(i_{a_2})/\partial i_{a_2} < 0$ and $\partial i^*_{a_2}(i_{a1})/\partial i_{a_1} < 0$.

I turn now to the effect of the principal's characteristics in this setup. Consider a scenario in which the principal's ability in the two areas is the same $\mu_1 = \mu_2 = \mu$ (thus, as in Section 3, μ can be interpreted as measuring general ability) and look at changes in the principal's knowledge in one of the areas. It is typical for principals to have a higher level of domain knowledge in one of the areas they oversee than in others. This can be the result, for example, of a CEO having gained functional experience as the division manager of only one of the divisions. Alternatively, one of the areas could be a mature business whereas the other is a new area into which the firm has only recently entered. To formalize this idea, I consider the effect of a change in the principal's knowledge in only one of the areas. In the single-agent framework, we have shown that an increase in x induces the agent to improve his recommendation and the principal to invest less effort (by Proposition 1). Therefore, in the two-agent setup, the decrease in the principal's effort in area i implies that his marginal cost of effort in area j is diminished. Intuitively, the effect of an increase in x_i on agent j's recommendation should be equivalent to that of a reduction in the marginal cost of the principal's effort in the single-agent case (by Proposition 2).

The first part of Lemma 4 below shows that this intuition is indeed correct. Because of the strategic complementarity between the recommendations, the increase in agent i's best-response recommendation due to an increase in x_i leads to an increase in the equilibrium levels of both v^*_i and v^*_j. Thus, *both* recommendations improve if the principal becomes more knowledgeable in *only one* of the areas.

The second part of Lemma 4 deals with the choices of effort by the two agents. To simplify, we consider the comparative statics exercise starting from an initial symmetric point $x_1 = x_2 = x$. As a result of an increase in the principal's knowledge in area 2, agent 1's best-response effort shifts in. As agent 2's recommendation will improve, the principal would exert more effort in area 1. Agent 1's payoff, if successful, thus decreases and his payoff if he fails increases. Hence, the agent's return on effort (the difference between the two) is lower.

The effect on agent 2's effort is more nuanced. As in the single-agent case (Proposition 1), the direct effect of an increase in the principal's knowledge is to increase the agent's return on effort. However, because in addition agent 1's recommendation increases, this works in the opposite direction. Under the sufficient (but not necessary) condition that $\underline{u}$ is sufficiently small, we obtain the result that agent 2's best-response shifts out. In this case, because the agents' efforts are strategic substitutes, agent 2's equilibrium effort increases whereas agent 1's effort decreases.

Lemma 4. Suppose that the principal's domain knowledge in area i rises (x_i increases). Then:

(i) both agents' recommendations improve.
(ii) provided $\underline{u}$ is sufficiently small, the effort exerted by agent i increases, whereas the effort of agent j decreases.

An increase in the principal's knowledge in one area results in an increase in "prominence" of the agent assigned to this area at the expense of the other agent. Being more knowledgeable, the principal can rely more on that agent. Consequentially, the agent enjoys more real authority and his effort and overall contribution to the organization increases. The freed-up "resources" are used by the principal to investigate the other agent's area more actively. Although this imposes discipline on that agent to make more palatable recommendations, it also diminishes his initiative and effort.

Roberts (2004), discusses the allocation of resources within firms between units that are in charge of the exploration of new areas and those devoted to the exploitation of existing technologies. There is a stark asymmetry in the information that is available to senior executives in each of the two areas. Exploitation groups are able to document their cases, and senior management, who is typically quite knowledgeable in existing areas, can easily process and verify them. In contrast, exploration groups will have a more difficult time quantifying the expected cash flow that can be expected from their recommended projects and management will have far less experience in verifying these reports. Roberts notes that this may tend to bias decisions in favor of established, performance-oriented businesses, which appears to be consistent with the results obtained here.

In Appendix B, I also consider a scenario in which the principal's abilities in the two areas may differ and look at the effect of a change in the ability to explore alternatives in one of the areas (μ_2). As μ_2 decreases, agent 2 becomes more willing to compromise in his recommendation. His best-response recommendation function thus shifts out. In contrast, because the decrease in μ_2 leads the principal to exert less effort in area 1,[14] agent 1 becomes less willing to compromise. Because of the strategic complementarity between the recommendations, there are two opposing forces on equilibrium. I show that in equilibrium the value of agent 2's recommendation necessarily goes up and provides a sufficient condition for agent 1's recommendation to go down.

Drawing conclusive predictions on the effect of an increase in the principal's ability in area 2 on equilibrium efforts in this case is hard, as there are two opposing forces which affect them. On the one hand, agent 2's return on effort decreases as he would compromise more his recommendation. On the other hand, if agent 1 is to compromise less, the principal's return on effort in area 1 increases. The principal would then concentrate less effort in area 2, which increases agent 2's payoff if successful.

[14] Observe that $-\frac{\partial i_{p_1}(v_1,v_2)}{\partial \mu_2} = -\frac{\mu_1\delta(\overline{v}-v_2)-\delta^2(\overline{v}-v_1)}{\left[\mu_1\mu_2-\delta^2\right]^2} = -\frac{\delta}{\mu_1\mu_2-\delta^2}\cdot i_{p_2}(v_1,v_2) < 0.$

5. Conclusions

■ This article investigates how the principal's characteristics shape the authority relations between him and his subordinates. I first consider the effect of the principal's domain-specific knowledge. When the principal is more knowledgeable, communication within the hierarchy improves, as the principal is more able to verify recommendations made by the agent. Consequently, he is able to entice the agent to make more favorable recommendations. The knowledgeable principal can then exert less effort himself, and as a result, the agent's real authority and effort are higher. We show that the outcome in this case is unambiguously better for both the principal and agent. This suggest that a high level of domain knowledge is likely to be an important ingredient of successful leadership.

