Protocol Design and (De-)Centralization*

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Abstract Should privately informed agents with diverging interests act independently or should they commit to a mechanism? This paper analyzes different communication and decision protocols when communication involves costly delay. It studies under which conditions agents should (i) choose their actions immediately and non-cooperatively, (ii) communicate and act independently or (iii) contract before receiving their information. Well-informed agents with similar preferences do not contract or communicate. Communication is desirable when preferences are similar and individual signals are of intermediate quality. Contracting on a Bayesian mechanism only pays when agents' prefered outcomes are not too strongly correlated, when information quality is high, and when the cost of delay is sufficiently low. When the correlation is negative and large enough, the optimal contract does not involve any communication.

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1 Introduction

It is one of the fundamental questions of organization theory whether decisions should be made inside an organization or whether it should be left to individual agents to act autonomously and without further coordination. Related to this is the question whether organizations require a minimum degree of homogeneity of interests among their members. This is frequently argued in debates about the adequate structure and composition of clubs, management boards, faculties, or international organizations such as the European Union, NATO, or the G8.

A good example is the case of Turkey's possible entry into the European Union. Valery Giscard d'Estaing, the president of Europe's constitutional assembly predicted that Turkish membership would mean "the end of the EU" because Turkey has "a different culture, a different approach, and a different way of life." Proponents of an entry instead stress the importance of synergies and externalities. They emphasize that Turkey is strategically placed, militarily powerful, and influential in the energy-rich states of Central Asia. Along these lines, former French prime minister Michel Rocard argues that "Geostrategy imposes [membership] on us." While externalities clearly are a good reason some form of cooperation, many people hold the opinion that with too much preference heterogeneity cooperation will not work in practice.

Recently, economists have interpreted decision making in organizations as a process of information aggregation. According to this view, the role of organizations is to aggregate decentralized information which is relevant for a collective decision. However, if one addresses the above questions with the tools of mechanism design theory, the result is disappointing. According to the revelation principle, any decentralized information aggregation mechanism can be replaced by a centralized mechanism. Such a centralized mechanism asks all participating agents for their private information and assigns the equilibrium outcome to the vector of statements. The fundamental question whether one should organize collective decision making in a joint organization or not can therefore not be addressed in a meaningful way with the tools of mechanism design theory. Moreover, the heterogeneity of preferences does not play any role for the centralization decision.

The present paper follows a different route. Communication within organizations is time consuming. A major advantage of uncoordinated decentralized decision making is that it does not require too much communication among the different agents. Consequently, decentralized decision making leads to results with a shorter delay. The present paper develops a theory that analyses the trade-off between the efficiency of information aggregation and the delay of decision making. A simple mechanism design problem is augmented with time consuming communication.

In the present model two agents may individually choose an action that influences the joint outcome. The joint outcome in turn determines individual payoffs. A high outcome requires the activity of both players (such as e.g. a foreign policy measure that is effective only if a sufficient number of countries joins in). Players are imperfectly informed about their own desired outcome and individually desired outcomes may be positively or negatively correlated. Both players make high losses when an inappropriate low outcome is chosen. Hence, an uninformed player would pick the high outcome - but he cannot enforce it alone. When one or two players gets a signal in favor of the high outcome then this outcome maximizes the expected surplus. However, when players' individual signals differ, the non-cooperative outcome may turn out to be the low one. Hence, coordination fails unless both players' preferences are perfectly aligned.

A key assumption of the model is that agents are imperfectly informed about their own underlying preferences over outcomes. Hence, when preferences are positively correlated, there is some scope for incentive compatible communication. Communication produces relatively little delay and it does not require any ex-post enforcement. In case of a negative correlation and if gains and losses are distributed unevenly, individuals may instead want to commit to a collective mechanism. This mechanism produces a larger delay and requires an ex-post enforcement of players' actions.

The framework permits to study how conflicts of interest, the quality of information and the cost of delay affect the optimal organizational form. The conventional wisdom on this issue is that only individuals who are likely to agree on major issues should constitute the membership of an institution. The present paper obtains a different result. When delay in decision-making is costly, individuals may decide to act non-cooperatively when their preferences coincide with a high probability. In this case very little can be gained from communication, coordination, or contracting. If however individual signals are not very reliable, communication may be useful - even in cases with correlated preferences. For negatively correlated preferences communication is useless when it is not accompanied by an appropriate enforcement mechanism. When participants are very likely to disagree, optimal organizations impose strict rules that do not react to individual signals at all. Slow Baysesian mechanisms are optimal only if there is an intermediate scope for conflict.

