Governing Adaptation

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Abstract

To remain competitive, an organization needs to respond to information about its environment while at the same time retaining coordination among its activities. We analyze how the allocation of decision rights within an organizational hierarchy influences the organization's ability to solve such problems of coordinated adaptation information is both soft and distributed inside the organization and the organizational participants behave strategically. The results show that, contrary to the common intuition, the performance differential between centralized and decentralized decision-making is non-monotone in the importance of coordination. Further, both of these common structures are dominated by asymmetric structures in sufficiently asymmetric environments (such as a small division developing a new product in the presence of a large division with an established product). Finally, if the incentive conflicts between the participants can be made sufficiently small, centralized decision-making is always dominated by decentralized decision-making.

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1 Introduction

To remain competitive, an organization needs to respond to information about its environment while at the same time retaining coordination among its activities. For example, consider the challenges of product development and positioning faced by a multi-product firm organized as a divisional hierarchy. In the course of their duties, each division manager (responsible for a given product or product group) learns information about his customers, technological developments and market conditions. A unilateral response to such information, say, in terms of new product offerings, can be valuable, but additional benefits can be realized by coordinating the responses of the various divisions: Cost economies can be realized by coordinating manufacturing, marketing and distribution, while maintaining the correct product configuration can help to realize potential complementarities between the products and to avoid unwanted cannibalization.

Achieving such coordinated adaptation poses an organizational challenge because three factors interact. First, specialization (by technology, region, customer group, or the like) means that decision-relevant information is distributed inside the organization, rather than being directly accessible to any single potential decision-maker. Second, much of that information is "soft," rather than communicable as hard facts. Third, different members of the organization can have conflicting preferences over the possible courses of action. The distributed nature of information necessitates the transmission of information from the informed agents to the decision-maker(s). Misalignment of preferences between the informed agents and the decision-maker(s) generates the problem of strategic communication, which in turn is amplified by the prominence of soft information. Finally, any misalignment of the preferences of the decision-maker(s) with the organizational objectives will lead to suboptimal decisions, even conditional on the information that can be made available.

Returning to our example, the optimal positioning of each product will depend on information held by all division managers (distributed information). Communicating one's opinion – say, about customer preferences – may be relatively easy, whereas providing verifiable information is significantly harder (soft information). Finally, the division managers are likely to prefer product offerings that are particularly profitable for their own division, even at the expense of overall firm profitability (conflicting preferences).

This paper constructs a model of such problems of coordinated adaptation and analyzes how the importance of coordination among the organization's activities and other divisional characteristics affect the relative performance of different governance structures. We consider an organization in which two divisions need to balance responding to local conditions and being coordinated with each other. Authority over the divisions can be allocated among two privately informed but biased division managers and an uninformed but unbiased headquarters, which leads us to analyze four distinct governance structures. Under *decentralized authority,* authority over the divisions is delegated to the respective division managers, while under *centralized authority,* both decision rights are retained by the headquarters. These two symmetric structures have received the most theoretical and empirical attention to date, and there is a growing body of evidence for the result that the need for coordination and centralized decision-making are generally positively related.

Asymmetries across divisions or business units, on the other hand, have received little to no theoretical or empirical attention. However, casual observation suggests that such asymmetries are relatively common in practice, with differences in size, market conditions, product life cycle and the underlying technology generating differences in the relative importance of adaptation and coordination across divisions. Further, there are some historic examples, such as the early treatment of the IBM PC division, that are suggestive of asymmetric treatment of divisions by the headquarters. As a result, we also analyze two asymmetric governance structures: *partial centralization*, where one division manager is delegated authority while the other division is controlled by the headquarters, and *directional authority*, where both decision rights are delegated to one of the division managers. An example of the former is the "firm within a firm" or "skunkworks" approach, in which a small division developing a new product is given substantial autonomy, while the divisions with established products are closely managed by the headquarters. An example of the latter is sometimes seen as the new product matures: a highly successful product may effectively take over the firm, while less successful products may be repositioned under existing divisions.

Under any governance structure, the division managers first learn their local conditions, after which they communicate with the decision-maker(s), followed by decision-making. By considering strategic behavior by the organizational participants, we endogenize both the quality of decision-making, conditional on the information available to the decision-maker(s), and the accuracy of information transmission, as influenced by the allocation of decision rights and the underlying environment. Motivated by the importance of soft information, communication is modeled as a cheap-talk game.

Our main result is a mapping from the underlying divisional characteristics, such as the importance of coordination (dependency), size, and volatility of the local environment, to the preferred governance structure. The mapping shows that in the case of symmetric divisions, the common intuition of coordination requiring centralized decision-making holds broadly true: When the need for coordination is sufficiently low, decentralized authority is preferred to limit the loss of information due to strategic communication and so the adaptiveness of the divisions. When the need for coordination is sufficiently high, centralized authority is preferred to improve coordination between the divisions. It is worth noting, however, that the actual performance differential between centralized and decentralized authority is S-shaped, with the two solutions converging both when coordination becomes very important and when coordination becomes unnecessary. Intuitively, when coordination is the overriding concern for divisional performance, the division managers are willing to coordinate their actions even under decentralization. Alternatively, when the divisions are fully independent, no incentive conflicts are present and perfect adaptation can be achieved also under centralization. It is only when the organization needs to balance conflicting needs for adaptation that the issue of conflicting preferences, and so the ability of the different governance structures to manage those conflicts, plays a meaningful role.

When the divisions are sufficiently asymmetric, then one of the asymmetric governance structures is the preferred choice. Intuitively, asymmetries in divisional characteristics alter the relative importance of adaptation and coordination (and so the relative importance of decision-making and communication) for the two divisions, and an asymmetric governance structure can find a better balance between those needs than a symmetric structure. We can distinguish between two types of asymmetries. First, when one division cares more about coordination but places a similar weight on adaptation, decentralizing only the more dependent division is preferred. In this case, partial centralization is used achieve more balanced adaptation relative to decentralized authority while limiting the losses due to strategic communication relative to centralized authority. Second, when one division cares significantly more about coordination and at the same time less about adaptation, then it is optimal to *weaken* the strategic position of the more dependent division. This weakening is achieved by delegating authority over the less dependent division to the respective division manager, while control over the more dependent division is either retained at the headquarters (partial centralization) or also delegated to the manager of the less dependent division (directional authority). In this case, allowing the more dependent division to gain authority would hinder both the adaptiveness of the less dependent division and communication and coordination across the divisions, while retaining authority over the less dependent division at the headquarters would lead to too little overall adaptation.

A particular result that follows from this part of the analysis is that if directional authority ever arises in equilibrium, control is always allocated to the division that cares *less* about coordination, other things constant. While this result can appear counter-intuitive, the intuition is straightforward and results from the distinction between the value and the equilibrium amount of coordination. Under directional authority, because one of the divisional managers controls both decisions, the decisions will be inherently (indeed, excessively) coordinated, independent of the actual value the manager places on coordination. The real cost of directional authority is the neglect of the adaptive needs of the division that loses authority, making the decisions coordinated around a suboptimal point. Therefore, given the choice between allocating both decisions to one of the division managers, it is better to allocate the decisions to the manager to whom adaptation is more valuable, other things constant.

Finally, while the focus of this paper is on understanding the role of the allocation of decision rights in influencing decision-making and communication in organizations, in practice the allocation of decision rights is only a part of the overall organizational design. To examine the robustness of the results, we introduce partial incentive alignment between the divisions and investigate the relationship between the relative performance of the different governance structures and the degree of incentive alignment. The results show that centralized authority and incentive alignment are substitutes, with increased incentive alignment decreasing the need for intervention by the headquarters.

The remainder of the paper is organized as follows. Section 2 reviews the related literature and section 3 describes the model. Section 4 derives the solution under decentralized authority. A unified framework for analyzing all four governance structures is derived in Appendix A, and section 5 uses this solution to analyze the alternative governance structures, focusing on the key differences with decentralized authority. Section 6 summarizes the results and discusses the empirical implications of the model. Section 7 discusses some extensions, including the role of incentive alignment, and section 8 concludes.

2 Related Literature

In viewing the organizational problem as one of coordinated adaptation under distributed information, the paper is intellectually indebted to the analysis of decision-making, authority and adaptation by, among others, Barnard (1938), Simon (1947), Cyert and March (1963) and Williamson (1975).[1] However, these descriptive theories are significantly broader in scope and blend in their discussion incentive conflicts, bounded rationality and technological considerations. In contrast, our analysis focuses purely on the impact that incentive conflicts among the organizational participants have on decision-making and communication in organizations and thus on the choice of governance structure.

Methodologically, we build on the seminal work of Crawford and Sobel (1982) (henceforth CS) on cheap talk and assume that the actors are unable to commit to a decision rule ex ante. In contrast to CS, the preference bias in our setting arises endogenously from the relative importance of coordination, and by considering the difference between decision-making by the informed agents and decision-making by the uninformed principal, the model distinguishes between vertical and horizontal communication. By allowing for the possibility of full agreement between the sender and the receiver(s), the communication equilibrium is analogous to Stein (1989) and Melumad and Shibano (1991). Finally, in our focus on multiple senders, we are closer to Battaglini (2002), but instead of each sender observing full, multidimensional information, the agents in our model observe only partial and independent information, making truth-telling impossible.

A number of recent papers are closely related to ours in their focus on organizational design and, in particular, on the roles of private information and communication in influencing the optimal allocation of decision rights. Dessein (2002) analyzes the CS setting and illustrates how delegation of the decision right is often preferred over the communication equilibrium because the cost of inaccurate information caused by strategic communication is often higher than the cost of biased decision-making. However, by focusing on a single decision, the model remains silent on issues of coordination. Alonso (2007) illustrates how sharing control of complementary decisions improves communication between an informed agent and an uninformed principal. However, the

[1] And similar considerations within the modern capabilities literature, especially Langlois and Robertson (1993,1995).

model does not allow for distributed information, which is central to our model.

Dessein and Santos (2006) examine a team-theoretic model that focuses on the limitations that the need for coordinated adaptation imposes on task specialization. However, by taking a team-theoretic approach with a fixed quality of communication, the model has no explicit role for authority.[2] In contrast, our model is about how different allocations of authority influence the organization's ability to achieve coordinated adaptation, given the degree of specialization.

Athey and Roberts (2001), Dessein, Garicano and Gertner (2005) and Friebel and Raith (2007) provide complementary perspectives on organizational design.[3] Athey and Roberts (2001) examine an incentive provision problem where two agents need to be induced to both provide productive effort and make good project choices. By allocating the right to choose projects to a third party, the inherent multitasking problem can be relaxed. Dessein, Garicano and Gertner (2005) examine how the optimal allocation of a synergy implementation decision among a functional manager (who learns the value of potential synergies) and two product managers (who learn the cost of synergy implementation in terms of compromised local adaptation) depends on the value of synergies, the value of local adaptation and the importance of productive effort exerted by the agents. Friebel and Raith (2007) examine a resource allocation problem, where two local agents exert effort to generate high-quality projects and the amount of resources available to them can be determined either ex ante (decentralization) or ex post by a central agent (centralization). In all three of these papers, the basic tension is between strong local incentives to induce effort and balanced global incentives to induce truthful communication and/or good decisions. However, by analyzing models with a single decision, none of these papers captures the strategic interaction between interdependent decisions that is at the heart of our model.

Finally, Alonso, Dessein and Matouschek (2008) (henceforth ADM) have independently developed a model very similar to ours but analyze only the case of symmetric divisions. Our results thus generalize the framework to allow for asymmetric divisions and provide a unified treatment of the governance structures. In consequence, this paper focuses more on the impact that asymmetries across divisions have on the choice

[2] Team-theoretic models have been used to examine organizational structures and hierarchies from various angles: information processing (e.g. Marshak and Radner (1972), Bolton and Dewatripont (1994)), problem-solving (e.g. Garicano (2000)), screening for interdependencies (Harris and Raviv (2002)), asset utilization (Hart and Moore (2005)) and coordination and experimentation (Qian, Ronald and Xu (2006)).

[3] See also Aghion and Tirole (1997) and Hart and Holmström (2002).

of governance structure, while the focus in ADM is on impact of the degree of incentive alignment. Rantakari (2007) examines the broader organizational design problem by extending the present framework to account for endogeous incentive alignment, quality of information and the choice of divisional dependency.

3 The Model

We examine the problem of coordinating the activities of two divisions, i and j. The ex post profit realized by division i is given by

$$\Pi_i = K_i - k_i \left((1 - r_i) (\theta_i - d_i)^2 + r_i (d_j - d_i)^2 \right),$$

where d_i and d_j stand for the decisions chosen for divisions i and j, and $\theta_i \sim U\left[-\overline{\theta}_i, \overline{\theta}_i\right]$ indexes the locally optimal decision, with θ_i and θ_j independently distributed. There are three exogenous variables of interest. The primary variable is $r_i \in (0, 1)$, which measures the relative importance of coordination to division i. We will refer to r_i as the *dependency* of division i. Second, $k_i > 0$ measures the overall importance of decision-making to division i and is associated with the overall size of the division. Finally, $\overline{\theta}_i$ measures the degree of environmental volatility faced by the division. The divisional performance is then given by how well the decision d_i matches the realized local conditions θ_i and how well the decision is coordinated with the actions of the other division d_j.

That divisions vary in size and in the environmental volatility they face appears immediate, with the product life cycle providing natural variation over time. The idea that the divisions can also vary in their need for coordination has received less attention. However, such asymmetries can arise for a variety of reasons. For example, the profitability of products targeted at high-income and low-income people is likely to depend differentially on meeting customer preferences and cost containment. Similarly, divisions can vary in the extent to which they depend on inputs supplied by other parts of the organization and in the extent to which they in turn supply other parts of the organization. For example, if one division uses the product of another division as an input to its production process, while the other division is able to sell its product both to that division and on the open market, then the division using the input is going to be more dependent on coordination of production than the division supplying the input.[4] Finally, differences in size can also lead to differences in dependency. A small, young division can be significantly more constrained in its behavior through choices made elsewhere in the organization than a large, established division.

Actors and payoffs: Associated with each division is a division manager, whom we will call agents i and j, respectively. Only agent i has direct access to information about θ_i and, in the main analysis, we assume that his objective is to maximize the profitability of his division, Π_i. In addition to the division managers, there exists headquarters that has no direct access to information about either θ_i or θ_j and her objective is to maximize $\Pi_i + \Pi_j$. We will refer to the headquarters as the principal and index it with P.