I also consider the effect of an increase in the principal's general abilities. In the context of the model, these abilities determine the effectiveness of the principal in considering alternatives on his own and separately from the agent. I show that this ability is a mixed blessing. On one hand, it limits the agent's opportunism and pushes him to make more favorable recommendations to the principal. On the other hand, it has an adverse effect on the agent's real authority and effort. As a result, the overall effect on the principal may be negative. Thus, this ability may not be a necessary requirement from successful leaders.

Appendix A

Parametric examples. In this section, I provide a couple of parametric examples of the model outlined in Section 2. In both examples, let $c(i) = 0.5i^2$. As $h(z) = z$ in this case, it follows from (2) that $i_p(v) = \frac{\overline{v}-v}{\mu}$ and $i'_p(v) = -\frac{1}{\mu}$. Because the function $c(i)$ does not satisfy the Inada conditions, we further assume that $\mu > \overline{v}$, in order to ensure that $i_p(v) < 1$ for all v.

Example 1. Let $u(v) = \sqrt{1-v^2}$, $\underline{v} = 0$ and normalize $\overline{v} = 1$ (the positive orthant of the unit circle). Substituting into the first-order condition (4), we obtain:

$$x\left[1-(v^*)^2\right] - (\mu - 1 + v^*)\, v^* = 0,$$

from which it can be shown after some calculations, that

$$v^* = \frac{\sqrt{\mu\,(\mu-2) + (2x+1)^2} - \mu + 1}{2\,(x+1)}$$

and thus

$$i_p(v^*) = \frac{2\,(x+1) + \mu - 1 - \sqrt{\mu\,(\mu-2) + (2x+1)^2}}{2\,(x+1)\,\mu}.$$

Taking a derivative shows that the sign of $di_p(v^*)/d\mu$ equals that of

$$-\mu + (2x+1)\left[(2x+1) - \sqrt{\mu\,(\mu-2) + (2x+1)^2}\right].$$

As $\mu > 1$, the second term is smaller than $(2x+1)[(2x+1) - \sqrt{(2x+1)^2 - 1}] \leq 1$ for $x \in [0, 1]$. Thus, $d[i_p(v^*)]/d\mu < 0$ for all x and for all μ.

Example 2. Let $u(v) = (\overline{v} - v)^{\alpha} + \underline{u}$, where $\alpha > 1$ and $\underline{u} \geq 0$. Substituting into the first-order condition (4), and simplifying we obtain:

$$x\,(\overline{v} - v^*) - \alpha\,[\mu - (\overline{v} - v^*)] = 0.$$

Thus, $v^* = \overline{v} - \frac{\alpha\mu}{x+\alpha}$. Substituting into $i_p(v^*)$ we obtain

$$i_p(v^*) = \frac{\alpha}{x+\alpha}.$$

Hence, the equilibrium level of the principal's effort is independent of μ.

Next, for Example 2 above where $\alpha = 1$, I explore the conditions under which the principal's utility increases as his ability to explore independently increases (μ decreases). Recall from (8) that a decrease in μ changes the principal's utility by

$$-\frac{\partial i_a^*}{\partial \mu}[\overline{V}(v^*) - \overline{V}(0)] - i_a^* \cdot (1 - i_p(v^*))\frac{\partial v^*}{\partial \mu} + i_a^* \cdot c(i_p(v^*)) + (1 - i_a^*) \cdot c(i_p(0)),$$

where $-(1 - i_p(v^*))\frac{\partial v^*}{\partial \mu} = \frac{x}{(x+1)^2}$. In addition,

$$i_a^* = \frac{x\mu}{(x+1)^2} - \frac{\overline{v}}{\mu}\underline{u}$$

is positive provided $\underline{u} \leq \frac{x\mu^2}{(x+1)^2\overline{v}}$ and

$$\overline{V}(v^*) = \overline{v} - \frac{\mu\,(x + 0.5)}{(x+1)^2}$$

$$\overline{V}(0) = 0.5\frac{\overline{v}^2}{\mu}.$$

Substituting into the derivative above thus yields

$$-\left[\frac{x}{(x+1)^2} + \frac{\overline{v}}{\mu^2}\underline{u}\right]\left[\overline{v} - \frac{\mu\,(x+0.5)}{(x+1)^2} - 0.5\frac{\overline{v}^2}{\mu}\right] + i_a^*\left(\frac{x}{(x+1)^2} + \frac{0.5}{(x+1)^2}\right) + (1 - i_a^*)0.5\frac{\overline{v}^2}{\mu^2}.$$

Picking a specific parameterization, let $x = 0.5$ and $\overline{v} = 0.9\mu$. Substituting, we get

$$-\left[\frac{2}{9} + 0.9\frac{\underline{u}}{\mu}\right]\left[0.9 - \frac{4}{9} - 0.405\right]\mu + i_a^* \times \frac{4}{9} + (1 - i_a^*) \times 0.405.$$

$$= -\left[\frac{2}{9} + \frac{\underline{u}}{\mu}\right]\frac{91}{1800}\mu + i_a^* \times \frac{4}{9} + (1 - i_a^*) \times 0.405.$$

Because the sum of the last two terms is bounded from above by $\frac{4}{9}$, a sufficient condition for the derivative to be negative is $\mu > \frac{3600}{91}$. In addition, setting $\underline{u} \leq \frac{20}{81}\mu$ guarantees $i_a^* > 0$.

Appendix B

Proofs of all lemmas and propositions not presented in the text follow.

Proof of Proposition 1.

(i) Recall the first-order condition (4), which implicitly determines v^*:

$$-x \cdot i_p'(v^*)\,[u(v^*) - u] + (1 - i_p(v^*))u'(v^*) = 0.$$

By Assumption 4, the term on the left-hand side is decreasing in v. Denote the initial value by v^*. As x increases, the first term in the first-order condition above increases. Hence, v^* has to increase for the first-order condition to continue to hold.

(ii) As $\partial v^*/\partial x > 0$ by (i), $d[i_p(v^*)]/dx = i_p'(v^*) \cdot \partial v^*/\partial x < 0$. The principal's rate of overruling $i_p(v^*)$ thus decreases.