Communication pays only for intermediate degrees of informedness. Both uninformed and fully informed players should act non cooperatively - the former because there is no information to be shared, the latter because the information is good enough. Communication pays in between. Informed agents should either play non-cooperatively (when conflicts are unlikely), use inflexible rules (when conflicts are frequent) or Bayesian mechanisms (intermediate cases).

Several other papers have relaxed the assumptions underlying the revelation principle in order to find out more about optimal decentralized decision making. Some of them derive richer organizational structures from limits to agents' ability to communicate. Most of these papers assume restrictions on agents' message space[1]. Other papers have imposed restrictions on agents' ability to sign complex state contingent contracts. The theory of incomplete contracts that has produced various results in favour of decentralized decision making (in particular Grossman and Hart, 1986, Hart and Moore, 1990, Rotemberg and Saloner 1994, Lülfesmann 1996, Seabright 1996). In the present paper no such restrictions are in place. Communication is merely assumed to create a delay. When delay is costly, and depending on the key parameters of the model, different organizational structures may arise. The conventional Bayesian mechanism is only optimal when the quality of individual information is sufficiently good and when the potential for conflicts among agents is neither too large nor too small.

The present paper contributes to the recent literature on delay in decision making that has emerged from Radner's (1993) seminal paper[2]. It is most closely related to recent work by Grüner and Schulte (2004), Grüner (2007), and Schulte and Grüner (2007), who have extended Radner's framework to include bounded rationality and incentive problems in decision making models with costly delay. The value added of the paper is that it analyzes situations with diverging preferences over outcomes[3]. In the spirit of Radner (1993), and similar to Grüner and Schulte (2004) the paper introduces a concept of a protocol that governs players' actions and determines the path and timing of communication. A protocol is an extensive form game that is subject to certain constraints. The constraints stem from the bounded rationality of decision makers who need time in order to send and understand signals. A simultaneous move-direct revelation mechanism would not be a feasible protocol in this setup because it requires that the receiver of the messages understands all signals instantaneously (or alternatively that delay in decision making does not play a role).

An excellent review of the literature on centralized versus decentralized decision making in organizations is given in Alonso, Dessein and Matoucheck (2006). An important

[1]Key contributions are Green and Laffont (1987), Laffont and Martimont (1998) Melhumad, Mokherjee and Reichelstein (1992, 1997).

[2]A non-exclusive list is Orbay (2002), Prat (1997), Radner and van Zandt (1992) and van Zandt (1997, 1998, 1999, 2003).

[3]Grüner and Schulte (2004) and Grüner (2007) instead deal with moral hazard problems within programmed hierarchies.

attempt to take into account the costs of information complexity in contracting is Segal (1999). References to related work by computer scientist can be found in Conitzer and Sandholm (2003).

Recently and independently, Mookherjee and Tsumagari (2007) have developed a theory of protocol design with asymmetric information and costly delay. They develop a similar concept of a communication protocol and apply it to a problem of joint production with an unknown cost parameter. The paper discusses the relation between the stochastic cost structure and optimal decentralization. My paper instead focuses on an common values setup with imperfect private information about preferences for a single outcome. This outcome in turn depends on individual actions. In my setup the role of more or less correlated preferences and the role of the quality of information can be studied.

Questions related to optimal communication protocols have been addressed in the context of committee voting, e.g. in Ottaviani and Sorensen (2001) and Gerardi and Yariv (2007). What is different in the present paper is that the delay of the protocol is key in determining the organizational choice.

2 The model

2.1 Decisions and Information

Consider two agents $i = 1, 2$. Each agent has to make a decision $x_i \in \{0, 1\}$. Decisions are agent-specific, i.e. they cannot be delegated to another agent. Both decisions determine the final outcome $x \in \{0, 1\}$ according to the technology $x = \min\{x_1, x_2\}$. Both agents' preferences are state-dependent, the individual-specific component of the state is denoted by $s_i \in \{0, 1\}$. Preferences over outcomes are described by a Bernoulli utility function $u_i(x, s_i)$ that assumes a high value when the outcome matches the individual state.

$$u_i(x, s_i) = \begin{cases} 1 & \text{if } \mathbf{x} = \mathbf{s}_i \\ 0 & \text{if } \mathbf{x} = 1 \wedge \mathbf{s}_i = 0 \\ -\alpha & \text{if } \mathbf{x} = 0 \wedge \mathbf{s}_i = 1 \end{cases} . \tag{1}$$

There is an extra cost $\alpha > 0$ that arises when an inappropriately low outcome ($x = 0$) is chosen. Hence, both agents prefer the outcome $x = 1$ when both states are equally likely. However, none of them can autonomously enforce this outcome.