It might appear excessively restrictive to focus on a situation where the division managers care only about their own divisions. However, because introducing partial incentive alignment between the divisions simply reduces (but does not eliminate) the underlying agency problem without changing the nature of that conflict, analyzing the case of maximal conflict is sufficient for understanding the basic tradeoffs involved. Incentive alignment does, however, improve the performance of the alternative governance structures (outlined below) at different rates. Section 7 extends the analysis to account for objective functions of the form $s\Pi_i + (1-s)\,\Pi_j$ to illustrate the additional insights that can gained from the interaction between incentive alignment and the preferred governance structure.

Governance structures: Within this framework, we analyze four governance structures, summarized in figure 1. Letting $\mathbf{d}^k$ denote the set of decision rights allocated to an actor $k \in \{i, j, P\}$, the alternatives are: *decentralized authority*, where each division manager decides how their division is operated ($\mathbf{d}^i = \{d_i\}, \mathbf{d}^j = \{d_j\}, \mathbf{d}^P = \{\varnothing\}$); *centralized authority*, where both decision rights are allocated to the headquarters ($\mathbf{d}^i = \{\varnothing\}, \mathbf{d}^j = \{\varnothing\}, \mathbf{d}^P = \{d_i, d_j\}$); *partial centralization*, where one decision right is centralized while the other is left at the divisional level ($\mathbf{d}^i = \{d_i\}, \mathbf{d}^j = \{\varnothing\}, \mathbf{d}^P = \{d_j\}$); and *directional authority*, where both decision rights are allocated to one of the division managers, essentially making one of the divisions a sub-division of the division gaining authority ($\mathbf{d}^i = \{d_i, d_j\}, \mathbf{d}^j = \{\varnothing\}, \mathbf{d}^P = \{\varnothing\}$).[5] These governance structures

[4] I would like to thank an anonymous referee for this example

[5] These four governance structures span the set of single-agent, unconditional decision-making structures that can arise in equilibrium. Governance structures where agent i would control d_j without also controlling d_i are never optimal in our model.

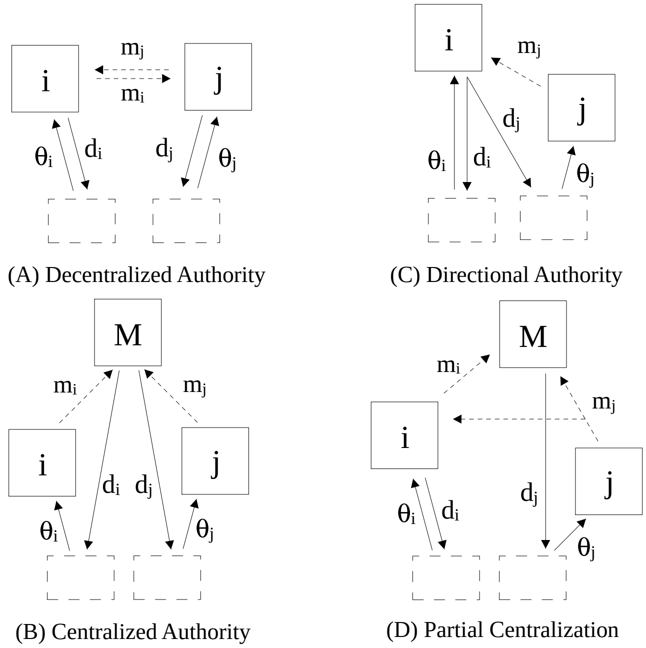


Figure 1: Alternative governance structures

are indexed by $g \in \{dec, cent, part(j), dir(i)\}$. In the case of partial centralization, j refers to the centralized activity, while in the case of directional authority, i refers to the division manager gaining control over both divisions.

Timing of events: The timing of events and the actions available to the actors are summarized in figure 2. At $t = 1$, the governance structure is chosen, before any private information is learned. At $t = 2$, the division managers learn their respective local conditions θ_i and θ_j. At $t = 3$, communication takes place, which is modeled as one round of simultaneous cheap talk. Foreseeing how the equilibrium decisions are formed at $t = 4$ and how they are influenced by additional information, the division managers strategically send non-verifiable messages m_i and m_j regarding their realized local conditions to the decision-maker(s). At $t = 4$, the actors controlling the decision rights choose decisions to optimize their objective functions, given the information available to them.[6] No interim contracting on the decisions or renegotiation of the governance structure is allowed.

For each governance structure, we solve for the Perfect Bayesian Equilibrium of

[6]Results in the case of sequential decision-making and communication are available from the author on request.

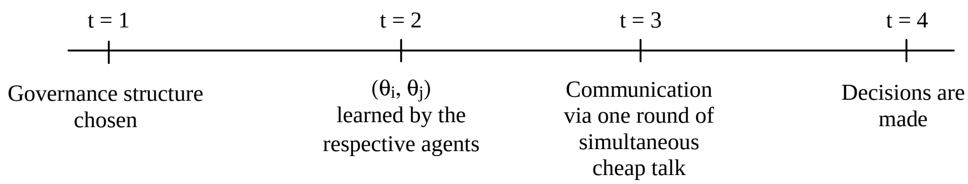


Figure 2: Timing of events

this game: in each stage, the actions of the actors need to be optimal given their beliefs and those beliefs need to be correct in equilibrium. At $t = 1$, the governance structure is chosen to maximize the total expected profits. Because maximizing profit in the present setting is the same as minimizing the total expected loss due to imperfect adaptation and imperfect coordination, we will focus on the loss formulation of the problem, where to organizational goal is to minimize $E(L_i + L_j)$, with $L_i = k_i\left((1 - r_i)(\theta_i - d_i)^2 + r_i(d_j - d_i)^2\right)$.

4 Decentralized Authority

We will begin the analysis by deriving the solution under decentralized authority, where each division manager retains control over the operation of his division. We first solve for the equilibrium decisions given the information available to the division managers. Having the equilibrium decisions, we then solve for the highest sustainable quality of communication, which is directly dependent on the equilibrium decisions. Having the equilibrium decisions and the quality of communication, we will then analyze the expected performance of decentralized authority relative to the first-best outcome (decisions that minimize $E(L_i + L_j)$ under perfect information) to understand when and why decentralized authority performs poorly. Section 5 repeats this exercise for the alternative governance structures and discusses when they are able to improve upon the decentralized solution. The comparative analysis of the governance structures is summarized in section 6.

4.1 Equilibrium Decisions

At the decision-making stage, the information available to agent i consists of (i) the realization of his local state θ_i, (ii) message m_j received from agent j, used by agent i to form beliefs over θ_j (denoted $E_i\theta_j$), and (iii) message m_i sent to agent j, used by agent j to form beliefs over the realization of θ_i ($E_j\theta_i$). Given this information, agent i solves

$$\min_{d_i} E_i \left(k_i \left((1-r_i)(\theta_i - d_i)^2 + r_i (d_j - d_i)^2\right)\right).$$

Taking the first-order conditions and rearranging gives the reaction functions for the two decisions:

$$d_i = (1-r_i)\,\theta_i + r_i E_i d_j \qquad \text{and} \qquad d_j = (1-r_j)\,\theta_j + r_j E_j d_i.$$

Solving the reaction functions for the equilibrium decisions yields the following proposition:

Proposition 1 ***Equilibrium decisions under decentralized authority:***

$$d_i^{dec} = (1-r_i)\,\theta_i + \tfrac{(1-r_j)r_i}{(1-r_i r_j)} E_i\theta_j + \tfrac{(1-r_i)r_i r_j}{(1-r_i r_j)} E_j\theta_i.$$

Proof. Special case of proposition 4. ■

Note that the equilibrium decisions take the form $d_i^{dec} = a_{i1}\theta_i + a_{i2}E_i\theta_j + a_{i3}E_j\theta_i$ (with $a_{i1} + a_{i2} + a_{i3} = 1$), where the expectations $E_i\theta_j$ and $E_j\theta_i$ are formed based on the messages m_j and m_i exchanged in the communication stage, and that the decisions (conditional on the available information) are solely determined by the relative dependency of the two activities, r_i and r_j.

To understand the intuition behind the equilibrium decisions, consider the following implicit thought experiment that occurs through the reaction functions when the equilibrium decisions are determined: Having observed θ_i and absent any communication (so that $E_i d_j = E_j d_i = 0$), agent i's decision would be given by $d_i = (1-r_i)\,\theta_i$. We will refer to this first coefficient of proposition 1, $a_{i1} = (1-r_i)$, as the *rate of direct* *adaptation*, as it measures how much the manager would respond to his information absent any accommodation by the other division.

By communicating information about the realization of θ_i, agent i is able to improve both the coordination between the decisions *and* the amount of adaptation he is able to achieve. Suppose agent i has sent a message m_i to agent j, inducing a belief $E_j\theta_i$. Because agent j puts weight r_j on coordination, he will accommodate the decision that he expects agent i to make. This accommodation, by improving the coordination between the decisions, allows agent i to further increase the amount adaptation, and so forth. Solving this iterative process gives then the coefficients a_{j2}, which we will refer to as the *rate of accommodation,* and a_{i3}, which we will refer to as the *rate of induced adaptation.* The sum $a_{i1} + a_{i3} = a_{i1+i3}$ will be called simply the *rate of adaptation.* An equivalent process over the beliefs over θ_j determines the weights a_{j1}, a_{i2} and a_{j3}.

Because of the strategic interaction between the decisions, the decisions will in expectation lie somewhere between agent i's preferred decisions $d_i = d_j = \theta_i$ and agent j's preferred decisions $d_i = d_j = \theta_j$. However, how far the equilibrium decisions are from each division manager's ideal point depends on how much weight each division manager places on coordination and, as a result, on the rates of accommodation. As r_i increases, any adaptation achieved by agent i becomes increasingly dependent on accommodation by agent j. As a result, agent j is able to decrease his rate of accommodation a_{j2} and so move the equilibrium decisions in his favor. The converse holds when r_j increases, with the increase in a_{j2} allowing agent i to move the equilibrium decisions towards his ideal decisions. Finally, along the diagonal $r_i = r_j = r$, each agent becomes increasingly dependent on the accommodation granted by the other, but at the same time each agent becomes more accommodating: $a_{i2} = a_{j2}$ is increasing in r. In simple terms, as coordination becomes more important, even self-interested agents become more willing to coordinate because their payoffs depend on it.

An important feature of the decisions is that they are independent of the overall importance of decision-making for the two divisions, k_i and k_j. The reason for this result is that in the decision-making stage, it is the dependency of the division that determines the weight that the division manager places on coordination, which in turn determines the strategic position of the two managers. The higher the dependency relative to the other division, the weaker the strategic position: A manager that cares primarily about coordination ends up accommodating the whims of the other division independent of the absolute value of adaptation or coordination. The first-best decisions, on the other hand, will reflect not only the overall value of coordination, but also the absolute value of adaptation, $k_i(1-r_i)$ and $k_j(1-r_j)$. Thus, not only will the decisions under decentralized authority be generally under-coordinated (because the agents do not internalize the full value of coordination), but they will also be generally coordinated around the wrong focal point (because the decisions reflect only relative, not absolute value of adaptation).

4.2 Equilibrium Communication

Not only do the rates of accommodation a_{i2} and a_{j2} play a large role in the determination of the equilibrium decisions, but as we will see below, as a measure of the incentive conflict between the two division managers, these coefficients are the sole determinants of the quality of communication between the division managers under decentralized authority.

As discussed above, agent i sends a message m_i about the realization of θ_i to achieve accommodation by d_j, which in turn allows i to achieve more adaptation. The discussion also made apparent the problem that the non-verifiability of information generates in the communication stage. In the decision-making stage, agent i would like to have $d_i = d_j = \theta_i$ and so achieve both perfect adaptation and perfect coordination. On the other hand, agent j's expected response to a message m_i is given by $a_{j2}E_j(\theta_i|m_i)$, where the rate of accommodation a_{j2} is strictly below one for all $r_j < 1$. As a result, if agent j expects agent i to tell the truth, agent i will exaggerate the realized θ_i to induce a higher level of accommodation by agent j, making fully informative communication impossible.

However, as shown by Crawford and Sobel (1982), partially informative communication can still potentially be achieved. This partially informative communication is achieved by partitioning the state-space so that any message m_i reveals only that θ_i belongs to some interval. Intuitively, such partitioning discretizes the response of the recipient and as a result the sender can be made to choose between an under-response from a lower message and an over-response from a higher message.

From this logic it is clear that for a partition to be incentive-compatible, it needs to be that when the realized state falls on the boundary between two elements (intervals) of the partition, the sender is indifferent between saying that the state belongs to either one of the intervals. That is, it needs to be that

$$E_iL_i\left(\theta_i^M, d_i(., E_j^L\theta_i), d_j(., E_j^L\theta_i)\right) = E_iL_i\left(\theta_i^M, d_i(., E_j^H\theta_i), d_j(., E_j^H\theta_i)\right).$$

Solving this indifference condition gives us the difference equation that defines the family of incentive-compatible partitions:

$$|\theta_{i,k} - \theta_{i,k-1}| - |\theta_{i,k-1} - \theta_{i,k-2}| = \tfrac{4}{\varphi_i^{dec}} |\theta_{i,k-1} - E_i\theta_j|,$$

where $\theta_{i,k}$ are the cutoffs of the partition, with k increasing away from the expected preference intersection $\theta_i = E_i\theta_j = 0$, and

$$\varphi_i^{dec} = \tfrac{a_{j2}}{1-a_{j2}} = \tfrac{r_j(1-r_i)}{(1-r_j)},$$

which uniquely determines the rate at which the size of the elements (intervals) needs to grow to counter the increasing incentives for i to exaggerate the realized θ_i.