(iii) The agent's effort i_a^* satisfies $c'(i_a^*) = \overline{U} - i_p(0)\underline{u}$. Observe that the agent's payoff if he fails, $i_p(0) \cdot \underline{u}$, does not depend on x. Applying the Envelope Theorem to (3), the effect of a change in x on $\overline{U}$, the agent's payoff, if successful, is of second order, whereas the effect through v^* is of first order:

$$\frac{d\overline{U}}{dx} = (1 - x) \cdot d[i_p(v^*)]/dx \cdot [\underline{u} - u(v^*)] > 0.$$

Thus, $\overline{U} - i_p(0)\underline{u}$ is increasing in x . Finally, as $c'' > 0$, i_a^* increases in x.

(iv) The principal's exante utility is given by:

$$V = i_a^*[i_p(v^*)\overline{v} + (1 - i_p(v^*))v^* - \mu c(i_p(v^*))] + (1 - i_a^*)[i_p(0)\overline{v} - \mu c(i_p(0))],$$

which is a weighted average of two terms, the first of which is the larger. To see this, note that $i_p(v^*)\overline{v} + (1 - i_p(v^*))v^* - \mu c(i_p(v^*)) > i_p(0)\overline{v} + (1 - i_p(0))v^* - \mu c(i_p(0)) > i_p(0)\overline{v} - \mu c(i_p(0))$, where the first inequality follows from revealed preference. As the weight, i_a^*, on the larger term is increasing in x, the entire weighted sum increases. Finally, by applying the Envelope Theorem to (3), it can be seen that the first term, in square brackets, $i_p(v^*)\overline{v} + (1 - i_p(v^*))v^* - \mu c(i_p(v^*))$, is increasing in x, as $\partial v^*/\partial x > 0$. Thus, V is increasing in x.

The agent's *ex ante* utility is

$$U = i_a^* \overline{U} + (1 - i_a^*) i_p(0) \cdot \underline{u} - c_a(i_a^*).$$

Applying the Envelope Theorem to (6) shows that $\frac{\partial U}{\partial x} = i_a^* \cdot \frac{\partial \overline{U}}{\partial x} > 0$. ■

Proof of Proposition 2. Assume that μ decreases:

(i) It follows from (2) that $\partial i_p(v)/\partial \mu = -h'(\frac{\overline{v}-v}{\mu}) \cdot (\overline{v} - v)/\mu^2 < 0$. Thus, as μ decreases, $i_p(v)$ increases.

(ii) Recall the first-order condition (4) for v^*:

$$\partial \overline{U}(v^*)/\partial v = -x \cdot i_p'(v^*)[u(v^*) - \underline{u}] + [1 - i_p(v^*)]u'(v^*) = 0.$$

Differentiating the first-order condition with respect to v^* and μ and applying the Implicit Function Theorem, it follows that

$$\frac{dv^*}{d\mu} = \frac{-\partial^2 \overline{U}(v)/\partial v \partial \mu}{\partial^2 \overline{U}(v)/\partial v^2}.$$

The term in the denominator, $\partial^2 \overline{U}(v)/\partial v^2$ is negative by Assumption 4. The numerator

$$-\frac{\partial^2 \overline{U}(v)}{\partial v \partial \mu} = x \frac{\partial i_p'(v)}{\partial \mu}[u(v^*) - \underline{u}] + \frac{\partial i_p(v)}{\partial \mu} u'(v^*)$$

is positive, because $\partial i_p(v)/\partial \mu < 0$ and as by Assumption 2, $\partial i_p'(v)/\partial \mu \geq 0$. Thus, $\frac{dv^*}{d\mu} < 0$.

(iii) The agent's effort is the solution to the first-order condition of (6),

$$c'(i_a^*) = \overline{U} - i_p(0) \cdot \underline{u}.$$

As $c'' > 0$, as μ decreases, the change in i_a^* has the same sign as the change in $\overline{U} - i_p(0) \cdot \underline{u}$. Applying the Envelope Theorem to (3), it follows that:

$$\frac{\partial[\overline{U} - i_p(0) \cdot \underline{u}]}{\partial \mu} = x \frac{\partial i_p(v^*)}{\partial \mu}[\underline{u} - u(v^*)] + (1 - x) \frac{d[i_p(v^*)]}{d\mu}[\underline{u} - u(v^*)] - \frac{\partial i_p(0)}{\partial \mu} \underline{u}.$$

As $\partial i_p(v)/\partial \mu < 0$, $d[i_p(v^*)]/d\mu \leq 0$ is sufficient for $\partial \left[\overline{U} - i_p(0) \cdot \underline{u}\right]/\partial \mu > 0$. Moreover, it is shown in equation (7) in the text that

$$d[i_p(v^*)]/d\mu = \partial i_p(v^*)/\partial \mu - i_p'(v^*) \cdot \partial v^*/\partial \mu.$$

Substituting above for $d[i_p(v^*)]/d\mu$ and rearranging, we obtain:

$$\frac{\partial[\overline{U} - i_p(0) \cdot \underline{u}]}{\partial \mu} = \left[\frac{\partial i_p(v^*)}{\partial \mu} + (1 - x) i_p'(v^*) \cdot \frac{\partial v^*}{\partial \mu}\right] \cdot [\underline{u} - u(v^*)] - \frac{\partial i_p(0)}{\partial \mu} \underline{u}.$$

Thus, a weaker sufficient condition for i_a^* to increase when μ decreases is $\partial i_p(v^*)/\partial \mu + (1 - x) \cdot i_p'(v^*)\, \partial v^*/\partial \mu \leq 0$. As $\partial i_p(v^*)/\partial \mu < 0$, the condition is clearly satisfied if x is sufficiently large.