Both agents receive a private signal $\theta_i \in \{0, 1\}$ about the true state of the world which is correlated with the individual state s_i. The probability that s_i and θ_i coincide is $p \in [1/2, 1]$. The joint probability distribution of states is

$$\begin{array}{ccc} \mathbf{s}_1 \setminus \mathbf{s}_2 & \mathbf{0} & \mathbf{1} \\ \mathbf{0} & a/2 & \frac{1-a}{2} \\ \mathbf{1} & \frac{1-a}{2} & a/2 \end{array}.$$

The parameter $a \in [0, 1]$ characterizes the potential conflict of interest between both players. At $a = 1$ both players always agree on what should be done while at $a = 0$ they disagree with certainty. An agent's total payoff is given by

$$u_i(x, s_i) - f(d), \tag{2}$$

where $d \in N$ denotes the delay involved in making the decision x and $f(\cdot)$ is strictly increasing with $f(0) = 0$. The values of a, α, and the function $f(\cdot)$ are common knowledge.

2.2 Ex-ante efficiency

When the cost parameter α is not too large, the decision rule $x(\theta_1, \theta_2)$ that maximizes the sum of the expected total payoffs of both agents reacts to the information of both players. In this case the welfare-maximizing decision rule is to implement the decision $x = 1$ instantaneously (i.e. with a delay $d = 0$) when at least one player receives signal $\theta_i = 1$. The instantaneous decision must be $x = 0$ otherwise.

When the cost parameter α is large enough, the decision rule that maximizes the sum of the expected payoffs is to implement $x = 1$ instantaneously and independently of the signals, i.e. even when $\theta_1 = \theta_2 = 0$. The corresponding threshold for α can be calculated from the following difference of expected utilities.

$$\begin{aligned} & E_{s_1,s_2}(u_1(1, s_1) + u_2(1, s_2) - u_1(0, s_1) + u_2(0, s_2) \mid \theta_1 = \theta_2 = 0) \\ = \\ & prob(s_1 = 1, s_2 = 1 \mid \theta_1 = \theta_2 = 0) \cdot (2 + 2\alpha) \\ & +prob(s_1 = 0, s_2 = 0 \mid \theta_1 = \theta_2 = 0) \cdot (-2) \\ & +prob(s_1 = 1, s_2 = 0 \mid \theta_1 = \theta_2 = 0) \cdot \alpha \\ & +prob(s_1 = 0, s_2 = 1 \mid \theta_1 = \theta_2 = 0) \cdot \alpha \end{aligned} \tag{3}$$

$$= \frac{\frac{a}{2}(1-p)^2}{\frac{a}{2}p^2 + \frac{a}{2}(1-p)^2 + 2\frac{1-a}{2}p(1-p)} \cdot (2+2\alpha) \tag{4}$$
$$+ \frac{\frac{a}{2}p^2}{\frac{a}{2}p^2 + \frac{a}{2}(1-p)^2 + 2\frac{1-a}{2}p(1-p)} \cdot (-2)$$
$$+ \frac{2\frac{1-a}{2}p(1-p)}{\frac{a}{2}p^2 + \frac{a}{2}(1-p)^2 + 2\frac{1-a}{2}p(1-p)} \cdot \alpha.$$