While φ_i^{dec} defines the relative size of two adjacent elements of the partition, it does not yet define the absolute size of the elements. Solving for the most informative partition, which minimizes the absolute size of the elements given φ_i^{dec}, gives the following proposition:

Proposition 2 ***Equilibrium communication under decentralized authority:***

The cutoffs of the finest incentive-compatible partition are characterized by

$$|\theta_{i,n}| = \alpha\left(\varphi_i^{dec}\right)^{|n|}\overline{\theta_i} \quad \textit{with} \quad n \in \{-\infty, ..., -1, 1, ...\infty\}, \textit{ where}$$

$$\alpha\left(\varphi_i^{dec}\right) = \tfrac{\varphi_i^{dec}}{\left(1+\sqrt{1+\varphi_i^{dec}}\right)^2} \in (0,1) \qquad \textit{and} \qquad \varphi_i^{dec} = \tfrac{a_{j2}}{1-a_{j2}} = \tfrac{r_j(1-r_i)}{(1-r_j)} \in (0,\infty).$$

Proof. Special case of proposition 5. ■

An example of this solution is illustrated in figure 3. Note that truth-telling is possible at the point of expected preference intersection because the expected response

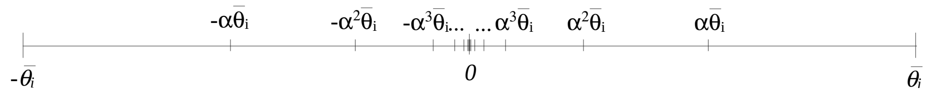


Figure 3: Structure of the most informative partition

of the recipient matches the ideal response of the sender. The rate at which the accuracy of messages decreases in $|\theta_i|$ is in turn uniquely determined by φ_i, which we will refer to as the *quality of communication* (by agent i about θ_i). As $\alpha\left(\varphi_i^{dec}\right) \to 1$, communication becomes fully informative, while $\alpha\left(\varphi_i^{dec}\right) \to 0$ implies binomial communication, which is always possible in the present setting due to the existence of the preference intersection.

The quality of communication by agent i is in turn solely determined by the rate of accommodation by agent j, a_{j2}. This result should be no surprise since, as discussed in section 4.1, it is the rate of accommodation that measures under decentralized authority the degree of conflict between the sender's preferred outcome and the recipient's equilibrium response. The higher the rate of accommodation, the smaller the incentive conflict and the higher the quality of communication that can be sustained. As the recipient becomes perfectly accommodating ($a_{j2} \to 1$), communication becomes perfect. Thus, in addition to influencing the equilibrium decisions, the relative dependency of the two divisions (and the resulting rates of accommodation by the managers) influence the ability of the division managers to share their private information with each other. Indeed, it is exactly *because* the equilibrium decisions vary with the importance of coordination that the quality of communication by each manager varies as well.

Figure 4 plots the quality of communication by agent i as a function r_i and r_j. Paralleling the rate of accommodation by agent j, the quality of communication by agent i is increasing in r_j, decreasing in r_i and increasing along the diagonal $r_i = r_j$. Thus, not only does an increase in r_i tilt the equilibrium decisions in favor of agent j, but it also compromises the ability of agent i to share his private information. Communication by agent i is accurate only when he expects the equilibrium decisions to be close to his ideal decisions $d_i = d_j = \theta_i$.

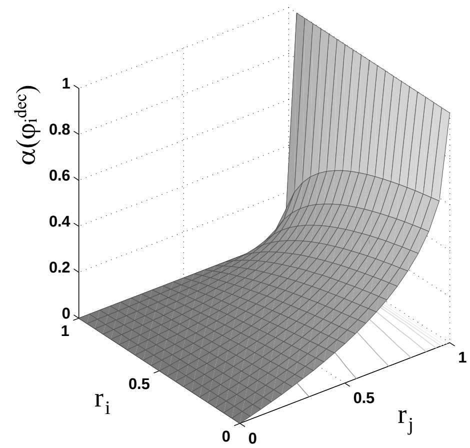


Figure 4: Quality of communication by agent i under decentralized authority

4.3 Expected Losses

Having derived the equilibrium decisions and the equilibrium quality of communication, we can solve for the expected loss for each activity:

Proposition 3 ***Expected losses under decentralized authority:***

$EL_i^{dec} = \Lambda_i^{dec}\left(\overline{\theta}_i^2 + \overline{\theta}_j^2\right) + \Gamma_{i-i}^{dec} V(\varphi_i^{dec})\overline{\theta}_i^2 + \Gamma_{i-j}^{dec} V(\varphi_j^{dec})\overline{\theta}_j^2$, *where*

$\Lambda_i^{dec} = \frac{k_i(1-r_i)r_i(1-r_j)^2}{3(1-r_i r_j)^2}$, $\quad \Gamma_{i-i}^{dec} = \frac{k_i r_i(1-r_i)}{3} - \Lambda_i^{dec}$, $\quad \Gamma_{i-j}^{dec} = \frac{k_i r_i(1-r_j)^2}{3} - \Lambda_i^{dec}$ $\quad$ *and*

$V\left(\varphi_i^{dec}\right)\overline{\theta}_i^2 = \frac{1}{4+3\varphi_i^{dec}}\overline{\theta}_i^2 = 3E\left(\theta_i - E_j\theta_i\right)^2.$

Proof. Special case of proposition 6. ■

We can thus write the expected loss to each activity as being composed of three components. The first component, $\Lambda_i^{dec}\left(\overline{\theta}_i^2 + \overline{\theta}_j^2\right)$, gives the expected loss under perfect information. There are three observations that can be made with respect to Λ_i^{dec}, which reflects the equilibrium decisions under decentralized authority. First, Λ_i^{dec} is decreasing in r_j for all r_i. The more dependent the other division is, the better the strategic position of manager i is in the decision-making stage. When the other division becomes fully dependent on coordination, then manager i can fully adapt to any local conditions knowing that the other division will accommodate. Second, Λ_i^{dec} is increasing in r_i, holding the value of adaptation $k_i(1-r_i)$ constant. Third, Λ_i^{dec} is non-monotone in r_i, holding size k_i constant. These two results reflect how the strategic position of the division in the decision-making stage translates into expected performance. When r_i is low, the division is largely free to adapt without any concerns for accommodation and the expected loss is low. As r_i increases, the strategic position of the division is weakened. In consequence, when the value of adaptation is constant, the outcome becomes progressively worse for the division. In contrast, when we hold size constant, the value of adaptation is simultaneously decreasing. Initially, the compromised adaptation generates an increasing expected loss, but eventually most gains are realized simply by accommodating the other division, leading to a decreasing expected loss.

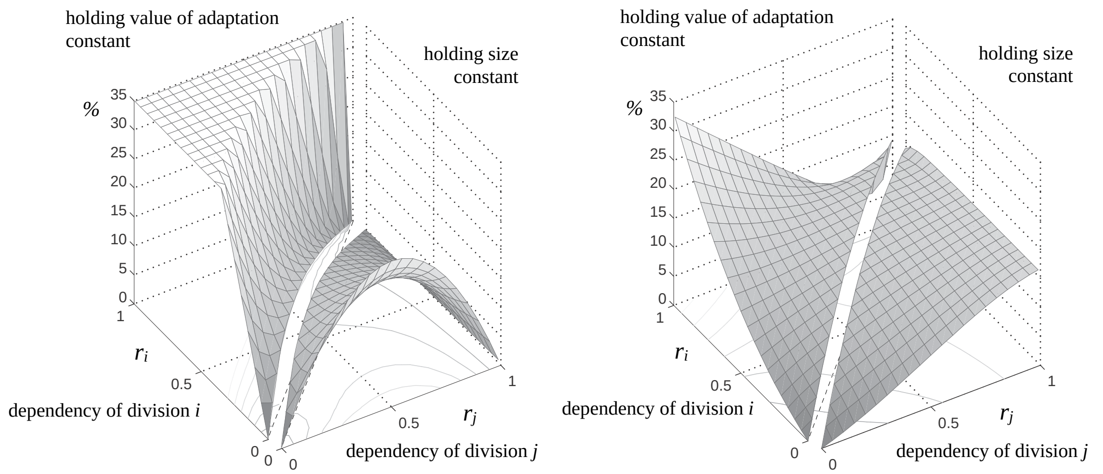
The additional expected loss resulting from strategic communication is given by the other two components, $\Gamma_i^{dec}V(\varphi_i^{dec})\overline{\theta}_i^2 + \Gamma_j^{dec}V(\varphi_j^{dec})\overline{\theta}_j^2$, where the first component measures the loss to division i from the strategic communication of θ_i and the second component measures the loss to division i from the strategic communication of θ_j. Note that each component is, in turn, composed of two parts, with Γ_i^{dec} measuring the *value* of accurate communication and $V(\varphi_i^{dec})$ measuring the actual accuracy of communication.[7] In the case of decentralized authority, the value of communication is determined by the cost of strategic uncertainty that the agents face over each other's decisions after communication, leading to coordination failures over and above any inherent biases in the equilibrium decisions.

To better understand how the expected total loss $E\left(L_i^{dec} + L_j^{dec}\right)$ varies with the environment, define the *relative loss due to biased decisions* by

$$\frac{E\left(L_i^{dec}+L_j^{dec}|\boldsymbol{\alpha}(.)=\mathbf{1}\right)-E\left(L_i^{FB}+L_j^{FB}\right)}{E\left(L_i^{FB}+L_j^{FB}\right)}$$

(*i.e.*, the percentage increase in the expected total loss over the first-best outcome when decentralized decision-making is substituted for optimal decisions under perfect information). Similarly, define the *relative loss due to strategic communication* by

[7] $\Gamma_{i-i}^{dec} + \Gamma_{j-i}^{dec} > 0$, so that more accurate communication is always beneficial in terms of the total expected loss. However, it is possible that $\Gamma_{j-i}^{dec} < 0$. The complications that can arise in this case are discussed in section 7.



(i) relative loss due to biased decisions *(ii) relative loss due to strategic communication*

Figure 5: Expected performance of decentralized authority, $\overline{\theta}_i = \overline{\theta}_j$

$$\frac{E\left(L_i^{dec}+L_j^{dec}|\boldsymbol{\alpha}\left(\boldsymbol{\varphi}^{dec}\right)\right)-E\left(L_i^{dec}+L_j^{dec}|\boldsymbol{\alpha}(.)=\mathbf{1}\right)}{E\left(L_i^{FB}+L_j^{FB}\right)}$$

($i.e.$, the percentage increase in the expected total loss over the first-best outcome when strategic communication is substituted for perfect information under decentralized decision-making). Normalizing the expected loss relative to the first-best outcome allows us to compare both the magnitude and relative importance of these two sources of loss.

The results with respect to the relative dependency of the divisions are summarized in figure 5, with the top-left triangles of each panel presenting the relative losses holding the value of adaptation constant and the bottom-right triangles presenting the relative losses holding size constant.

Consider first the diagonal, where we increase the dependency of the divisions symmetrically (in which case it doesn't matter whether we hold k_i or $k_i\,(1 - r_i)$ constant). When the dependency of both divisions is low, decentralized authority performs well. First, the decisions are only midly biased because coordination carries only little value. Second, communication, while inaccurate, is also not very valuable, because the need for coordination is low and the agents have direct access to information about their respective local conditions. As we increase the dependency of the divisions, two things happen. First, the own-division bias of the agents leads to decisions that are increasingly under-coordinated, increasing the relative loss due to biased decision. Second, communication becomes more important because of the increasing value of coordination. In consequence, both sources of loss initially increase in magnitude. However, as we increase the dependency of the divisions further, the quality of decision-making starts eventually improving. The reason for this is that as the divisions become highly dependent, the agents have no other option but to coordinate if they want to maximize the profitability of their divisions. For example, if the divisions need to agree on common standard and such agreement is highly valuable, the divisions are able to coordinate on one. The same, however, doesn't apply with respect to communication. Even if the divisions will agree on a standard, they do disagree on which standard to adopt. In consequence, valuable information is lost in the communication stage as the agents are trying to persuade each other to accommodate their preferences. Indeed, while the decisions converge to first-best as $r_i, r_j \to 1$, the quality of communication remains bounded away from perfect.

Second, consider the top-left triangles, where we introduce asymmetry in the dependency of the divisions while holding the value of adaptation constant. This dimension isolates the strategic advantage that the less-dependent division gains in the decision-making stage. We can see how rapidly the position of the more dependent division is worsened even under a small asymmetry and how extremely costly it is for the organizational performance.[8] The loss due to strategic communication comes a distant second in its relative importance, but still carries some weight. As the decisions become biased against the more dependent division, the less accurately the agent in charge of that division is able to communicate his private information, further weakening his ability to undetake valuable adaptation.

Finally, consider the bottom-right triangles, where we introduce asymmetry in the dependency of the divisions while holding the size of the divisions constant. Here, the initial effect of the asymmetry is the same as in the previous case, where the less dependent division prevents the more dependent division from undertaking valuable adaptation. However, as we increase the dependency of the more dependent division further, the associated asymmetry in the importance of adaptation implies that the decisions *should* favor the less dependent division. In consequence, much like along the diagonal with respect to the mutual dependency of the divisions, the relative loss due to strategic decision-making will be decreasing in the degree of asymmetry, given that

[8] We have capped the figure at 35% relative loss due to biased decision-making to keep the figures comparable. The relative loss is monotonically increasing in the asymmetry and peaks at 100%.

the asymmetry is high enough. As $r_j \to 1$, division i is able to ahieve its ideal decisions $d_i^{dec} = d_j^{dec} = \theta_i$, but these decisions are also profit-maximizing because division j cares only about coordination. The relative loss due to strategic communication, however, continues to increase. The reason for this result is that even if agent i becomes increasingly able to communicate his private information (because of the increasingly favorable decisions), the relative value of that communication is also increasing because the profitability of division j is increasingly dependent on the ability to coordinate with division i.

In summary, both the magnitude and the relative importance of the sources of loss vary systematically with the underlying divisional characteristics. The expected loss is small when both divisions are relatively independent. When the divisions are either both highly dependent or highly asymmetric in both their value of adaptation and dependency, the primary source of loss is strategic communication. When the divisions are asymmetric in their dependency but similar in the value of adaptation, then the primary source of loss is the bias in the equilibrium decisions. Finally, when the divisions are relatively symmetric and of intermediate dependency, then decision-making and communication are of equal concern.