(iv) There are several opposing effects on the principal's utility of a decrease in μ (see (8) in the text). On the one hand, the principal benefits from the fact that the agent increases the value of his recommendation (as can be seen from (ii) above). In addition, there is a direct positive effect of the reduction in the cost of effort. On the other hand, the principal is hurt if the agent's effort goes down ((iii) above). The overall effect is ambiguous in general and depends on the relative sizes of these effects. ■

Proof of Lemma 2. Equilibrium (v_1^*, v_2^*) is characterized by the system of first-order conditions:

$$\frac{\partial \overline{U}_1}{\partial v_1} = i_{a_2}^* \frac{\partial U_1^{yy}(v_1^*, v_2^*)}{\partial v_1} + (1 - i_{a_2}^*) \frac{\partial U_1^{yn}(v_1^*)}{\partial v_1} = 0, \tag{B1}$$

$$\frac{\partial \overline{U}_2}{\partial v_2} = i_{a_1}^* \frac{\partial U_2^{yy}(v_1^*, v_2^*)}{\partial v_2} + (1 - i_{a_1}^*) \frac{\partial U_2^{ny}(v_2^*)}{\partial v_2} = 0,$$

where

$$\frac{\partial U_1^{yy}(v_1^*, v_2^*)}{\partial v_1} = x_1 \left[\underline{u} - u(v_1^*)\right] \frac{\partial i_{p1}(v_1^*, v_2^*)}{\partial v_1} + \left[1 - i_{p1}(v_1^*, v_2^*)\right] u'(v_1^*),$$

$$\frac{\partial U_1^{yn}(v_1^*)}{\partial v_1} = x_1 \left[\underline{u} - u(v_1^*)\right] \frac{\partial i_{p1}\left(v_1^*, 0\right)}{\partial v_1} + \left[1 - i_{p1}\left(v_1^*, 0\right)\right] u'(v_1^*).$$

As $\partial i_{p1}(v_1^*, v_2^*)/\partial v_1 = \partial i_{p1}\left(v_1^*, 0\right)/\partial v_1$ and as $i_{p1}\left(v_1^*, 0\right) < i_{p1}(v_1^*, v_2^*)$, then $\partial U_1^{yn}(v_1^*)/\partial v_1 < \partial U_1^{yy}(v_1^*, v_2^*)/\partial v_1$.Thus, it follows from (B1) that $\partial U_1^{yn}(v_1^*)/\partial v_1 < 0$ and $\partial U_1^{yy}(v_1^*, v_2^*)/\partial v_1 > 0$.

Denote the agent's best-response functions by $v_1^*(v_2)$ and $v_2^*(v_1)$, respectively. Then, by the Implicit Function Theorem, the slope of the best-response is

$$\frac{\partial v_1^*(v_2)}{\partial v_2^*} = -\frac{\partial \overline{U}_1}{\partial v_1 \partial v_2^*} / \frac{\partial \overline{U}_1}{\partial v_1^2}.$$

The denominator,

$$\frac{\partial^2 \overline{U}_1}{\partial (v_1)^2} = i_{a_2}^* \frac{\partial^2 U_1^{yy}(v_1^*, v_2^*)}{\partial (v_1)^2} + (1 - i_{a_2}^*) \frac{\partial^2 U_1^{yn}(v_1^*)}{\partial (v_1)^2},$$

is negative, as

$$\frac{\partial^2 U_1^{yy}(v_1^*, v_2^*)}{\partial (v_1)^2} = \left(1 - i_{p1}(v_1^*, v_2^*)\right) u''(v_1^*) + \frac{2x_1 u'(v_1^*)}{1-\delta^2} < 0$$

$$\frac{\partial^2 U_1^{yn}(v_1^*)}{\partial (v_1)^2} = \left(1 - i_{p1}\left(v_1^*, 0\right)\right) u''(v_1^*) + \frac{2x_1 u'(v_1^*)}{1-\delta^2} < 0.$$

As $\frac{\partial U_1^{yn}(v_1^*)}{\partial v_1 \partial v_2} = 0$,

$$\frac{\partial^2 \overline{U}_1}{\partial v_1 \partial v_2^*} = i_{a_2}^* \frac{\partial^2 \left[U_1^{yy}(v_1^*, v_2^*)\right]}{\partial v_1 \partial v_2} = -i_{a_2}^* \frac{\delta}{1-\delta^2} u'(v_1^*) > 0.$$

Combining these results, it follows that $\frac{\partial v_1^*(v_2^*)}{\partial v_2^*} > 0$. In a similar manner, one can show $\frac{\partial v_2^*(v_1^*)}{\partial v_1^*} > 0$. Thus, v_1 and v_2 are strategic complements. ■

Proof of Lemma 3. Consider the agents' choice of effort in the first stage. Agent 1 maximizes:

$$\max_{i_{a_1}} i_{a_1}\left[i_{a_2} U_1^{yy} + \left(1 - 1_{a_2}\right) U_1^{yn}\right] + \left(1 - i_{a_1}\right)\left[i_{a_2} U_1^{ny} + \left(1 - 1_{a_2}\right) U_1^{nn}\right] - c\left(i_{a_1}\right).$$

Similarly, agent 2 solves:

$$\max_{i_{a_2}} i_{a_2}\left[i_{a_1} U_2^{yy} + (1 - 1_{a1}) U_2^{ny}\right] + \left(1 - i_{a_2}\right)\left[i_{a_1} U_2^{yn} + (1 - 1_{a1}) U_2^{nn}\right] - c\left(i_{a_2}\right).$$

The first-stage equilibrium is determined by the system of first-order conditions:

$$H_1 = i_{a_2} \cdot \left[U_1^{yy} - U_1^{ny}\right] + (1 - i_{a2}) \cdot \left[U_1^{yn} - U_1^{nn}\right] - c'(i_{a_1}^*) = 0, \tag{B2}$$

$$H_2 = i_{a_1} \cdot \left[U_2^{yy} - U_2^{yn}\right] + (1 - i_{a1}) \cdot \left[U_2^{ny} - U_2^{nn}\right] - c'\left(i_{a_2}^*\right) = 0.$$