This expression is negative if

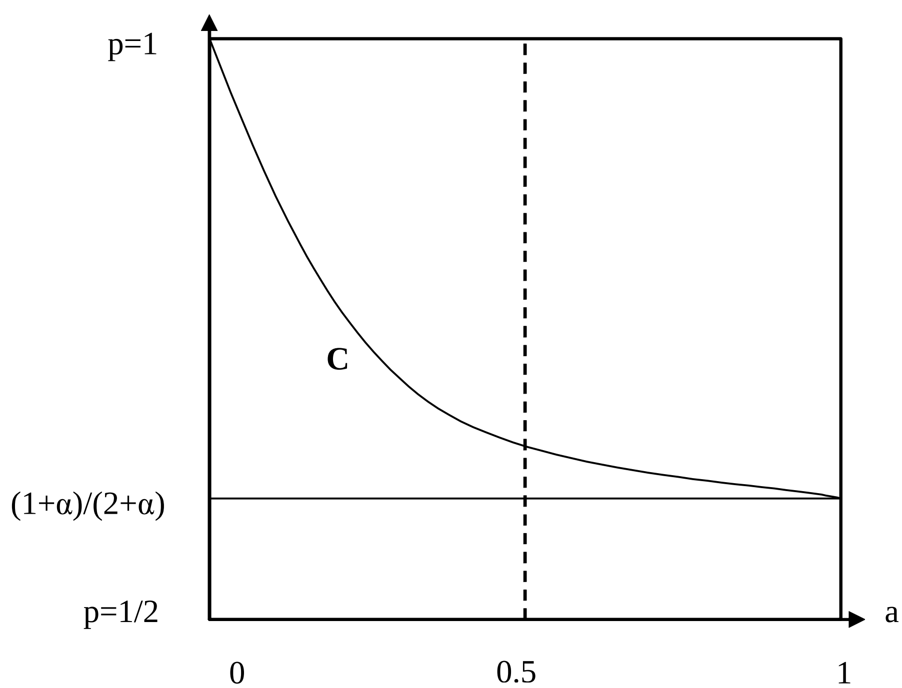
$$\alpha < \frac{a(2p-1)}{(1-p)(a(1-p)+(1-a)p)} =: \bar{\alpha}(a,p). \tag{5}$$

For uninformative signals ($p = 1/2$), the right hand side of (5) becomes zero. In this case (and for neighboring cases $p > 1/2$) the optimal decision is state-independent.

Lemma 1 *The decision rule that maximizes the sum of the expected total payoffs is to instantaneously implement the decision*

$$x(\theta_1,\theta_2) = \begin{cases} \max\{\theta_1,\theta_2\} & if\ \alpha \leq \bar{\alpha}(a,p) \\ 1 & if\ \alpha \geq \bar{\alpha}(a,p) \end{cases}. \tag{6}$$

Figure 1 depicts the curve C that separates the combinations of a and p for which the best decision is state-dependent (above C) or state-independent (below C).



Lemma 1: Optimal decision rule.

3 Protocols

A protocol is an extensive form game which satisfies a number of constraints. These constraints concern the timing of communication acts and actions, and the delay involved. A *basic protocol* does not involve an ex-post enforcement of an agreement while a *contractual protocol* does. Under a basic protocol, all that agents can do is to send messages before they act simultaneously.

Definition 1 *A basic protocol is an extensive form game with the following properties:*

(i) The game starts with the moves of nature that determine the states $s_i \in \{0, 1\}$ *and the signals* $\theta_i \in \{0, 1\}$ *according to the joint distribution specified above.*

(ii) Signals θ_i *are private information of player* i*.*

(iii) Both agents can communicate sequentially after obtaining their signals by sending messages $m_i \in \{0, 1\}$ *.*

(iv) Sending a message takes one unit of time.

(v) Actions are not observable and do not take time.

Four basic protocols in which communication precedes actions are available (see Table 1): the protocol without any communication (quiet protocol), two symmetric one-sided communication protocols and a two-sided communication protocol. A contractual protocol requires a third agent who sequentially collects the players' messages, computes the corresponding profile of actions, and informs both agents about what they have to do.

I assume that at a pre-play stage both agents can commit to playing the protocol which maximizes their expected payoffs.

4 Quiet protocol and lack of coordination

The quiet protocol is the Bayesian game in which both agents simultaneously choose their actions x_i without prior communication. The delay of this protocol is $d = 0$. The game is a finite game with four pure strategies for each player - it always has an equilibrium. In any informative[4] Bayesian equilibrium of the quiet protocol, an agent chooses $x_i = 1$ if he receives signal $\theta_i = 1$. There are three different types of informative equilibria. None of them maximize the sum of player's payoffs unless $a = 1$ and $p = 1$.

[4]Informative means that the outcome x is not independent of the agents' signals.

4.1 Sincere equilibrium

A sincere equilibrium, in which $x_i = s_i$, exists if α is not too large. An agent chooses $x_i = 0$ if he receives signal $s_i = 0$ - given that the other agent follows the same plan - if

$$\begin{aligned}
& prob\left(s_i = 1, \theta_j = 1 \mid \theta_i = 0\right) \cdot (-\alpha) \\
& + prob\left(s_i = 0, \theta_j = 0 \mid \theta_i = 0\right) \cdot 1 \\
& + prob\left(s_i = 1, \theta_j = 0 \mid \theta_i = 0\right) \cdot (-\alpha) \\
& + prob\left(s_i = 0, \theta_j = 1 \mid \theta_i = 0\right) \cdot 1 \\
> \; & prob\left(s_i = 1, \theta_j = 1 \mid \theta_i = 0\right) \cdot 1 \\
& + prob\left(s_i = 0, \theta_j = 0 \mid \theta_i = 0\right) \cdot 0 \\
& + prob\left(s_i = 1, \theta_j = 0 \mid \theta_i = 0\right) \cdot (-\alpha) \\
& + prob\left(s_i = 0, \theta_j = 1 \mid \theta_i = 0\right) \cdot 0.
\end{aligned} \tag{7}$$