5 Alternative Governance Structures

As derived in Appendix A, a unified framework exists for characterizing the solution under all four governance structures. In particular, the equilibrium decisions under governance structure g take the form

$$d_i^m = a_{i1}^g E_m\theta_i + a_{i2}^g E_m E_n \theta_j + a_{i3}^g E_n E_m \theta_i,$$

where m and n are the actors controlling the decision right for divisions i and j, respectively, with $a_{i1}^g + a_{i2}^g + a_{i3}^g = 1$. Similarly, the indifference condition defining the communication equilibrium under governance structure g takes the form

$$|\theta_{i,k} - \theta_{i,k-1}| - |\theta_{i,k-1} - \theta_{i,k-2}| = \tfrac{4}{\varphi_i^g} |\theta_{k-1}|,$$

and thus the most informative partition is characterized by

$$|\theta_i^n| = \alpha\left(\varphi_i^g\right)^{|n|}\overline{\theta_i}, \text{ where } \alpha\left(\varphi_i^g\right) = \frac{\varphi_i^g}{\left(1+\sqrt{1+\varphi_i^g}\right)^2} \in (0,1).$$

Finally, we can write the expected loss to division i under governance structure g as

$$EL_i^g = \Lambda_i^g\left(\overline{\theta}_i^2 + \overline{\theta}_j^2\right) + \Gamma_{i-i}^g V(\varphi_i^g)\overline{\theta}_i^2 + \Gamma_{i-j}^g V(\varphi_j^g)\overline{\theta}_j^2.$$

Since the algebraic expressions of the coefficients contain little direct economic intuition, we will not focus on them.[9] Instead, in what follows, we will focus on the economic intuition behind their determination and their consequences for the expected organizational performance.

While the structure of the solution is similar across the governance structures, the solutions themselves exhibit significant differences in their expected performance $E\left(L_i^g + L_j^g\right)$. These differences arise for four interrelated reasons. First, the differences in the objective function(s) of the decision-maker(s) across the governance structures translate into systematic differences in the equilibrium decisions. Second, these differences in equilibrium decisions translate into differences in the equilibrium quality of communication by the two agents. Third, whether agent i retains control of his activity or not directly impacts his qualitative motives for communication and thus his equilibrium quality of communication. Fourth, the differences in equilibrium decisions and the motives for communication translate into differences in the *value* of communication.

Because each governance structure provides a qualitatively different combination of equilibrium decisions and quality and value of communication, the relative performance of each governance structure varies systematically with the underlying environment. In consequence, each governance structure arises as the preferred (second-best) governance structure under specific environmental conditions. In the remainder of the section, we will analyze the equilibrium outcomes under the alternative governance structures of centralized authority, partial centralization and directional authority, focusing on how the decision-making and communication stages differ from the outcome under decentralized authority. The results of sections 4 and 5 are then brought together in section 6, where we analyze the relationship between divisional characteristics, such as

[9] They can be derived immediately from proposition 6.

dependency, size and environmental volatility, and the preferred governance structure, and discuss the empirical implications of the model.

5.1 Decision-making

Centralized authority: Under centralized authority, the headquarters retains control over both divisions. Because the objective of the headquarters is to optimize the overall performance of the organization, the decisions she makes are first-best conditional on the information available to her. These decisions are given by

$$d_i^{cent} = a_{i1+i3}^{cent} E_P \theta_i + a_{i2}^{cent} E_P \theta_j = \frac{k_i(1-r_i)(k_j+k_i r_i) E_M \theta_i + k_j(1-r_j)(k_i r_i + k_j r_j) E_M \theta_j}{(k_i+k_j r_j)(k_j+k_i r_i) - (k_i r_i + k_j r_j)^2}.$$

Thus, as discussed earlier, the first-best decisions, unlike the decisions under decentralized authority, do not reflect the relative dependency of the divisions. Instead, the amount of coordination between the decisions reflects the overall value of coordination $(k_i r_i + k_j r_j)$, while the focal point of coordination (whether the decisions favor division i or division j, given the amount of coordination) reflects the importance of adaptation for the two divisions: $k_i (1 - r_i)$ and $k_j (1 - r_j)$.

Partial centralization: Under partial centralization, the headquarters controls one of the divisions while the other division is managed locally. This change has two effects on the equilibrium decisions relative to decentralized authority. First, the decisions will be more coordinated, and second, they will favor the division retaining independence.

To understand the intuition behind these changes, consider the case where d_i is centralized. Now, instead of the weight r_i placed on coordination by the division manager, the headquarters (who internalizes the coordination benefits for the other division) places a weight $\frac{k_i r_i + k_j r_j}{k_i + k_j r_j} > r_i$ on coordination, while manager j continues to place weight r_j on coordination. Because the headquarters places a higher weight on coordination, the decisions will in expectation be closer together. However, exactly because the headquarters places a higher weight on coordination, the strategic position of manager j is improved.

Whether the quality of decision-making increases or decreases relative to decentralized authority depends on which decision is centralized. If the divisions are symmetric, then such partial interference is always damaging because the coordination benefits never outweigh the induced bias in the focal point of coordination. Similarly, if the more dependent division is centralized, its strategic position is weakened even further. Centralizing the less dependent activity, on the other hand, can be used to improve the quality of decision-making, because it prevents the divisional manager from using the low dependency to its strategic advantage. In particular, if the dependency of the centralized division goes to zero, then the equilibrium decisions converge to first-best, because the division retaining independence no longer undervalues coordination.

Directional authority: Under directional authority, one of the division managers gains authority over both decisions. Because the divisional manager cares only about the profitability of his division, he will simply set $d_i = d_j = \theta_i$, thus achieving perfect adaptation and coordination and maximizing the profitability of his division, while completely neglecting the adaptive needs of the other division. Giving full authority to one of the division managers is, therefore, typically very damaging from the perspective of the quality of decision-making. However, if the division losing authority cares primarily about coordination, then the loss can be small.

In summary, with respect to the quality of decision-making, centralized authority performs best because it makes, by assumption, first-best decisions conditional on the available information. Directional authority performs the worst among the alternative governance structures. Partial centralization can have either worse or better quality of decision-making relative to decentralized authority, depending on whether the more or less dependent division is centralized.

5.2 Communication

Centralized authority: While the equilibrium decisions are first-best conditional on the information available to the headquarters, the manager of the headquarters needs to rely solely on information communicated to her by the self-interested divisional managers. This change in the use of information alters both the value and quality of communication relative to decentralized authority.

Recall that under decentralized authority, agent i communicated to induce accommodation by agent j, which both improved coordination and allowed agent i to achieve

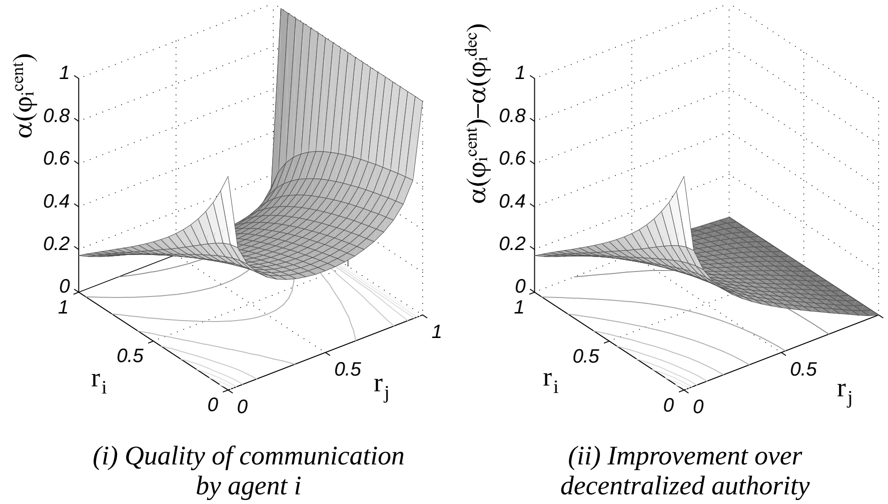


Figure 6: Quality of communication by agent i under centralized authority, $k_i = k_j$

more adaptation. As a result, the quality of communication was uniquely determined by the rate of accommodation a_{j2}^{dec}. Under centralized authority, communication is needed to achieve any adaptation in the first place. Sending a message m_i induces adaptation by the principal (with d_i) at the rate a_{i1+i3}^{cent} and accommodation (with d_j) at the rate a_{j2}^{cent}.

Consider now the incentives to exaggerate faced by the agent. First, from the perspective of adaptation, the rate of responsiveness of the principal is given by her rate of adaptation a_{i1+i3}^{cent} instead of her rate of accommodation. The responsiveness of the principal is thus higher $\left(a_{i1+i3}^{cent} \geq a_{j2}^{dec}\right)$, leadingly to correspondingly higher quality of communication than under decentralized authority. Second, the coordination component further limits the incentives to exaggerate. This result follows because $a_{i1+i3}^{cent} - a_{j2}^{cent} \geq 0$, so that the decisions diverge in $|m_i|$ and the cost of improved adaptation is worsened coordination.

Intuitively, the quality of communication should then be some function of $(1 - r_i)\, a_{i1+i3}^{cent}$, measuring the perceived value of exaggeration to the division manager in terms of improved adaptation, and $r_i \left(a_{i1+i3}^{cent} - a_{j2}^{cent}\right)$, measuring the cost of exaggeration in terms of worsened coordination. Indeed, this is the case, and we can write the quality of communication under centralized authority as

$$\varphi_i^{cent} = \frac{(1-r_i)\left(a_{i1+i3}^{cent}\right)^2 + r_i\left(a_{i1+i3}^{cent} - a_{j2}^{cent}\right)^2}{(1-r_i)a_{i1+i3}^{cent}\left(1-a_{i1+i3}^{cent}\right) - r_i\left(a_{i1+i3}^{cent} - a_{j2}^{cent}\right)^2} \geq \varphi_i^{dec}.$$

The equilibrium quality of communication by agent i is summarized in figure 6. We can see that while the quality of communication under centralized authority is always higher than under decentralized authority, this difference is decreasing in the importance of coordination to either division. Under centralized authority, as the importance of coordination increases, the principal becomes less adaptive. This reduction in a_{i1+i3}^{cent} increases the incentive conflict between the principal and agent i and, therefore, worsens the quality of communication. In contrast, under decentralized authority, as the importance of coordination increases, the agents become increasingly accommodating to each other's needs. This increase in a_{j2}^{dec} in turn leads to an increase the quality of communication.

While the quality of communication is higher under centralized authority, so is the value of accurate communication, because the principal is fully dependent on the information communicated to her by the agents. We can see this by noting that

$$\left(\Gamma_{i-i}^{cent} + \Gamma_{j-i}^{cent}\right) V\left(\varphi_i^*\right) > \left(\Gamma_{i-i}^{dec} + \Gamma_{j-i}^{dec}\right) V\left(\varphi_i^*\right) \quad \forall r_i, r_j < 1.$$

That is, the marginal value of improved communication at a given quality of communication is always higher under centralized authority. Indeed, this difference is such that, even after accounting for the differences in the quality of communication, the relative loss due to strategic communication is almost everywhere higher under under centralized authority.

Partial centralization: Communication under partial centralization is the most subtle case to analyze comprehensively and we will only focus on the key intuition. Consider first the incentives for communication. The problem faced by agent j (retaining control) is analogous to the problem he faces under decentralized authority, in that he sends m_j to induce accommodation, but now by the principal. Because the principal is more accommodating than agent j, the quality of communication by agent i is always higher than under decentralized authority (and can be also higher than under centralized authority).

The problem faced by agent i (losing control) is analogous to the problem he faces under centralized authority, in that he sends m_i to induce both adaptation by d_i and accommodation by d_j. The differences are two-fold. First, because of the strategic advantage of the agent retaining control, the principal is less responsive to i's messages, increasing the incentive conflict relative to centralized authority. Second, because of the reduced coordination between the decisions, the constraint on exaggeration provided by the coordination component is stronger. As a consequence, the quality of communication by agent i under partial centralization can either dominate his quality of communication under both decentralized and centralized authority, or be dominated by both.

Because of this variation, the equilibrium loss due to strategic communication cannot generally be ranked with respect to centralized or decentralized authority. However, for our purposes it is sufficient to note that the loss is generally lower than under centralized authority because only one decision is centralized (limiting the value of communication), and it can be even lower than under decentralized authority. The latter result arises when (i) one of the divisions is highly dependent while caring little about adaptation, and (ii) the headquarters centralizes the more dependent activity. The intuition for this result follows from the facilitating impact of such partial centralization. As discussed above, partial centralization makes the centralized division more accommodating to the adaptive needs of the division retaining independence. Because the behavior of the centralized division becomes more accommodating, the division that retains authority becomes more forthcoming with its private information. This improvement in communication by the less dependent division, in turn, improves the coordination between the divisions, which is highly valuable to the division that is highly dependent, and can outweigh the loss of information regarding the adaptive needs of the more dependent division.

Directional authority: Because the division manager who gains control will always set $d_i = d_j = \theta_i$ independent of the messages sent, communication is irrelevant under directional authority. Correspondingly, the loss due to strategic communication is zero. As we will see below, the benefit from this elimination of the need to communicate can sometimes be sufficiently large to make directional authority the preferred governance structure, despite the highly biased decisions.

In summary, the loss due to strategic communication is lowest under directional authority, while the other governance structures cannot be strictly ranked. Typically, centralized authority is most dependent on communication, followed by partial centralization and decentralized authority, a pattern that reflects the separation of decision-making from the location of primary information. However, partial centralization can have a lower loss due to strategic communication than either decentralized or centralized authority when the centralized division is highly dependent and places only a low value of adaptation.

6 Relative Performance

Having discussed the basic differences between the governance structures, we can now consider how the divisional characteristics of size, environmental volatility and dependency impact the choice of governance structure. Because the results with respect to dependency are the most nuanced, we will begin with that discussion, and conclude with the impact of asymmetries in environmental volatility and size.

Relative dependency: The mapping from the dependency of the two activities to the preferred governance structure is given in figure 7, with the top-left triangle depicting the comparative statics holding the value of adaptation constant and the bottom-right triangle depicting the comparative statics holding the size of the divisions constant.

Decentralized authority arises as the preferred governance structure only when the dependency of both divisions is low. Under these conditions, the equilibrium decisions are only mildly biased and communication, while inaccurate, is also unimportant, because each agent has direct access to local information and little coordination is needed. Whenever the dependency of either division is sufficiently high, centralized authority dominates decentralized authority because of its ability to eliminate the bias from the equilibrium decisions. However, the performance differential between the two is non-monotone, with the two solutions converging both when $r_i, r_j \to 0$, in which case communication becomes perfect under centralized authority, and when $r_i, r_j \to 1$, in which case the decisions under decentralized authority converge back to first-best. The advantage of centralized authority over the alternative governance structures is largest in the region of intermediate and symmetric dependency.