Recall that $U_1^{yy} < U_1^{yn}$, $U_1^{ny} > U_1^{nn}$, and that $U_2^{yy} < U_2^{ny}$, $U_2^{yn} > U_2^{nn}$. By the Implicit Function Theorem, the slopes of the best-response functions $i_{a_1}^*\left(i_{a_2}\right)$ and $i_{a_2}^*\left(i_{a_1}\right)$ are then negative,

$$\frac{di_{a_1}^*\left(i_{a_2}\right)}{di_{a2}} = -\frac{H_{12}}{H_{11}} = -\frac{U_1^{yy} - U_1^{ny} - \left[U_1^{yn} - U_1^{nn}\right]}{-c''(i_{a_1}^*)} = \frac{U_1^{yy} - U_1^{yn} - \left[U_1^{ny} - U_1^{nn}\right]}{c''(i_{a_1}^*)} < 0$$

$$\frac{di_{a_2}^*\left(i_{a_1}\right)}{di_{a_1}} = -\frac{H_{21}}{H_{22}} = -\frac{U_2^{yy} - U_2^{yn} - \left[U_2^{ny} - U_2^{nn}\right]}{-c''(i_{a2}^*)} = \frac{U_2^{yy} - U_2^{ny} - \left[U_2^{yn} - U_2^{nn}\right]}{c''(i_{a2}^*)} < 0.$$

Thus, the effort choices are strategic substitutes. ■

Proof of Lemma 4.

(i) Here we consider the recommendations game for a given profile of efforts $(i_{a1}^*, i_{a_2}^*)$. The first-order conditions characterizing the recommendations are:

$$R_1(v_1^*, v_2^*) = i_{a_2}^* \frac{\partial U_1^{yy}(v_1^*, v_2^*)}{\partial v_1} + (1 - i_{a_2}^*) \frac{\partial U_1^{yn}(v_1^*)}{\partial v_1} = 0, \tag{B3}$$

$$R_2(v_1^*, v_2^*) = i_{a_1}^* \frac{\partial U_2^{yy}(v_1^*, v_2^*)}{\partial v_2} + (1 - i_{a_1}^*) \frac{\partial U_2^{ny}(v_2^*)}{\partial v_2} = 0.$$

Consider the effect of a small increase in x_2 on the equilibrium recommendations. Differentiating the system of equations above with respect to $\left(v_1^*, v_2^*, x_2\right)$ and noting that $R_{1,x_2} = 0$, we obtain, by Cramer's law,

$$\frac{\partial v_1^*}{\partial x_2} = \frac{R_{12} R_{2,x_2}}{\Delta},$$
$$\frac{\partial v_2^*}{\partial x_2} = \frac{-R_{11} R_{2,x_2}}{\Delta},$$

where $\Delta = R_{11}R_{22} - R_{12}R_{21}$. Given that $\frac{\partial i_{p1}(v_1^*,v_2^*)}{\partial v_1} = \frac{\partial i_{p1}\left(v_1^*,0\right)}{\partial v_1} = -\frac{\mu_2}{\mu_1\mu_2-\delta^2}$, $\frac{\partial i_{p2}(v_1^*,v_2^*)}{\partial v_2} = \frac{\partial i_{p2}\left(0,v_2^*\right)}{\partial v_2} = -\frac{\mu_1}{\mu_1\mu_2-\delta^2}$ and $\frac{\partial i_{p1}(v_1^*,v_2^*)}{\partial v_2} = \frac{\delta}{\mu_1\mu_2-\delta^2}$, we get, after some derivations:

$$R_1 = [u(v_1^*) - \underline{u}]\frac{x_1\mu_2}{\mu_1\mu_2 - \delta^2} + \{i_{a_2}^*[1 - i_{p1}(v_1^*, v_2^*)] + (1 - i_{a_2}^*)[1 - i_{p1}(v_1^*, 0)]\}u'(v_1^*) \tag{B4}$$

$$R_2 = [u(v_2^*) - \underline{u}]\frac{x_2\mu_1}{\mu_1\mu_2 - \delta^2} + \{i_{a_1}^*[1 - i_{p2}(v_1^*, v_2^*)] + (1 - i_{a_1}^*)[1 - i_{p2}(0, v_2^*)]\}u'(v_2^*) \tag{B5}$$

implying

$$R_{11} = (1 + x_1)\,u'(v_1^*)\frac{\mu_2}{\mu_1\mu_2 - \delta^2} + \left[i_{a_2}^*\left(1 - i_{p_1}(v_1^*, v_2^*)\right) + (1 - i_{a_2}^*)\left(1 - i_{p_1}\left(v_1^*, 0\right)\right)\right]u''(v_1^*) < 0$$
$$R_{22} = (1 + x_2)\,u'(v_2^*)\frac{\mu_1}{\mu_1\mu_2 - \delta^2} + \left[i_{a_1}^*\left(1 - i_{p_2}(v_1^*, v_2^*)\right) + (1 - i_{a_1}^*)\left(1 - i_{p_2}\left(0, v_2^*\right)\right)\right]u''(v_2^*) < 0$$

and $R_{12} = -i_{a_2}^*\frac{\delta}{\mu_1\mu_2-\delta^2}u'(v_1^*) > 0$ and $R_{21} = -i_{a_1}^*\frac{\delta}{\mu_1\mu_2-\delta^2}u'(v_2^*) > 0$.
As

$$\Delta > (1 + x_1)(1 + x_2)\cdot u'(v_1^*)u'(v_2^*)\frac{\mu_1\mu_2}{\left[\mu_1\mu_2 - \delta^2\right]^2} - i_{a_1}^* i_{a_2}^* \cdot u'(v_1^*)u'(v_2^*)\frac{\delta^2}{\left[\mu_1\mu_2 - \delta^2\right]^2} > 0,$$

the equilibrium stability condition is satisfied. In addition, $R_{2,x_2} = \frac{\mu_1}{\mu_1\mu_2-\delta^2}\cdot\left[u(v_2^*) - \underline{u}\right] > 0$ and hence, $\frac{\partial v_1^*}{\partial x_2} = \frac{R_{12}R_{2,x_2}}{\Delta} > 0$ and $\frac{\partial v_2^*}{\partial x_2} = \frac{-R_{11}R_{2,x_2}}{\Delta} > 0$. Both recommendations thus rise as the principal's knowledge of area 2 increases. Finally, note for future reference that provided $v_1^* = v_2^*$,

$$\frac{\partial v_2^*}{\partial x_2}\Big/\frac{\partial v_1^*}{\partial x_2} = -R_{11}/R_{12} > \frac{(1 + x_1)\,\mu_2}{i_{a_2}^*\,\delta} > 1. \tag{B6}$$