This leads to:

$$\begin{aligned}
0 &< \frac{1}{2}(1-p)(ap + (1-a)(1-p)) \cdot (-1-\alpha) \\
& \quad + \frac{1}{2} p (ap + (1-a)(1-p)) + \frac{1}{2} p (a(1-p) + (1-a)p)
\end{aligned} \tag{8}$$

$$\Leftrightarrow$$

$$p > (1-p)(ap + (1-a)(1-p)) \cdot (1+\alpha) \tag{9}$$

$$\Leftrightarrow \tag{10}$$

$$1 + \alpha < \frac{p}{(1-p)(ap + (1-a)(1-p))}. \tag{11}$$

This is the necessary and sufficient condition for the existence of a sincere equilibrium. It holds for large enough values of p, small enough costs α, and small enough values of the correlation parameter a. At $\alpha = 0$ a sincere equilibrium exists if $p \geq 1/2$. For $\alpha < 0$, and $p < 1$ a coordination problem arises. The sincere equilibrium is inefficient because one signal $\theta_i = 0$ is not sufficient to produce the decision $x = 0$.

4.2 Symmetric insincere equilibrium

In a symmetric insincere equilibrium agents with signal $\theta_i = 1$ choose action $x_i = 1$ while those with signal zero randomize. Consider such an equilibrium and call γ the probability that a player with signal $\theta_i = 0$ chooses $x_i = 0$. Indifference requires that

$$
\begin{aligned}
& prob\left(s_i=1,\theta_j=1\mid\theta_i=0\right)\cdot(-\alpha) \\
& +prob\left(s_i=0,\theta_j=0\mid\theta_i=0\right)\cdot 1 \\
& +prob\left(s_i=1,\theta_j=0\mid\theta_i=0\right)\cdot(-\alpha) \\
& +prob\left(s_i=0,\theta_j=1\mid\theta_i=0\right)\cdot 1 \\
= \;& prob\left(s_i=1,\theta_j=1\mid\theta_i=0\right)\cdot 1 \\
& +prob\left(s_i=0,\theta_j=0\mid\theta_i=0\right)\cdot\gamma \\
& +prob\left(s_i=1,\theta_j=0\mid\theta_i=0\right)\cdot(-\gamma\alpha+(1-\gamma)) \\
& +prob\left(s_i=0,\theta_j=1\mid\theta_i=0\right)\cdot 0.
\end{aligned} \tag{12}
$$

This condition can be simplified to

$$
\begin{aligned}
0 \;=\;& \frac{1}{2}(1-p)\left(ap+(1-a)(1-p)\right)\cdot(-1-\alpha) \\
& +\frac{1}{2}p\left(ap+(1-a)(1-p)\right)\cdot(1-\gamma) \\
& +\frac{1}{2}(1-p)\left(a(1-p)+(1-a)p\right)\cdot(-\alpha+\gamma\alpha-(1-\gamma)) \\
& +\frac{1}{2}p\left(a(1-p)+(1-a)p\right),
\end{aligned} \tag{13}
$$

and solved for γ as

$$
\gamma=\frac{1+(1-p)\alpha-2p}{p^2\alpha(2a-1)+(a+p)\alpha-a(2p-1)-3ap\alpha}. \tag{14}
$$

The insincere equilibrium also aggregates information inefficiently. In particular, two signals in favor of the outcome $x=0$ may lead to the outcome $x=1$ while mixed signals may lead to outcome $x=0$.

4.3 Asymmetric equilibrium

The third possible equilibrium is an asymmetric one in which one agent always chooses action 1 while the other one acts sincerely, i.e. chooses $x_i=\theta_i$. Acting sincerely is a best reply when

$$
1+\alpha<\frac{prob\left(s_i=0\mid\theta_i=0\right)}{prob\left(s_i=1\mid\theta_i=0\right)}=\frac{p}{1-p}. \tag{15}
$$

The equilibrium only exists when the sincere equilibrium fails to exist. According to condition (11), always choosing action 1 is only a best reply when the correlation of preferences is sufficiently strong. For $\alpha\leq\bar{\alpha}(a,p)$ this equilibrium aggregates information inefficiently because the signal $(\theta_1,\theta_2)=(1,0)$ maps into the decision $x=0$.