While centralized authority dominates decentralized authority in all regions but low dependency, centralized authority is in turn dominated by at least one of the asymmetric governance structures when the divisions are sufficiently asymmetric. The reason for this result is that in asymmetric environments an asymmetric governance structure is able to limit the losses due to strategic communication that would follow from full centralization of decision-making.

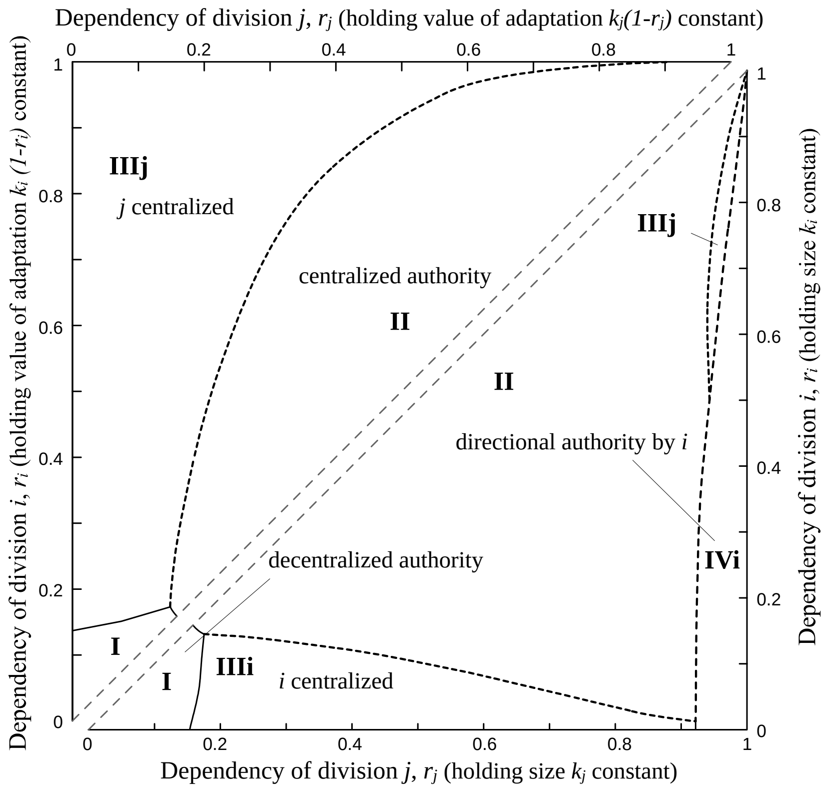


Figure 7: Choice of governance structure

The nature of the preferred asymmetric solution, in turn, depends on the underlying asymmetry and the primary source of inefficiency under decentralized authority. Consider first the top-left triangle, which holds the value of adaptation constant. In this case, the preferred solution is centralizing the less dependent division. As discussed in sections 4.3 and 5.1, when the need for adaptation is symmetric while the dependency is asymmetric, then the primary source of loss under decentralized authority is the bias in the equilibrium decisions. By centralizing the less dependent division, the headquarters is able to restore balance in the decision-making stage and eliminate most of that bias, while limiting the need for information transmission relative to full centralization.

Second, consider the bottom-right triangle, which holds the size of the divisions constant. When the dependency of division i is low while the dependency of division j is intermediate, the previous logic applies – the primary source of loss under decentralized authority is biased decision-making and partial centralization of the less dependent division eliminates most of that bias. However, when division j becomes highly dependent (and thus places a low value on adaptation), then the primary source of loss under decentralized authority is the loss due to strategic communication by the manager of the less dependent division and the resulting coordination failures. Now, the outcome under decentralized authority can be improved upon by centralizing the *more* dependent activity, or simply giving full authority to the less dependent division (directional authority). Both solutions *increase* the bias in the equilibrium decisions, but as a result improve coordination, either by inducing more accurate transmission of information (partial centralization) or by eliminating the need for communication completely (directional authority).

Environmental volatility and size: If the divisions are symmetric with respect to both environmental volatility ($\overline{\theta}_i = \overline{\theta}_j$) and size ($k_i = k_j$), then the absolute level of either variable has no impact on the preferred governance structure. In the case of size, the result is obvious. In the case of volatility, the result is a little more surprising because of the common argument of a positive relationship between volatility and decentralization. The reason for this result is the fact that the relative quality of communication across the governance structures is independent of the absolute volatility.[10] Asymmetries in either variable, on the other hand, do play a role. In short, increasing either $\overline{\theta}_i$ or k_i skews the governance structure in agent i's favor. That is, the set of decision rights controlled by agent i is (weakly) increasing and the set of decision rights controlled by agent j is (weakly) decreasing. The intuition is straightforward. An increase in either variable increases the relative importance of getting d_i "right." As a result, any inaccuracies in communication or biases in the equilibrium decisions going against division i become more damaging. In consequence, to limit these losses, the governance structure is biased in favor of that division. Thus, while the preferred governance structure is independent of the absolute level of volatility, a division that faces a *relatively* more volatile environment should be granted more authority.

6.1 Historic examples and empirical implications

This paper has focused on analyzing how the allocation of decisions rights inside an organizational hierarchy impacts the quality of decision-making and communication inside the organization, other things constant. Because the allocation of decision rights

[10] See Rantakari (2007) for a model where the link arises indirectly through the choice of production technology.

is only one of many organizational design parameters, and because the allocation of decision rights can impact the behavior of the organizational participants over and above decision-making and communication, the model is only a partial theory of organizational structures. For a similar reason, we prefer to interpret the model as analyzing the allocation of decision rights within fixed firm boundaries instead of dealing with moving firm boundaries through intergration. Integration, by altering the ownership of the assets, will always alter the objectives of the organizational participants. In consequence, while we believe that similar considerations can play a role in the decision to integrate, the role of asset ownership should be integrated into the framework before extending the logic of the present analysis to discussing firm boundaries. In the remainder of the section, we will first look at three historic examples where firms have reallocated authority inside firm boundaries in response to changing market conditions to illustrate the general logic and plausibility of our framework. We then discuss the more rigorous empirical testability of the predictions and some of the existing empirical results.

General Motors in the 1920s-1960s: Freeland (1996) describes changes in the organizational structure of GM. The changes match well with variations in the relative value of coordination until the end of World War II. The initial reorganization of GM in the 1920s generated a fairly decentralized organization where the individual divisions were not only responsible for operating decisions but also contributed to the strategic decisions.[11] This structure matched well the market conditions. First, the reorganization segmented the car market among the divisions and thus limited demand-side interdependencies. Second, at the time, meeting customer demands was the key to success, which made customization relatively more valuable than any cost savings achievable through coordinated production. This all changed following the Great Depression, as lower incomes made low cost the key driver behind success. In response, GM standardized components and realigned the divisions to minimize costs, and at the same time centralized decision-making to ensure sufficient coordination and conflict resolution among the divisions.

During World War II, the organization was again decentralized, coming to resemble the structure of 1920s. With the switch to military production, the wide array of products that needed to be produced implied that the divisions could no longer share

[11] While decentralized, the structure was still more centralized than the original loose agglomeration of businesses.

production facilities. Instead, each division would again specialize in distinct markets, eliminating the need for coordination. Further, the high amount of uncertainty over the technologies necessitated the use of local knowledge and rapid operating decisions. Both changes supported a switch back to decentralization. Finally, following the war, the organization came to exhibit increasing separation between strategic planning by the headquarters and operations at the divisional level. This separation led to a disconnect between the hierarchical levels and as conflicts arose, the headquarters started taking an increasingly active part in the management of operations, re-centralizing decision-making. The headquarters again sought to cut costs through increased coordination, which it achieved by forcing the divisions to use standardized parts and designs. Indeed, the cost cutting was successful, as it was in the 1930s. The market conditions, and the resulting costs of centralization were, however, different. While the market of the 1930s focused on cost rather than quality, with little product variety and little value to technological innovation, in the 1960s, the cost savings came at the increasing cost of compromised adaptability and product quality, making GM ill-suited to deal with the competitive pressures of 1970s.

IBM in the 1980s: Bersnahan et al's (2007) history of the IBM PC provides an example of a varying (and asymmetric) organizational structure. The IBM of the 1960s and 1970s was a tightly integrated organization with a highly centralized decision-making structure. This structure was well suited to managing coordinated, large-scale development projects and to providing large-computing systems to corporate clients. This all changed temporarily in 1980, when it established an independent division with considerable autonomy to produce a PC design for commercialization and then, after the unprecedented success of the IBM PC, re-centralized the division in 1985.

It is again relatively easy to see how the general pattern of reorganization fits with the present model. The PC market of the early 1980s was highly uncertain and fluid, requiring rapid and accurate responses to changing conditions. Further, because the division was small and the overlap between PCs and mainframes minimal, there existed little initial need for coordination. As predicted, a division with limited impact on the rest of the organization, operating in a highly volatile environment, was granted significant autonomy. As the PC division grew, however, the interdependencies became an issue. The PC division actively used its autonomy to its own benefit and as the PC gained popularity, people inside IBM began to believe that the PC division could significantly harm the mainframe business. In consequence, the PC division was re-centralized and coordinated with the rest of the organization.

Was the re-centralization a mistake? With a twenty-twenty hindsight, the answer is obvious. The PC division should have retained its independendence and potentially gain further authority over the rest of the organization to better align IBM with the PC market instead of the mainframe market, which required a distinctively different strategies. The problem is that in 1985, the mainframe business was doing extremely well. Under the expectation that the markets would continue to grow in parallel, the centralization choice could have made sense because of the potential benefits of coordination, even if the PC division would no longer be perfectly aligned with its particular market conditions. However, as the history unfolded, IBM clearly made the wrong organizational decision.

Microsoft in the 1990s: As Bresnahan et al also explain, a sequence of events very similar to the IBM PC case took place in the mid-1990s when Microsoft responded to the rise of Netscape and the Internet. Historically, Microsoft had been a tightly centrally managed organization, much like IBM. In response to Netscape, Microsoft set up a new division, the Internet Platform and Tools Division (IPTD) to compete with Netscape. After the browser war was over, however, the division was integrated back into the main organization.

Two differences to the IBM case stand out. First, the IPTD never gained significant autonomy but was centrally controlled as the other divisions (centralized authority instead of partial centralization). Second, after the browser wars, the IPTD was integrated into the Operating Systems Division instead of continuing as a separate unit (directional authority instead of centralized authority). A potential explanation for the difference in the initial response comes from the initial asymmetry. The PC started as a small project relatively independent of the main business, while the development of the Internet Explorer and related applications was a matter of urgency with a large-scale impact on the rest of the business. Coordination was needed from the start to manage the conflicting demands between the IPTD and the Operating Systems Division regarding the design and functionality of APIs, the relationship to MSN, and the conflicting desires for pushing people to upgrade to Windows 95 and pushing people to adapt IE instead of Netscape. Balanced coordination was needed, for which centralized decision-making provided a satisfactory, even if delayed, solution.

After the browser war was over, the relative value of the different parts of the business changed again, and Microsoft faced the challenge of deciding upon its future approach towards the Internet. Based on the solution chosen, it is apparent that Microsoft decided that centrally coordinating the conflicts of running both its traditional business and an internet strategy were too large, and decided to give priority to its traditional business. This thinking is also suggested by the fact that before the IPTD was dissolved completely as a separate entity, the headquarters managed that division with an increasingly heavy hand relative to the other divisions, forcing it to make increasingly large concessions. Future will tell whether this was the right choice. Putting the IPTD under the Operating Systems Division eliminated conflicting demands for adaptation, which has allowed Microsoft to thrive in its traditional lines of business. At the same time, this lack of focus on the Internet has left vacant various market opportunities that might provide a future threat to Microsoft.

There is, thus, some historical evidence that firms respond to changes in the market conditions roughly as predicted by the framework, but most of the predictions still face the challenge of rigorous empirical testing. The main challenge lies in constructing measures of the two key variables of the model: The allocation of decision-making authority and the relative dependency of the operating units (size and volatility are relatively more straightforward to estimate).[12] First, the measured allocation of decision rights should reflect who actually makes decisions. As a result, all four governance structures could reflect the same organizational chart. While there are no fully objective measures of the allocation of authority, surveys provide a means (and are increasingly used) to generate measures of the location of authority inside organizations.

Second, the degree of organizational interdependencies will be equally hard to measure accurately across organizations. However, surveys and the knowledge of industry experts can be used to obtain information about the underlying production technology, market characteristics, and opinions regarding the dependency on other units, ability to operate as a stand-alone unit, ease of substituting to external suppliers, and the impact that the division has on the other units. Such information can then be complemented with data from input-output tables and measures of intra-firm flows of goods and services. Given sufficient care, a combination of such measures should be able to reflect not only the level but also the asymmetries in the degree of dependency.

Subsets of such measures have already been used to some extent and with some success in the empirical literature. Consistent with the predictions of the model, Christie et al (2003), Colombo and DelMastro (2004) and Abernethy et al (2004) all find that the

[12] The degree of informational asymmetry between hierarchical levels provides another challenge.

degree of decentralization in organizations is negatively related the degree of intrafirm interdependencies. Further, Colombo and DelMastro (2004) show that delegation is increasing in the size of the unit, suggesting that the relative position of units matters. However, none of the papers analyze in detail asymmetries in interdependence. Keating (1997) does focus explicitly on asymmetric links, but analyzes only their impact on the structure of compensation. He finds that the impact on compensation does depend on the direction the dependency. Finally, Abernethy et al (2004) find some evidence that less authority is granted to a manager who is very dependent on the behavior of others. In conclusion, while testing the predictions of the model poses a clear empirical challenge, it appears theoretically feasible and some preliminary evidence exists in support of the predictions.

7 Underlying assumptions and extensions

This section considers some of the underlying assumptions of the model. First, we show that, contrary to most cheap-talk models, the most informative communication equilibrium is not always preferred by all the participants, an aspect that can complicate the equilibrium selection problem. Second, to illustrate the robustness of the results, we extend the results to account for imperfect local information and to allow for incentive alignment between the divisional managers. Rantakari (2007) analyzes the simultaneous choice of technological integration, compensation structure and the allocation of decision rights as driven by the underlying environment. The results show that the basic advantages and disadvantages of the different governance structures continue to play a role in more elaborate settings.

The two assumptions that remain unexamined are the possibility of bargaining and selective intervention in the interim stage, and the potential implementation problems that can arise when the decision-maker and the implementer are two separate agents. Relaxing either one appears a promising avenue for future research.