(ii) Consider the effect of a change in x_2 on the agents' level of effort. The effort levels are determined by a system of first-order conditions:

$$H_1 = i_{a_2}^*\cdot\left[U_1^{yy} - U_1^{ny}\right] + (1 - i_{a_2}^*)\cdot\left[U_1^{yn} - U_1^{nn}\right] - c'(i_{a_1}^*) = 0,$$
$$H_2 = i_{a_1}^*\cdot\left[U_2^{yy} - U_2^{yn}\right] + (1 - i_{a_1}^*)\cdot\left[U_2^{ny} - U_2^{nn}\right] - c'\left(i_{a_2}^*\right) = 0.$$

Differentiating the system with respect to $\left(i_{a_1}, i_{a_2}, x_2\right)$ and applying Cramer's law

$$\frac{\partial i_{a_1}^*}{\partial x_2} = \frac{-H_{1,x_2}H_{22} + H_{12}H_{2,x_2}}{H_{11}H_{22} - H_{12}H_{21}},$$
$$\frac{\partial i_{a_2}^*}{\partial x_2} = \frac{-H_{11}H_{2,x_2} + H_{1,x_2}H_{21}}{H_{11}H_{22} - H_{12}H_{21}},$$

where $H_{11} = -c''(i_{a_1}^*) < 0$, $H_{22} < -c''\left(i_{a_2}^*\right) < 0$. In addition, recall that $U_1^{yy} < U_1^{yn}$ and $U_1^{ny} > U_1^{nn}$ and that $U_2^{yy} < U_2^{ny}$ and $U_2^{yn} > U_2^{nn}$. Thus, $H_{12} = U_1^{yy} - U_1^{ny} - \left(U_1^{yn} - U_1^{nn}\right) = U_1^{yy} - U_1^{yn} - \left(U_1^{ny} - U_1^{nn}\right) < 0$ and $H_{21} = U_2^{yy} - U_2^{ny} - U_2^{yn} - U_2^{nn} < 0$.
The change in x_2 affects both agents' best-response functions through the effect on the recommendations. Observe from above that $H_{1,x_2} < 0$ and $H_{2,x_2} > 0$ are sufficient conditions for $\frac{\partial i_{a_1}^*}{\partial x_2} < 0$ and $\frac{\partial i_{a_2}^*}{\partial x_2} > 0$. We now show that both of these sufficient conditions are met. Consider first H_{1,x_2}:

$$\begin{aligned} H_{1,x_2} &= i_{a_2}^*\cdot\frac{d\left[U_1^{yy} - U_1^{ny}\right]}{dx_2} + (1 - i_{a_2}^*)\cdot\frac{d\left[U_1^{yn} - U_1^{nn}\right]}{dx_2} \\ &= \left[i_{a_2}^*\frac{di_{p1}(v_1^*, v_2^*)}{dx_2} + (1 - i_{a_2}^*)\frac{di_{p1}\left(v_1^*, 0\right)}{dx_2}\right]\left(\underline{u} - u(v_1^*)\right) \\ &\quad + \left\{i_{a_2}^*\left[1 - i_{p1}(v_1^*, v_2^*)\right] + (1 - i_{a_2}^*)\left[1 - i_{p1}\left(v_1^*, 0\right)\right]\right\}u'(v_1^*)\frac{\partial v_1^*}{\partial x_2} - \frac{di_{p_1}\left(0, v_2^*\right)}{dx_2}\cdot\underline{u}. \end{aligned}$$

The third term is negative as $\frac{di_{p1}(0,v_2^*)}{dx_2} = \frac{\partial i_{p1}(0,v_2^*)}{\partial v_2} \cdot \frac{\partial v_2^*}{\partial x_2} > 0$. The second term is negative as $\partial v_1^*/\partial x_2 > 0$. To sign the first term, note that $\frac{d[i_{p1}(v_1^*,v_2^*)]}{dx_2} = \frac{-\mu_2}{\mu_1\mu_2-\delta^2}\frac{\partial v_1^*}{\partial x_2} + \frac{\delta}{\mu_1\mu_2-\delta^2}\frac{\partial v_2^*}{\partial x_2}$ and that $\frac{d[i_{p1}(v_1^*,0)]}{dx_2} = \frac{-\mu_2}{\mu_1\mu_2-\delta^2}\frac{\partial v_1^*}{\partial x_2}$. Thus,

$$\begin{aligned}
i_{a_2}^* \frac{di_{p1}(v_1^*, v_2^*)}{dx_2} + (1-i_{a_2}^*)\frac{d\left[i_{p1}(v_1^*, 0)\right]}{dx_2} &= \frac{-\mu_2}{\mu_1\mu_2-\delta^2}\frac{\partial v_1^*}{\partial x_2} + i_{a_2}^* \frac{\delta}{\mu_1\mu_2-\delta^2}\frac{\partial v_2^*}{\partial x_2} \\
&> \frac{-\mu_2}{\mu_1\mu_2-\delta^2}\frac{\partial v_1^*}{\partial x_2} + i_{a_2}^* \frac{\delta}{\mu_1\mu_2-\delta^2}\frac{(1+x_1)\mu_2}{i_{a_2}^*\delta}\frac{\partial v_1^*}{\partial x_2} \\
&= \frac{1}{\mu_1\mu_2-\delta^2}\left[-\mu_2 + (1+x_1)\mu_2\right]\frac{\partial v_1^*}{\partial x_2} > 0,
\end{aligned}$$

where the first inequality follows from (B6). The first term is thus negative as well, implying that $H_{1,x_2} < 0$. Next, consider the sign of

$$H_{2,x_2} = i_{a_1}^* \frac{d\left[U_2^{yy} - U_2^{yn}\right]}{dx_2} + (1-i_{a_1}^*)\frac{d\left[U_2^{ny} - U_2^{nn}\right]}{dx_2}.$$