4.4 Uninformative equilibrium

In addition there may be an uninformative equilibrium in which both players choose $x_1 = x_2 = 1$ independently of their signal. This equilibrium exists if the signals are not too informative. Playing $x = 1$ at $\theta_i = 0$ is a best reply if

$$1 + \alpha > \frac{prob\,(s_i = 0 \mid \theta_i = 0)}{prob\,(s_i = 1 \mid \theta_i = 0)} = \frac{p}{1 - p}. \tag{16}$$

One can easily verify that condition (5) implies (16), hence, this equilibrium maximizes the sum of the expected payoffs $u_1(x, s_1) + u_2(x, s_2)$.

4.5 Efficiency

The mixed strategies equilibrium may coexist with one of the two pure strategies equilibria. However, the results in Section 6 do not rely on the selection of one particular equilibrium. What is important is that the three informative equilibria do not make efficient use of the available information.

Proposition 1 *(i) The quiet protocol has three kinds of informative Bayesian equilibria: a truthful equilibrium, a symmetric mixed equilibrium and an asymmetric equilibrium in which one player chooses $x = 1$ and the other one chooses a truthful action. For $a, p \neq 1$ neither equilibrium maximizes the sum of the expected payoffs $u_1(x, s_1) + u_2(x, s_2)$ of both players conditional on the available observation (θ_1, θ_2).*

(ii) For $a = p = 1$ all informative equilibria maximize the sum of the expected payoffs.

(iii) For $p \leq \frac{1+\alpha}{2+\alpha}$ there is an uninformative equilibrium with $x_1 = x_2 = 1$. This equilbrium maximizes welfare.

Proof (i) First consider the case $a, p \neq 1$. The sincere equilibrium leads to the outcome $x = 1$ only if both players observe $\theta_1 = \theta_2 = 1$. The asymmetric equilibrium leads to the outcome $x = 0$ when $\theta_1 = 1$ and $\theta_2 = 0$. The mixed equilibrium may lead to outcome $x = 1$ when both signals are zero. (ii) Next consider $a = p = 1$. According to (14) at $a = p = 1$ the mixed equilibrium yields $\gamma = 1$. The other two equilibria also maximize the sum of both players' payoffs. (iii) Follows from the fact that condition (5)) implies (16). *Q.E.D.*

5 Protocols with communication

5.1 One-sided communication protocol

Under one-sided communication, one player, say player 1, sends a signal $m_1 \in \{0,1\}$ to his counterpart after receiving his private signal. Thereafter, both players simultaneously decide on the value of x_i. The delay of this protocol is $d = 1$. This protocol always has equilibria with uninformative messages in which player 2 disregards messages received and both players act as described in Proposition 1. In addition there may be a Pareto-superior informative equilibrium which maximizes the sum of the expected payoffs $u_1(x, s_1) + u_2(x, s_2)$. In this equilibrium player 1 sends sincere messages and always chooses $x_1 = 1$, and player 2 chooses $x_2 = 1$ if and only if at least one of the signals equals 1.

Proposition 2 *(Consulting equilibrium) (i) For all p there exists a value $\hat{a}(p) \leq 1$ such that for all $a > \hat{a}(p)$ the one-sided communication protocol has an equilibrium in which player 1 sends sincere messages $m_1 = \theta_1$, and always chooses $x_1 = 1$, and player 2 chooses $x_2 = \max\{m_1, \theta_2\}$. This equilibrium maximizes the sum of both players' expected payoffs $E(u_1(x, s_1) + u_2(x, s_2))$. (ii) There is a value $\tilde{p} < 1$ such that for all $p > \tilde{p}$, $\hat{a}(p) < 1$.*

Proof (i) First consider player 1's message. The message is unimportant when this player chooses $x_1 = 0$. I therefore concentrate on the case where $x_1 = 1$. Taking player 2's strategy $x_2 = \max\{m_1, \theta_2\}$ as given, the outcome is $x = 0$ if and only if both signals are zero. For large enough values of p, player 1 strictly prefers to truthfully report that $\theta_1 = 0$ when $a = 1$. The strict preference explains part (ii) of the Proposition. Moreover, choosing $x_1 = 1$ is optimal when preferences are correlated strongly enough because, at $a = 1$, player 2 acts in player 1's best interest.