Incentives to listen: The analysis focused on the most informative incentive compatible communication equilibrium, relying on the observation that the most informative equilibrium maximizes the overall profitability of the organization. The most informative equilibrium is also preferred by the sender of the message. However, because of the costs associated with accommodation, when a divisional manager retains control of his division (decentralization or partial centralization), he might prefer not to listen. In other words, unlike in most cheap-talk models, the most informative communication equilibrium need not be Pareto superior. To see this, recall that the value of communication to agent i under governance structure g is given by Γ^g_{i-j}. If $\Gamma^g_{i-j} \leq 0$, more accurate information regarding θ_i hurts division j. For example, in the case of decentralized authority, agent i would prefer not to listen when

$$r_j \geq \overline{r}_j = \tfrac{1-\sqrt{1-r_i}}{r_i}.$$

The intuition for this result follows from the strategic interaction between the decisions. While listening to an informative message helps to reduce coordination failures, this reduction is achieved through the process of accommodation. Because accommodation induces additional adaptation, the cost of accommodation can exceed the gains from improved coordination accruing to that division. By not listening, the agent commits not to accommodate, which in turn limits the amount of adaptation undertaken by the sender. As a result, communication can break down if coordination is sufficiently important to the sender relative to the receiver, in which case the rate of induced adaptation (and thus the cost of accommodation) is large relative to the rate of direct adaptation (and thus the cost of coordination failure resulting from not listening).[13] In consequence, while the solution under decentralized authority converges to the solution under centralized authority when coordination becomes extremely important, the equilibrium is also less stable, which can make centralized authority strictly preferred even when coordination is very important.

Noisy local information: The results presented in the analysis are robust to noisy local information. In particular, if agent i observes a signal s_i that is equal to θ_i with probability p_i but is a random draw from $U[-\overline{\theta}_i, \overline{\theta}_i]$ with probability $(1-p_i)$, the expected loss under governance structure g is given by

$$\begin{aligned} EL^g_i = {} & \Lambda^g_i \left(\left(p_i\overline{\theta}_i\right)^2 + \left(p_j\overline{\theta}_j\right)^2 \right) + \Gamma^g_{i-i} V\left(\varphi^g_i\right) \left(p_i\overline{\theta}_i\right)^2 + \Gamma^g_{i-j} V\left(\varphi^g_j\right) \left(p_j\overline{\theta}_j\right)^2 \\ & + \tfrac{(1-r_i)}{3}\left(1-p_i^2\right)\overline{\theta}_i^2. \end{aligned}$$

The model is thus equivalent to a perfect-information model with the states distributed on $U[-\widetilde{\overline{\theta}}_i, \widetilde{\overline{\theta}}_i]$, where $\widetilde{\overline{\theta}}_i = p_i\overline{\theta}_i$, plus a common additional loss term reflecting

[13] For the same reason, the agent retaining control under partial centralization is more likely to prefer not to listen compared to decentralized authority, as the manager puts more weight on coordination.

the quality of local information.[14] Intuitively, because all the participants are rational, they discount information in the same way. Conflict exists only over how that information should translate into final decisions. As a result, the relative incentive conflict between the actors is unchanged when the local information is noisy. This is no longer the case if the communication process itself is noisy, as that does affect the degree of incentive conflict between the agents. Also, if p_i are endogenous, differences across the governance structures arise because of the differing incentives to acquire information.

Incentive alignment: What does matter for the comparative statics is the degree of incentive alignment between the division managers. To illustrate the role of incentive alignment, consider a situation where agent i retains a share s_i of the payoff to division i and gains a share $1 - s_j$ of the payoff to division j, so that agent i's objective function becomes $U_i = s_i L_i + (1 - s_j) L_j$. The first-order effect of incentive alignment in communication and decision-making is immediate. As $s_i \rightarrow 1 - s_j$, the interests of the local agents become perfectly aligned both with each other and with the overall goal of profit-maximization and so the first-best solution is achieved under all governance structures.

The rates of convergence, however, do differ across governance structures, leading to a systematic relationship between the degree of incentive alignment and the choice of governance structure. These results are illustrated in figure 8, which represents the choice of governance structure analogous to figure 7 for two different levels of incentive alignment. The intuition for the comparative statics follows from two observations. First, incentive alignment impacts the quality of decision-making and the quality of communication at different rates, with decision-making improving faster than communication. As a result, the returns to incentive alignment come initially in terms of improvements in decision-making and later in terms of improvements in communication. Second, as discussed in sections 4-6, the governance structures differ in the severity of these two sources of loss.

In short, as incentive alignment is increased, all the alternative governance structures become increasingly attractive relative to centralized authority, because they are less dependent on accurate communication. Similarly, decentralized authority and directional authority become increasingly attractive relative to the other governance structures, because they exhibit the largest initial bias in equilibrium decisions. The behavior of partial centralization is slightly more nuanced but follows the same intu-

[14] For a proof, see Appendix B.

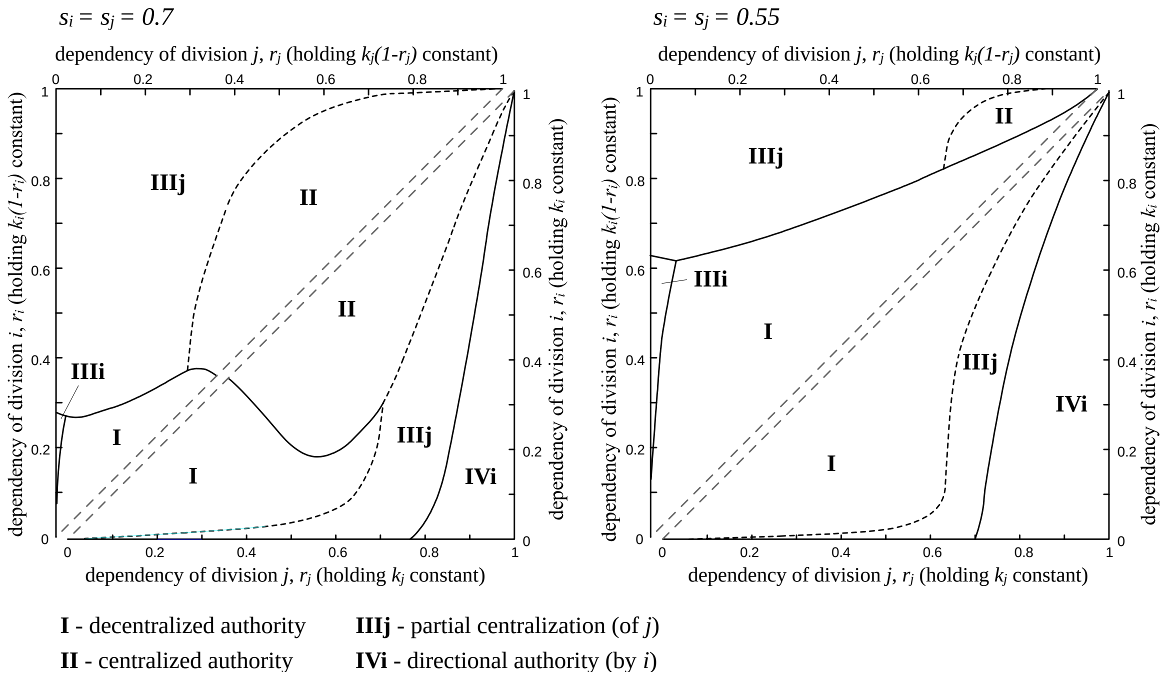


Figure 8: Incentive alignment and the choice of governance structure

ition. Consider first the partial centralization of the more dependent division, which was used to facilitate coordination at the expense of decision-making. Initially, partial centralization becomes more attractive because the bias in the equilibrium decision is decreased. However, as incentive alignment is increased further, it in turn begins to lose ground to directional authority and decentralized authority, which are even less dependent on communication. Second, consider the partial centralization of the less dependent division, which was used to restore balance in the decision-making stage. As incentive alignment is increased, it loses ground to decentralized authority because of the improvement in decision-making, while gaining ground from centralized authority exactly for the same reason.

As $s_i \to (1 - s_j)$, both partial centralization and centralized authority are eliminated as equilibrium governance structures and the choice is made between directional authority and decentralized authority. However, it is worth noting that, unlike in the symmetric case, where centralized authority is eliminated as an equilibrium outcome strictly before perfect incentive alignment is achieved, decision-making by the headquarters remains an equilibrium outcome for some parameter values all the way to the limit in the asymmetric settings, either to facilitate coordination (partial centralization) when holding size constant while allowing for asymmetries both in the value of adaptation and dependency, or to balance decision-making (partial centralization and centralized authority) when holding the value of adaptation constant.

8 Conclusion

We have investigated how the allocation of decision rights inside an organization can be used to influence decision-making and communication among strategic agents when decisions need to balance coordination and adaptation and when information is both soft and distributed.

Decentralized authority, where each division manager retains control of division, is the preferred method of organization when coordination is sufficiently unimportant to both divisions. The equilibrium decisions are then only mildly biased and communication, while inaccurate, is also unimportant because each division manager has direct access to his local information.

Centralized authority, where both decision rights are allocated to the headquarters, is the preferred method of organization when the importance of coordination is intermediate to high and not too asymmetric. By making profit-maximizing decisions, the headquarters is able to eliminate the biases in the equilibrium decisions under decentralized authority. However, because the headquarters needs to rely solely on information communicated to him by the division managers, the quality of adaptation remains limited. The advantage of centralized authority is largest in the region of intermediate importance of coordination, where the under-coordination problem under decentralized authority is particularly damaging. As the importance of coordination grows further, the division managers become increasingly willing to coordinate their decisions under decentralized authority and as a result the decisional advantage of centralized authority is eroded.

Partial centralization, where one of the decisions is centralized while the other is left under local control, is the preferred governance structure under two very different asymmetric environments. First, centralizing only the less dependent division is sufficient to eliminate most of the bias in the equilibrium decisions under decentralized authority, while limiting the total informational losses relative to centralized authority. Second, centralizing only the more dependent division helps to improve the information flows from the division managers by increasing the bias in the equilibrium decisions, a gain which outweighs the cost of increased bias when the dependent division is sufficiently dependent.

An alternative solution in the case of high dependency of one division is simply to allocate both decision rights to the manager of the less dependent division (directional authority). Even if the manager gaining control will make very biased decisions relative to the alternative governance structures, the allocation does eliminate all strategic uncertainty from the decision-making process. When the manager losing control cares primarily about coordination, the resulting gains from the full elimination of strategic uncertainty will outweigh the further increase in the bias of the equilibrium decisions.

Finally, we illustrated how centralized decision-making and incentive alignment and are substitutes. This result followed from two observations. First, the quality of decision-making improved faster in the degree of incentive alignment than the quality of communication. Second, the governance structures relying on centralized control (centralized authority and partial centralization) were more dependent on accurate communication than the governance structures relying on local control (decentralized and directional authority).

Taken together, these results suggest that the term "importance of coordination" is too coarse for deriving clean organizational implications. First, coordination poses an organizational challenge only when it needs to balance conflicting needs for adaptation. Second, one needs to account for asymmetric interdependencies between divisions as they may warrant asymmetric solutions. Finally, one needs to account for the distibution of the costs and benefits of coordination among the organizational participants, since the degree of incentive alignment impacts the relative performance of the different governance structures at differing rates. However, once these three qualifiers are accounted for, a consistent relationship emerges between the underlying environment and the preferred governance structure.

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A The General Solution

We will derive here the general solution to the framework analyzed. We will first derive the equilibrium decisions, then the equilibrium quality of communication and finally the expected losses.

A.1 Equilibrium Decisions

In the final stage of the game, the actors holding the decision rights choose decisions that maximize their payoffs conditional on their current information. Let m and n denote the identity of the decision-maker for activities i and j, respectively, and let ω_m denote the information held by agent m when deciding. Also, let $E_m(.)$ denote $E\left(.|\omega_m\right)$ and $\left(\beta_i^m, \beta_j^m\right)$ denote the weights that agent m places on activities i and j, respectively. Then, m solves:

$$\min_{d_i} E_m \left[\begin{array}{c} \beta_i^m k_i \left((1-r_i)(\theta_i - d_i)^2 + r_i (d_j - d_i)^2 \right) \\ +\beta_j^m k_j \left((1-r_j)(\theta_j - d_j)^2 + r_j (d_j - d_i)^2 \right) \end{array} \right],$$

and symmetrically for n. For example, under centralized authority, $\beta_i^m = \beta_j^m = 1$, and under decentralized authority, $\beta_i^m = s_i, \beta_j^m = (1-s_j)$, where s_i is the share of L_i retained by agent i and $(1-s_j)$ the share of L_j gained by agent i. The first-order conditions are then

$$d_i^m = \frac{\beta_i^m k_i (1-r_i) E_m \theta_i + \left(\beta_i^m k_i r_i + \beta_j^m k_j r_j\right) E_m d_j}{\beta_i^m k_i + \beta_j^m k_j r_j} \qquad d_j^n = \frac{\beta_j^n k_j (1-r_j) E_n \theta_j + \left(\beta_j^n k_j r_j + \beta_i^n k_i r_i\right) E_n d_i}{\beta_j^n k_j + \beta_i^n k_i r_i}.$$

Define for notational simplicity

$$a_1 = \frac{\beta_i^m k_i (1-r_i)}{\beta_i^m k_i + \beta_j^m k_j r_j}, \quad a_2 = \frac{\beta_i^m k_i r_i + \beta_j^m k_j r_j}{\beta_i^m k_i + \beta_j^m k_j r_j}, \quad b_1 = \frac{\beta_j^n k_j (1-r_j)}{\beta_j^n k_j + \beta_i^n k_i r_i} \quad \text{and} \quad b_2 = \frac{\beta_j^n k_j r_j + \beta_i^n k_i r_i}{\beta_j^n k_j + \beta_i^n k_i r_i},$$

which are simply the weights placed on adaptation and coordination by the decision-maker(s). The first-order conditions simplify to

$$d_i^m = a_1 E_m \theta_i + a_2 E_m d_j \qquad \text{and} \qquad d_j^n = b_1 E_n \theta_j + b_2 E_n d_i,$$

and the equilibrium decisions are then given by the intersection of the two reaction functions and summarized in the following proposition:

Proposition 4 ***Equilibrium Decisions:***

Let m and n be the identity of the decision-maker for activities i and j, respectively. Then,

$$d_i^m = \frac{a_1(1-b_2a_2)E_m\theta_i + a_2b_1E_mE_n\theta_j + a_2b_2a_1E_nE_m\theta_i}{1-b_2a_2} = a_{i1}^g E_m\theta_i + a_{i2}^g E_mE_n\theta_j + a_{i3}^g E_nE_m\theta_i.$$

Proof. See Appendix B ■

The logic behind the coefficients is the same as the one discussed in section 4. Absent any coordination, adaptation by decision-maker m is limited to a_1. Coordination and the associated improvement in adaptation is achieved by mutual accommodation. The more decision-maker m cares about coordination and the more decision-maker n cares about adaptation, the more m ends up accommodating: a_2b_1. Equivalently, the more accommodation m is able to get from n, and the more he or she is dependent on it, the more adaptation is achieved through the induced component: $a_2b_2a_1$. The equilibrium biases are in turn determined by the underlying importance of coordination for each of the two activities and the divisional biases (if any) of the decision-maker(s). The less weight decision-maker m places on coordination, the more favorable decisions he is able to induce. The equilibrium decisions converge to first-best when $\beta_i^m \to \beta_j^m$ and $\beta_j^n \to \beta_i^n$.