Under the symmetry assumption, one can show that

$$\begin{aligned}
\frac{d\left[U_2^{yy} - U_2^{yn}\right]}{dx_2} &= \left[\frac{\mu}{\mu^2-\delta^2}\left[u(v_2^*) - \underline{u}\right] + \left(1 - i_{p2}(v_1^*, v_2^*)\right)u'(v_2^*)\right]\cdot\frac{\partial v_2^*}{\partial x_2} - \frac{\delta}{\mu^2-\delta^2}\frac{\partial v_1^*}{\partial x_2}u(v_2^*) \\
\frac{d\left[U_2^{ny} - U_2^{nn}\right]}{dx_2} &= \left[\frac{\mu}{\mu^2-\delta^2}\left[u(v_2^*) - \underline{u}\right] + \left(1 - i_{p2}\left(0, v_2^*\right)\right)\cdot u'(v_2^*)\right]\cdot\frac{\partial v_2^*}{\partial x_2}.
\end{aligned}$$

Substituting into H_{2,x_2} and using the first-order condition for v_2^*, (B5)

$$H_{2,x_2} = \frac{1}{\mu^2-\delta^2}\left[(1-x)\mu\frac{\partial v_2^*}{\partial x_2}\left[u(v_2^*) - u\right] - i_{a_1}^*\delta\frac{\partial v_1^*}{\partial x_2}u(v_2^*)\right].$$

At the limit, where $u = 0$, the term in square brackets is positive as by assumption $(1-x)\mu > \delta > i_{a_1}^*\delta$ and as $\frac{\partial v_2^*}{\partial x_2} > \frac{\partial v_1^*}{\partial x_2}$ by (B6). By continuity, the sufficient condition holds also if u is sufficiently small. Moreover, as can be easily observed, the condition is not a necessary one. Thus, $H_{2,x_2} > 0$. Hence, $\partial i_{a_1}^*/\partial x_2 < 0$ and $\partial i_{a_2}^*/\partial x_2 > 0$. ■

Below, I consider a second comparative statics exercise in the model with two agents, in which the principal's ability to explore alternatives in area 2 only, μ_2, increases.

Differentiating the system of equations (B3) with respect to $\left(v_1^*, v_2^*, \mu_2\right)$ and applying Cramer's law, we get

$$\begin{aligned}
\frac{\partial v_1^*}{\partial \mu_2} &= \frac{-R_{22}R_{1,\mu_2} + R_{12}R_{2,\mu_2}}{\Delta}, \\
\frac{\partial v_2^*}{\partial \mu_2} &= \frac{-R_{11}R_{2,\mu_2} + R_{21}R_{1,\mu_2}}{\Delta},
\end{aligned}$$

where $\Delta = R_{11}R_{22} - R_{12}R_{21} > 0$. Now

$$R_{2,\mu_2} = x_2\left[\underline{u} - u(v_2^*)\right]\frac{\partial i_{p2}(v_1^*, v_2^*)}{\partial v_2\partial\mu_2} - \left[i_{a_1}^*\frac{\partial i_{p2}(v_1^*, v_2^*)}{\partial\mu_2} + (1-i_{a_1}^*)\frac{\partial i_{p2}\left(0, v_2^*\right)}{\partial\mu_2}\right]u'(v_2^*).$$

Noting that $\frac{\partial i_{p2}(v_1,v_2^*)}{\partial\mu_2} = -\frac{\mu_1}{\mu_1\mu_2-\delta^2}\cdot i_{p_2}(v_1, v_2^*) < 0$ and $\frac{\partial^2 i_{p2}(v_1^*,v_2^*)}{\partial v_2\partial\mu_2} = \frac{\delta}{\mu_1\mu_2-\delta^2}\cdot\frac{\partial i_{p1}(v_1^*,v_2^*)}{\partial v_2} > 0$, we conclude that $R_{2,\mu_2} < 0$. Agent 2's best–response thus shifts out as μ_2 decreases. Similarly

$$R_{1,\mu_2} = x_1\left[\underline{u} - u(v_1^*)\right]\frac{\partial^2 i_{p1}(v_1^*, v_2^*)}{\partial v_1\partial\mu_2} - \left[i_{a_2}^*\frac{\partial i_{p1}(v_1^*, v_2^*)}{\partial\mu_2} + (1-i_{a_2}^*)\frac{\partial i_{p1}\left(v_1^*, 0\right)}{\partial\mu_2}\right]u'(v_1^*).$$

Noting that $\frac{\partial i_{p1}(v_1^*,v_2^*)}{\partial\mu_2} = \frac{\delta}{\mu_1\mu_2-\delta^2}\cdot i_{p_2}(v_1^*, v_2^*) > 0$ and $\frac{\partial^2 i_{p1}(v_1^*,v_2^*)}{\partial v_1\partial\mu_2} = \frac{\delta}{\mu_1\mu_2-\delta^2}\cdot\frac{\partial i_{p2}(v_1^*,v_2^*)}{\partial v_1} = \frac{\delta^2}{\left(\mu_1\mu_2-\delta^2\right)^2} > 0$, we observe that there are two opposing effects on R_1 of a change in μ_2. The second term is the change in the expected marginal loss in case the principal's effort fails $(1 - i_{p1})$. As μ_2 increases, the principal's effort in area 1 increases, which makes this case less likely. This term is thus positive. The first term is negative and reflects the change in $\partial i_{p1}(v_1^*, v_2^*)/\partial v_1$.