Next consider player 2. Suppose that player 1 sends sincere messages and chooses $x_1 = 1$. Player 2 chooses $x_2 = \max\{m_1, \theta_2\}$ if the correlation parameter a is large enough. He chooses $x_2 = 1$ if his own signal is 1, and, when $\alpha \leq \bar{\alpha}(a, p)$, he chooses $x_2 = 0$ if both signals are zero. He chooses $x_2 = 1$ when his signal θ_2 is zero and the message is $m_1 = 1$ provided that:

$$
\begin{aligned}
& prob\,(s_i = 1 \mid \theta_j = 1, \theta_i = 0) \cdot 1 \\
& +prob\,(s_i = 0 \mid \theta_j = 1, \theta_i = 0) \cdot 0 \\
\geq\; & prob\,(s_i = 1 \mid \theta_j = 1, \theta_i = 0) \cdot (-\alpha) \\
& +prob\,(s_i = 0 \mid \theta_j = 1, \theta_i = 0) \cdot 1,
\end{aligned}
\tag{17}
$$

or

$$(1+\alpha) \geq \frac{prob\,(s_i = 0 \mid \theta_j = 1, \theta_i = 0)}{prob\,(s_i = 1 \mid \theta_j = 1, \theta_i = 0)}. \tag{18}$$

The right hand side is monotonously decreasing in a and assumes the value 1 at $a = 1$ and $p > 1/2$. *Q.E.D.*

In any other equilibrium of the one-sided communication protocol, either (i) player 1 sends uninformative messages, (ii) player 1 mixes when he sends messages (iii) player 1 does not always choose $x_1 = 1$ when he observes $\theta_1 = 0$, or (iv) player 2's choice is not affected by player 1's messages. For a sufficiently large correlation parameter a and for $\alpha \leq \bar{\alpha}\,(a, p)$ any such equilibrium is Pareto dominated by the one described in the Proposition 2.

Costly communication is useless when agents' preferences are negatively correlated. In equilibrium, any systematic reaction to the own message would be abused by the sender and cannot be optimal for the receiver. Hence, when $a < 1/2$ there is no equilibrium in which choices of one player respond to messages sent by the other player.

5.2 Two-sided communication protocol

Under two-sided communication, player 1 sends a message $m_1 \in \{0, 1\}$ to player 2 after he receives his private signal. Following this, player 2 returns a message $m_2 \in \{0, 1\}$ to player 1. In a final stage, both players simultaneously decide on the values of x_1 and x_2. The delay is $d = 2$. Is there an equilibrium with truthtelling and identical actions? Knowing the correct signals, players with mixed signals agree what to do when the correlation of individual states is sufficiently strong and when the signals are of sufficiently poor quality. However, when such an equilibrium exists, there is no value added with respect to the one-way communication equilibrium from Proposition 2. In this case, one-sided communication strictly dominates two-sided communication because it generates a smaller delay.

5.3 Contractual protocol

In the setup of section 2, a direct Bayesian mechanism would ask both players for simultaneous and independent messages and assign a pair of actions (x_1, x_2) to those announcements. In the present framework with delayed information processing, I assume that a third party is needed to collect verifiable messages (in two periods) and to subsequently inform the players what to do (in a third period). This mechanism has a total delay of

$d = 3$.[5] Deviations are verified and punished if one of the agents asks for a verification. However, no such extra delay arises along the equilibrium path.[6]

For $\alpha \leq \bar{\alpha}(a, p)$ the surplus-maximizing solution is to fix $x = \max\{\theta_1, \theta_2\}$. The corresponding direct revelation mechanism is incentive compatible if the cost α is not too large. The final decision is monotonous in the message, i.e. the probability that action 1 is chosen increases when message 1 is sent.

5.4 Strict rule

A special case of a contractual protocol is a strict rule. This protocol fixes actions $x_1 = x_2 = 1$ and it does not include any message stage. All that is required is the possible verification of the two actions. Again, verification only takes place when one agent complains about the outcome. With a sufficient punishment, verification does not take place along the equilibrium path and the total delay is zero.

6 Optimal protocol

6.1 Scope for communication with intermediate information

The optimal choice of the decision protocol depends on several dimensions of the decision problem: the correlation of preferences, the quality of the signals, the cost of inappropriate inactivity, and the costs of delay and verification. Similar to Grossman and Hart (1986) I do not present a full characterization of the optimal solution and instead highlight some important boundary solutions. It follows from the continuity of both players' payoff functions in a, α, and p that there exist environments around those parameter values to which the results extend (see also Figure 1).