A.2 Equilibrium Communication

In the communication stage, the agents send non-verifiable messages about their local conditions to the decision-maker(s). Given the equilibrium decisions from above and letting β_i and β_j denote the weights placed by agent i on L_i and L_j, respectively, the indifference condition for agent i is given by

$$\begin{aligned} &E_i\left(\beta_i L_i\left(\theta_i^M, d_i(.,m^L), d_j(.,m^L)\right) + \beta_j L_j\left(\theta_j, d_i(.,m^L), d_j(.,m^L)\right)|.,m^L\right) \\ &\quad = E_i\left(\beta_i L_i\left(\theta_i^M, d_i(.,m^H), d_j(.,m^H)\right) + \beta_j L_j\left(\theta_j, d_i(.,m^H), d_j(.,m^H)\right)|.,m^H\right). \end{aligned}$$

Rearranging the indifference condition and solving the difference equation yields the following proposition:

Proposition 5 ***Equilibrium quality of communication:*** *Under any governance structure, we can write the indifference condition defining the family of incentive-compatible partitions as*

$$|\theta_{i,k} - \theta_{i,k-1}| - |\theta_{i,k-1} - \theta_{i,k-2}| = \frac{4}{\varphi_i(r_i,r_j,s_i,s_j,g)} |\theta_{i,k-1} - E_i\theta_j| ,$$

with g indexing the governance structure and k increasing away from the expected preference intersection ($\theta_i = E_i\theta_j$). The constant $\varphi_i(.)$ is given by

$$\varphi_i(r_i, r_j, s_i, s_j, g) \\ = \frac{a_1\left[\beta_i k_i(1-r_i)(1-I_{m=i}(1-b_2a_2))^2+\left(\beta_i k_i r_i+\beta_j k_j r_j\right)(b_1-I_{m=i}(1-b_2a_2))^2+\beta_j k_j(1-r_j)b_2^2\right]}{\left[\beta_i k_i(1-r_i)a_2b_1(1-I_{m=i}(1-b_2a_2))-\left(\beta_i k_i r_i+\beta_j k_j r_j\right)a_1(b_1-I_{m=i}(1-b_2a_2))b_1-\beta_j k_j(1-r_j)b_2^2a_1\right]} \in (0,\infty) ,$$

where $I_{m=i} \in \{1,0\}$ is an indicator function for whether the sender (agent i) retains control over his own activity (d_i). The cutoffs of the finest incentive-compatible partition are then given by

$$\theta_{i,n} - E_i\theta_j = \alpha(\varphi_i)^n \left(\overline{\theta} - E_i\theta_j\right) \text{ for } \theta_{i,n} > E_i\theta_j \ (n \in \{1,...,\infty\}) ,$$
$$\theta_{i,n} - E_i\theta_j = -\alpha(\varphi_i)^{|n|} \left(\overline{\theta} + E_i\theta_j\right) \text{ for } \theta_{i,n} < E_i\theta_j \ (n \in \{-\infty,...,-1\}) ,$$

where $\alpha(\varphi_i) = \frac{\varphi_i}{\left(1+\sqrt{1+\varphi_i}\right)^2} \in (0,1)$,

with $|n| = 1$ indexing the furthest interior cutoff and $|n| \to \infty$ implying $\theta_{|n|} \to E_i\theta_j$.

Proof. See Appendix B ■

While the equation for φ_i appears complex, the intuition behind the equation is straightforward. Note that both the numerator and the denominator are comprised of three components. The first component captures how much weight agent i places on his own adaptation, coupled with how much a marginal exaggeration would improve the outcome through the equilibrium decisions. This component is always positive in the denominator so that the bigger the weight on adaptation, the greater the incentive to exaggerate, other things constant.

The second component is the overall weight put on coordination by the agent. In the case of $I_{m=i} = 1$, the denominator is negative, while in the case of $I_{m=i} = 0$ it is positive. Thus, in the case of the agent retaining control, the accuracy of communication is decreasing in the weight placed by the agent on coordination. This result follows because in this case, exaggeration allows the agent both to improve coordination (because successful exaggeration would induce a larger response by the other agent) and to achieve additional adaptation (because the agent would trade some of the gains in coordination for additional adaptation). In contrast, in the case where the agent doesn't control the decision, the two decisions are diverging in $|m_i|$ and thus damaging the coordination component.

Finally, the third component gives the weight placed by the agent on adaptation by the other division. This component is always negative in the numerator and thus the quality of communication is increasing in the weight placed on the other division's adaptation. Intuitively, since any successful exaggeration worsens adaptation by the other division, this constrains the incentives to exaggerate. As the incentives of the agent become perfectly aligned with the equilibrium decisions, $\varphi_i \rightarrow \infty$ and communication becomes perfectly informative.

A.3 Expected Losses

Having derived the equilibrium decisions and the resulting quality of communication, the expected losses follow from a simple substitution of these solutions into the payoff functions. However, to illustrate the impact of communication, let us look at the outcomes component-wise. For the adaptation component, we can write

$$E\left(\theta_i - d_i\right)^2 = \tfrac{a_2^2}{(1-b_2a_2)^2}\left(\left(b_1\right)^2 \overset{(A)}{E}\left(E_m\theta_i\right)^2 + b_2a_1\left(b_2a_1 + 2b_1\right)\overset{(B)}{E}\left(E_m\theta_i - E_nE_m\theta_i\right)^2\right)$$
$$+ \overset{(C)}{EVar_m}\theta_i + \tfrac{1}{(1-b_2a_2)^2}\left(a_2b_1\right)^2 \overset{(D)}{E}\left(E_mE_n\theta_j\right)^2.$$

Here, (A) captures the baseline loss caused by the limit on adaptation imposed by the need to coordinate decisions, as given by the equilibrium decisions and (C) captures the interim uncertainty over the appropriate course of action faced by the decision-maker, constituting the *fundamental uncertainty* over θ_i remaining at this stage and is thus present only when agent i is not allowed to decide d_i and communication is inaccurate. (B) captures the cost of the fact that when communication is inaccurate, even if agent i would make the decision, the induced component of adaptation is based on an inaccurate message. Finally, (D) gives the cost of accommodating d_j in terms of compromised adaptation. The size of these components follows directly from the equilibrium decisions.

In a similar fashion, we can write the coordination component as

$$E\left(d_j - d_i\right)^2 = \tfrac{1}{(1-b_2a_2)^2}\left(b_1a_1\right)^2 \left(\overset{(A)}{E\left(E_mE_n\theta_j\right)^2 + E\left(E_nE_m\theta_i\right)^2} \right. \\ \left. + \overset{(B)}{b_1^2E\left(E_n\theta_j - E_mE_n\theta_j\right)^2} + \overset{(C)}{a_1^2E\left(E_m\theta_i - E_nE_m\theta_i\right)^2}\right.$$

Here, (A) captures the baseline divergence in decisions, caused by the need for adaptation. Parts (B) and (C) capture the *strategic uncertainty* remaining in the interim stage, caused by the inaccurate communication and the associated inability to predict exactly what the opponent is going to do.

To bring the two together in a simple form, we can rearrange $(\theta_i - d_i)^2$ based on the common knowledge components, which gives

$$Var_m\theta_i + a_2^2\left(E_m\theta_i - E_nE_m\theta_i\right)^2 + \tfrac{(a_2b_1)^2}{(1-b_2a_2)^2}\left(\left(E_nE_m\theta_i\right)^2 + \left(E_mE_n\theta_j\right)^2\right).$$

Then, adding up $(1-r_i)(\theta_i - d_i)^2 + r_i(d_j - d_i)^2$ gives us

$$\tfrac{k_ib_1^2\left((1-r_i)a_2^2 + r_ia_1^2\right)}{(1-b_2a_2)^2}\left(\left(E_nE_m\theta_i\right)^2 + \left(E_mE_n\theta_j\right)^2\right) + k_i(1-r_i)Var_m\theta_i \\ + k_i\left((1-r_i)a_2^2 + r_ia_1^2\right)\left(E_m\theta_i - E_nE_m\theta_i\right)^2 + k_ir_ib_1^2\left(E_n\theta_j - E_mE_n\theta_j\right)^2.$$

Now, whether any of the three last terms are present in any given situation depends on the identity of the decision-maker(s) and the underlying accuracy of information. For example, under perfect primary information and decentralized authority, $Var_m\theta_i = 0$, but because communication will generically be imperfect, the last two coefficients will be positive. Similarly, under centralized authority, $Var_m\theta_i > 0$, but the last two terms are not present because the manager knows what he knows. What remains is to solve the expectations by using the partition equilibrium solved above, which then gives the following proposition:

Proposition 6 ***Expected Losses:***

In the case of simultaneous communication, we can write the expected loss to activity i as

$$EL_i = \Lambda_i^g \left(A(\varphi_i)\,\overline{\theta}_i^2 + A(\varphi_j)\,\overline{\theta}_j^2 \right) + \Lambda_{i-i}^g B(\varphi_i)\,\overline{\theta}_i^2 + \Lambda_{i-j}^g B(\varphi_j)\,\overline{\theta}_j^2,$$

where Λ_k^g *is shorthand for* $\Lambda_k(r_i, r_j, s_i, s_j, g)$, *constants that depend only on the underlying environment, the amount of payoff sharing present and the governance structure chosen, and*

$$A(x) \equiv \frac{(1-\alpha(x))(1+\alpha(x))^2}{4\left(1-\alpha(x)^3\right)}, \qquad B(x) \equiv \frac{(1-\alpha(x))^3}{12\left(1-\alpha(x)^3\right)}.$$

Proof. See Appendix B ■

Corollary 7 *An alternative way to write the expected loss to activity i is:*

$$EL_i = \Lambda_i^g \left(\overline{\theta}_i^2 + \overline{\theta}_j^2\right) + \Gamma_{i-i}^g V(\varphi_i^g)\,\overline{\theta}_i^2 + \Gamma_{i-j}^g V\left(\varphi_j^g\right)\overline{\theta}_j^2,$$

where $\Gamma_{i-i}^g = \frac{\Lambda_{i-i}^g}{3} - \Lambda_i^g$, $\Gamma_{i-j}^g = \frac{\Lambda_{i-j}^g}{3} - \Lambda_i^g$ *and* $V(\varphi_i^g) = 3B(\varphi_i^g) = \frac{1}{4+3\alpha(x)}$

The loss can be thus written as being composed of two parts. First, $\Lambda_i^g\left(\overline{\theta}_i^2 + \overline{\theta}_j^2\right)$ measures the loss under perfect information given the equilibrium decisions under governance structure g while $\Gamma_{i-i}^g V(\varphi_i^g)\,\overline{\theta}_i^2 + \Gamma_{i-j}^g V\left(\varphi_j^g\right)\overline{\theta}_j^2$ captures the additional loss caused by inaccurate communication. $V\left(\varphi_j^g\right)$ is simply a scaled variance of the recipients belief $\left(3E(\theta_i - E_k\theta_i)^2\right)$ as determined by the quality of communication φ_i^g and Γ_{i-i}^g measures how costly this inaccuracy is as determined by the allocation of decision rights and thus the equilibrium decisions.

B Proofs and Derivations

B.1 Proposition 4

The first-order conditions are given by

$$d_i^m = a_1 E_m \theta_i + a_2 E_m d_j \qquad \text{and} \qquad d_j^n = b_1 E_n \theta_j + b_2 E_n d_i,$$

where

$$E_m d_j = b_1 E_m E_n \theta_j + b_2 E_m E_n d_i \qquad \text{and} \qquad E_n d_i = a_1 E_n E_m \theta_i + a_2 E_n E_m d_j.$$

Note that since $E_n d_i$ and $E_m d_j$ are based solely on the messages m_i, m_j sent, "what you think that I know" and so all higher-order beliefs (which are equal) are common knowledge.[15] Thus, we can write by repeated substitution

$$d_i^m = a_1 E_m \theta_i + a_2 \left(b_1 E_m E_n \theta_j + b_2 \left(a_1 E_n E_m \theta_i + a_2 \left(b_1 E_m E_n \theta_j + b_2 \left(... \right) \right) \right) \right),$$

which, after rearranging, simplifies to

$$d_i^m = \frac{a_1 (1 - b_2 a_2) E_m \theta_i + a_2 b_1 E_m E_n \theta_j + a_2 b_2 a_1 E_n E_m \theta_i}{1 - b_2 a_2}.$$

B.2 Proposition 5

The linearity of the solution follows directly from the quadratic form of the payoffs and the linearity of the equilibrium decisions in all information. In particular, we can write the objective function of the sender (agent i) as:

$$\min_{m_i} E_i \left[\begin{array}{c} \beta_i k_i \left((1 - r_i) \left(\theta_i - d_i \left(., m_i \right) \right)^2 + \left(\beta_i k_i r_i + \beta_j k_j r_j \right) \left(d_i \left(., m_i \right) - d_j \left(., m_i \right) \right)^2 \right) \\ + \beta_j k_j \left(1 - r_j \right) \left(\theta_j - d_j \left(., m_i \right) \right)^2 \end{array} \right]$$

where m_i stands for the message sent, and our task is to solve for an incentive-compatible partition of the message space. Let $I_{m=i} \in \{0, 1\}$ be an indicator function

[15] The solution in the case of an exogenous probability of communication failure is available from the author on request.