Consider now the effect on equilibrium recommendations of a change in μ_2 around the symmetric initial point: $\mu_1 = \mu_2 = \mu$, $x_1 = x_2 = x$ (and hence, $v_1^* = v_2^*$). Under symmetry $i_{p2}(v^*, v^*) = i_{p1}(v^*, v^*)$ and $i_{p2}(v^*, 0) = i_{p1}(0, v^*)$ and thus,

$$R_{2,\mu_2} = \frac{\mu}{\mu^2-\delta^2}\left\{x\left[\underline{u} - u(v^*)\right]\frac{\mu}{\mu^2-\delta^2} + \left[i_a^*\cdot i_{p1}(v^*, v^*) + (1-i_a^*)\cdot i_{p1}(0, v^*)\right]u'(v^*)\right\}$$

$$R_{1,\mu_2} = \frac{\delta}{\mu^2-\delta^2}\left\{x[\underline{u}-u(v^*)]\frac{\delta}{\mu^2-\delta^2} - \left[i_a^* \cdot i_{p1}(v^*,v^*) + (1-i_a^*)\cdot i_{p1}(0,v^*)\right]u'(v^*)\right\}.$$

Recall that R_{11}, R_{22}, R_{12}, and R_{21} are derived in the proof of Lemma 4 above and that $R_{11} < (1+x_1)\,u'(v_1^*)\frac{\mu_2}{\mu_1\mu_2-\delta^2} < 0$ and $R_{21} = \frac{-i_{a_1}^*\delta}{\mu_1\mu_2-\delta^2}u'(v_2^*)$. Thus,

$$\frac{\partial v_2^*}{\partial \mu_2} = \frac{-R_{11}R_{2,\mu_2} + R_{21}R_{1,\mu_2}}{\Delta} < \frac{-u'(v^*)\left[\frac{\mu}{\mu^2-\delta^2}R_{2,\mu_2} + \frac{i_a^*\delta}{\mu^2-\delta^2}R_{1,\mu_2}\right]}{\Delta}.$$

The term in brackets is negative as can be observed directly, as $\mu > \delta$. Thus $\frac{\partial v_2^*}{\partial \mu_2} < 0$.

The effect of an increase in ability (a reduction in μ_2) on v_1^* is difficult to sign in general. The sign of the total effect is that of $R_{22}R_{1,\mu_2} - R_{12}R_{2,\mu_2}$. The total effect is positive if $R_{1,\mu_2} < 0$. However, if $R_{1,\mu_2} > 0$, there are two opposing effects. The first, direct effect, is negative. As the principal becomes more cost-efficient in area 2, he exerts more effort in area 2 (and less in area 1), and thus agent 1 finds it optimal to lower his recommendation. The second, strategic effect, is positive: because agent 2 raises his recommendation and as recommendations are strategic complements, so does agent 1. The total effect is negative whenever the direct effect outweighs the strategic effect and vice versa.

Consider next the effect of a change in μ_2 on the agents' effort. The effort levels are determined by a system of first-order conditions:

$$H_1 = i_{a_2}^* \cdot \left[U_1^{yy} - U_1^{ny}\right] + (1-i_{a_2}^*)\cdot\left[U_1^{yn} - U_1^{nn}\right] - c'(i_{a_1}^*) = 0,$$
$$H_2 = i_{a_1}^* \cdot \left[U_2^{yy} - U_2^{yn}\right] + (1-i_{a_1}^*)\cdot\left[U_2^{ny} - U_2^{nn}\right] - c'\left(i_{a_2}^*\right) = 0.$$

Differentiating the first-order conditions, and by Cramer's law

$$\frac{\partial i_{a_1}^*}{\partial \mu_2} = \frac{-H_{1,\mu_2}H_{22} + H_{12}H_{2,\mu_2}}{H_{11}H_{22} - H_{12}H_{21}},$$
$$\frac{\partial i_{a_2}^*}{\partial \mu_2} = \frac{-H_{11}H_{2,\mu_2} + H_{1,\mu_2}H_{21}}{H_{11}H_{22} - H_{12}H_{21}},$$

where $H_{11} < 0$, $H_{22} < 0$, $H_{12} < 0$, and $H_{21} < 0$ were shown in the proof of Lemma 4. Thus, $H_{1,\mu_2} < 0$ and $H_{2,\mu_2} > 0$ are sufficient conditions for $\partial i_{a_1}^*/\partial\mu_2 < 0$ and $\partial i_{a2}^*/\partial\mu_2 > 0$, and where

$$H_{1,\mu_2} = i_{a_2}^* \cdot \frac{d\left[U_1^{yy} - U_1^{ny}\right]}{d\mu_2} + (1-i_{a_2}^*)\cdot\frac{d\left[U_1^{yn} - U_1^{nn}\right]}{d\mu_2},$$
$$H_{2,\mu_2} = i_{a_1}^* \frac{d\left[U_2^{yy} - U_2^{yn}\right]}{d\mu_2} + (1-i_{a_1}^*)\frac{d\left[U_2^{ny} - U_2^{nn}\right]}{d\mu_2}.$$

$H_{1,\mu_2} < 0$ implies that the expected net return on agent 1's effort decreases in μ_2. Provided agent 1 compromises more when μ_2 goes up (when $\partial v_1^*/\partial\mu_2 > 0$), this works in this direction. The fact that $\partial v_2^*/\partial\mu_2 < 0$, however, has a countervailing effect as it implies that the principal's return on effort in area 2 increases. This works to lower the principal's effort in area 1 and thus to encourage effort by agent 1.

$H_{2,\mu_2} > 0$ implies that the expected net return on agent 2's effort increases in μ_2. The fact that agent 2 compromises less when μ_2 goes up ($\partial v_2^*/\partial\mu_2 < 0$) works in this direction. If $\partial v_1^*/\partial\mu_2 > 0$, however, the principal's return on effort in area 1 is lower, implying that his effort in area 2 would be higher, everything else being equal. This force thus works to lower agent 2's return on effort.

As the efforts are strategic substitutes, the two conditions together, if met, are sufficient to pin down the effect on equilibrium efforts. In this case, an increase in the principal's ability in area 2 (a reduction in μ_2) leads to a decrease in agent 2's effort and to an increase in agent 1's effort.

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