for whether the sender retains control for his own activity. Then we can write the indifference condition component-wise (dropping constant components):[16]

$$\begin{aligned}\Delta\left(\theta_i - d_i\left(.,m_i\right)\right)^2 &= a_1^2\left(1 - I_{m=i}\left(1-b_2a_2\right)\right)^2\left(\theta_k+\theta_{k-2}-2\theta_{k-1}\right)\\ &\quad -2a_1a_2b_1\left(1 - I_{m=i}\left(1-b_2a_2\right)\right)\left(\theta_{k-1}-E_i\theta_j\right)\end{aligned}$$

$$\Delta\left(\theta_j - d_j\left(.,m_i\right)\right)^2 = \left(b_2a_1\right)^2\left(\theta_k+\theta_{k-2}-2\theta_{k-1}\right) + 2\left(b_2a_1\right)^2\left(\theta_{k-1}-E_i\theta_j\right)$$

$$\begin{aligned}\Delta\left(d_i\left(.,m_i\right) - d_j\left(.,m_i\right)\right)^2 &= a_1^2\left(b_1 - I_{m=i}\left(1-b_2a_2\right)\right)^2\left(\theta_k+\theta_{k-2}-2\theta_{k-1}\right)\\ &\quad +2a_1^2\left(b_1 - I_{m=i}\left(1-b_2a_2\right)\right)b_1\left(\theta_{k-1}-E_i\theta_j\right)\end{aligned}$$

substituting back and rearranging gives then:

$$\begin{aligned}\theta_k &= 2\theta_{k-1}-\theta_{k-2}\\ &\quad +4\frac{\left[\beta_ik_i(1-r_i)a_2b_1(1-I_{m=i}(1-b_2a_2))-\left(\beta_ik_ir_i+\beta_jk_jr_j\right)a_1(b_1-I_{m=i}(1-b_2a_2))b_1-\beta_jk_j(1-r_j)b_2^2a_1\right]}{a_1\left[\beta_ik_i(1-r_i)(1-I_{m=i}(1-b_2a_2))^2+\left(\beta_ik_ir_i+\beta_jk_jr_j\right)(b_1-I_{m=i}(1-b_2a_2))^2+\beta_jk_j(1-r_j)b_2^2\right]}\left(\theta_i-E_i\theta_j\right)\end{aligned}$$

or

$$\theta_n = 2\theta_{n-1}-\theta_{n-2}+4\frac{1}{\varphi_i^g}\left(\theta_{n-1}-E_i\theta_j\right)$$

The general solution to the difference equation with the above structure is given by:

$$\theta_n - E_i\theta_j = \frac{\varphi}{4\sqrt{1+\varphi}}\left(\left(\frac{\varphi}{\left(1-\sqrt{1+\varphi}\right)^2}\right)^n - \left(\frac{\varphi}{\left(1+\sqrt{1+\varphi}\right)^2}\right)^n\right)\left(\theta_1-E_i\theta_j\right)$$

let l and k be the two different cutoffs. Then,

$$\frac{\theta_l-E_i\theta_j}{\theta_k-E_i\theta_j} = \frac{\frac{\varphi}{4\sqrt{1+\varphi}}\left(\left(\frac{\varphi}{\left(1-\sqrt{1+\varphi}\right)^2}\right)^l - \left(\frac{\varphi}{\left(1+\sqrt{1+\varphi}\right)^2}\right)^l\right)}{\frac{\varphi}{4\sqrt{1+\varphi}}\left(\left(\frac{\varphi}{\left(1-\sqrt{1+\varphi}\right)^2}\right)^k - \left(\frac{\varphi}{\left(1+\sqrt{1+\varphi}\right)^2}\right)^k\right)} = \varphi\frac{\left(1+\sqrt{1+\varphi}\right)^{2l}-\left(1-\sqrt{1+\varphi}\right)^{2l}}{\left(1+\sqrt{1+\varphi}\right)^{2k}-\left(1-\sqrt{1+\varphi}\right)^{2k}}$$

define $k=n$ and $l=n-x$, where x is the distance between the two cutoffs, with $x=1$ implying adjacent cutoffs. This substitution allows us to write the equation as

$$\frac{\theta_{n-x}-E_i\theta_j}{\theta_n-E_i\theta_j} = \frac{\left(1+\sqrt{1+\varphi}\right)^{2(n-x)}-\left(1-\sqrt{1+\varphi}\right)^{2(n-x)}}{\varphi^{n-x}}\frac{1}{\frac{\left((1+\sqrt{1+\varphi})^{2n}-(1-\sqrt{1+\varphi})^{2n}\right)}{\varphi^n}}$$

[16] We make the assumption that agent i doesn't have better information about θ_j than the person deciding d_j. In the simultaneous one-round case, there is no prior information and as a result this condition is trivially satisfied

Now, to solve for the most informative partition (which minimizes the absolute size of the intervals conditional on the relative size of the adjacent intervals being given by φ), we let $n \to \infty$. Observe that:

$$\lim_{y\to\infty} \frac{\left(1-\sqrt{1+\varphi}\right)^{2y}}{\varphi^y} = \lim_{y\to\infty} \frac{\left(2-2\sqrt{1+\varphi}+\varphi\right)^{y}}{\varphi^y} = 0$$

as long as $\varphi > 0$. Therefore, the above rearranges to:

$$\frac{\theta_{n-x}-E_i\theta_j}{\theta_n - E_i\theta_j} = \left(\frac{\varphi}{\left(1+\sqrt{1+\varphi}\right)^2}\right)^x = \alpha\left(\varphi\right)^x$$

Letting $\theta_n = \overline{\theta}$ gives the full characterization of the partition. The solution going backwards ($\theta_n < E_i\theta_j$) follows similarly.

B.3 Proposition 6

To solve the expectations we use the communication equilibrium from above (we continue to let α to stand for α_i to simplify):

(a) probabilities

The probability of $\theta_i \in [\theta_{k-1}, \theta_k]$ is simply:

$$\begin{array}{ll} \left(\frac{\overline{\theta}-E_i\theta_j}{2\overline{\theta}}\right)\alpha^{i-1}\left(1-\alpha\right) & \theta_i > E_i\theta_j \\ \left(\frac{E_i\theta_j+\overline{\theta}}{2\overline{\theta}}\right)\alpha^{i-1}\left(1-\alpha\right) & \theta_i < E_i\theta_j \end{array}$$

where $i = 1$ indexes the furthest partition.

(b) cutoffs

The cutoffs are in turn given by:

$$\theta_i = E_i\theta_j + \alpha^i\left(\overline{\theta}_i - E_i\theta_j\right),$$

where $i = 0 \to \theta_i = \overline{\theta}$ and symmetrically downwards

(c) conditional expectations and variances

From the cutoffs it follows immediately that

$$E\theta_i = E_i\theta_j + \tfrac{1}{2}\alpha^{i-1}(1+\alpha)\left(\overline{\theta} - E_i\theta_j\right) \qquad \theta_i > E_i\theta_j$$
$$E\theta_i = E_i\theta_j - \tfrac{1}{2}\alpha^{i-1}(1+\alpha)\left(\overline{\theta} + E_i\theta_j\right) \qquad \theta_i < E_i\theta_j$$

(d) ex ante expectations and variances

First, note that since learning is a random walk, $EE\theta_i = 0$. The two components that do matter are $E\left(E_j\theta_i\right)^2$ and $EVar(\theta_i)$

Evaluating $E\left(E_j\theta_i\right)^2$:

$$E\left(E_j\theta_i\right)^2 = \sum_{i=1}^{\infty}\left(\tfrac{\overline{\theta}-E_i\theta_j}{2\overline{\theta}}\right)\alpha^{i-1}(1-\alpha)\left(E_i\theta_j + \tfrac{1}{2}\alpha^{i-1}(1+\alpha)\left(\overline{\theta}-E_i\theta_j\right)\right)^2 + \sum_{i=1}^{\infty}\left(\tfrac{\overline{\theta}+E_i\theta_j}{2\overline{\theta}}\right)\alpha^{i-1}(1-\alpha)\left(E_i\theta_j - \tfrac{1}{2}\alpha^{i-1}(1+\alpha)\left(\overline{\theta}+E_i\theta_j\right)\right)^2$$

$$E\left(E_j\theta_i\right)^2 = \tfrac{1}{4}\left(\left(1+\tfrac{\alpha(1-\alpha)}{(1-\alpha^3)}\right)\overline{\theta}^2 - \left(1-\tfrac{3\alpha(1-\alpha)}{(1-\alpha^3)}\right)\left(E_i\theta_j\right)^2\right)$$

Similarly for $E\left(\theta_i - E_j\theta_i\right)^2$:

$$E\left(\theta_i - E_j\theta_i\right)^2 = \sum_{i=1}^{\infty}\left(\tfrac{\overline{\theta}-E_i\theta_j}{2\overline{\theta}}\right)\alpha^{i-1}(1-\alpha)\tfrac{1}{12}\left(\alpha^{i-1}(1-\alpha)\left(\overline{\theta}-E_i\theta_j\right)\right)^2 + \sum_{i=1}^{\infty}\left(\tfrac{\overline{\theta}+E_i\theta_j}{2\overline{\theta}}\right)\alpha^{i-1}(1-\alpha)\tfrac{1}{12}\left(\alpha^{i-1}(1+\alpha)\left(\overline{\theta}+E_i\theta_j\right)\right)^2$$

$$EVar_j\theta_i = \tfrac{1}{12}\left(\tfrac{(1-\alpha)^3}{(1-\alpha^3)}\right)\left(\overline{\theta}^2 + 3\left(E_i\theta_j\right)^2\right)$$

in the case of simultaneous one-round communication, $E_i\theta_j = E_j\theta_i = 0$, and we get the functions $A(x)$ and $B(x)$ of the proposition. Finally, note that $A(x)+B(x) = \frac{1}{3}$ and that

$$B(x) \equiv \frac{(1-\alpha(x))^3}{12\left(1-\alpha(x)^3\right)} = \frac{\left(1-\frac{x}{(2+x+2\sqrt{1+x})}\right)^3}{12\left(1-\left(\frac{x}{(2+x+2\sqrt{1+x})}\right)^3\right)} = \frac{\left(2+2\sqrt{1+x}\right)^3}{12\left(\left(2+x+2\sqrt{1+x}\right)^3 - x^3\right)}$$
$$= \frac{\left(2+2\sqrt{1+x}\right)^3}{12\left(\left(2+2\sqrt{1+x}\right)^3 + 3x^2\left(2+2\sqrt{1+x}\right) + 3x\left(2+2\sqrt{1+x}\right)^2\right)}$$
$$= \frac{4\left(1+\sqrt{1+x}\right)^2}{12\left(4\left(1+\sqrt{1+x}\right)^2 + 3x^2 + 6x\left(1+\sqrt{1+x}\right)\right)}$$
$$= \frac{\left(1+\sqrt{1+x}\right)^2}{3\left(4\left(2+x+2\sqrt{1+x}\right) + 3x\left(2+x+2\sqrt{1+x}\right)\right)} = \frac{1}{3(4+3x)}.$$

Then, to simplify notation for the analysis, we define $V(x) = 3B(x) = \frac{1}{4+3x}$.

B.4 Expected loss under noisy local information

Recall from A.2 that the expected loss under any governance structure simplifies to

$$\frac{k_i b_1^2\left((1-r_i)a_2^2+r_i a_1^2\right)}{(1-b_2a_2)^2}\left((E_nE_m\theta_i)^2+(E_mE_n\theta_j)^2\right)+k_i(1-r_i)Var_m\theta_i$$
$$+k_i\left((1-r_i)a_2^2+r_ia_1^2\right)(E_m\theta_i-E_nE_m\theta_i)^2+k_ir_ib_1^2(E_n\theta_j-E_mE_n\theta_j)^2.$$

First, note that given the signal s_i, agent i's belief about the realized θ_i is given by p_is_i. In consequence, agent i's belief about the realization of θ_i is distributed $U\left[-p_i\overline{\theta}_i, p_i\overline{\theta}_i\right]$, while the receiver's belief upon receiving a message m_i is given by $p_iE(s_i|m_i)$. Because $p_i's$ cancel each other out in the degree of incentive conflict, the communication solution presented goes directly through and can be defined either in the space of signals or in the space of beliefs. The only component that directly depends on the quality of primary information is $Var_m\theta_i$. When $m=i$,

$$E(\theta_i-E_i\theta_i)^2=p_iE(\theta_i-p_i\theta_i)^2+(1-p_i)E(\theta_i-p_ix_i)^2=(1-p_i^2)\frac{\overline{\theta}_i^2}{3}.$$

When $m\neq i$,

$$E(\theta_i-E_m\theta_i)^2=E(\theta_i-p_iE_ms_i)^2=p_iE(\theta_i-p_iE_m\theta_i)^2+(1-p_i)E(\theta_i-p_iE_mx_i)^2.$$

Now, note that $E(\theta_i-p_iE_mx_i)^2=E\theta_i^2+p_i^2E(E_mx_i)^2$ and that $E(\theta_i-p_iE_m\theta_i)^2=E(\theta_i-E_m\theta_i)^2+(1-p_i)^2E(E_m\theta_i)^2$. Adding the two components together and adding and subtracting $p_i^2E(\theta_i-E_m\theta_i)^2$ gives

$$p_i\left(E(\theta_i-E_m\theta_i)^2+(1-p_i)^2E(E_m\theta_i)^2\right)+(1-p_i)\left(E\theta_i^2+p_i^2E(E_mx_i)^2\right)$$
$$+p_i^2E(\theta_i-E_m\theta_i)^2-p_i^2E(\theta_i-E_m\theta_i)^2$$

$$(1-p_i^2)E\theta_i^2+(1-p_i)p_i^2E(E_mx_i)^2-p_i^2(1-p_i)E(E_m\theta_i)^2+p_i^2E(\theta_i-E_m\theta_i)^2$$

and noting that $E(E_mx_i)^2=E(E_m\theta_i)^2$, this simplifies to

$$E(p_i\theta_i-p_iE_m\theta_i)^2+(1-p_i^2)\frac{\overline{\theta}_i^2}{3}.$$

First component is equivalent to the fundamental uncertainty that would be present if the state was distributed on $U\left[-p_i\overline{\theta}_i, p_i\overline{\theta}_i\right]$ and the second component gives the additional loss due to inaccurate primary information. The equivalence is thus established.