Scope for communication only arises for an intermediate information quality because neither fully informed nor fully uninformed agents can gain from communication.

Proposition 3 *(Scope for communication) (i) For perfectly informative signals ($p = 1$)*

[5] Alternatively, one could assume that both players sequentially send verifiable signals to one another and then calculate the appropriate actions afterwards. The delay would only be 2.

[6] Realistic environments can be thought of in which - due to an enforcement - an extra delay may arise. This is the case when both agents do not perfectly control their actions. An equilibrium involves that a deviation occurs with positive probability - otherwise the out-of equilibrium action "verify" is not credible. Alternatively both agents could ex-ante commit to verify the x_i ex-post with a positive probability. If verification takes time then this involves an extra delay.

and fully uninformative signals ($p = 1/2$) any communication protocol is inferior to non-cooperative action (quiet protocol).

(ii) For intermediate values of p, there is a lower bound $\hat{a} < 1$ such that for all $a \geq \hat{a}$ there is a cost of delay $f(1) > 0$ for which one-sided communication is optimal.

Proof (i) In any communication protocol with perfect and with uninformative signals, individual decisions x_i are unaffected by the messages received from the other player. This is obvious for uninformative signals: in the unique equilibrium both agents choose $x_i = 1$ independently of the messages received. With perfect signals, agents decide truthfully instead and they do not respond to the messages of the second player. The other player's message does not carry additional information about the own state. Given the positive cost of delay, communication is strictly inferior to the quiet protocol.

(ii) We know from Proposition 2 (condition (15)) that one-sided communication works (in the sense that the sender sends truthful messages and the receiver uses them) and improves coordination (in the sense that the surplus maximizing outcome obtains) for $a = 1$ and some $p \in (1/2, 1)$. In the corresponding equilibrium the sender sends truthful messages and chooses action 1 and the receiver implements a social optimum. For all $p < 1$, one can always pick a sufficiently small cost of delay $f(1) > 0$ so that this communication protocol is superior to the quiet protocol. At $a = 1$ it is also superior to a mechanisms that has a delay of 3. The proposition follows from the continuity of equilibrium payoffs in a. *Q.E.D.*

Interestingly, communication only goes in one direction. The agent who sends the signal does not adjust his own action to his information. This consulting relationship arises endogenously.

The following Proposition characterizes the situations in which decentralization is optimal.

Proposition 4 *(The quiet protocol) (i) For $a = 1$ there is a value $\tilde{p} < 1$ such that for all $p \geq \tilde{p}$ the best institution is the quiet protocol.*

(ii)For $p = 1$ there is a value $\hat{a} < 1$ such that for all $a \geq \hat{a}$ the best institution is the quiet protocol.

(iii) For all a there is a value $\check{p} \in (0.5, 1)$ such that for all $p \leq \check{p}$ the best institution is the quiet protocol.

Proof: (i) and (ii) Consider $a = p = 1$. Under a quiet protocol, all equilibria maximize total expected surplus - excluding the cost of delay (note that there are many equilibria because agents can choose several surplus maximizing actions when signals are zero). This is strictly better than the payoff under a communication protocol. Parts (i) and (ii) follow from the continuity of all equilibrium payoffs in a and p.

(iii) First consider $p = 1/2$. There is a unique equilibrium in which both agents choose $x = 1$. This equilibrium is constrained efficient. The proposition follows from the continuity of all payoffs in p and from a strict inequality in the deviation conditions at $p = 1/2$. *Q.E.D.*

6.2 Foreseeable conflict and strict rules

When both agents' preferences are perfectly negatively correlated ($a = 0$) there is no need to communicate or to use a Bayesian mechanism. Under a quiet protocol, uninformed agents always decide to go ahead with the project, i.e. they fix $x_i = 1$. Informed agents do not play this equilibrium and act truthfully instead. in this case the outcome is always $x = 0$. Hence, from an ex-ante perspective, both agents benefit from a strict rule that fixes $x_1 = x_2 = 1$.

Proposition 5 *(Strict rule) For all p there is a value $\hat{a} \in \left(\bar{\alpha}^{-1}(\alpha, p), 1\right)$ such that for all $a \leq \hat{a}$ the best institution is a strict rule. If, in addition, $p > \check{p}$ then the strict rule is uniquely optimal.*

Proof: We know from (16) that, for $p \leq (1+\alpha)/(2+\alpha)$, there is an equilibrium of the quiet protocol in which both players choose $x = 1$ independently of their signal. This is also the second-best outcome when $\alpha > \bar{\alpha}(a, p)$. When instead $p > (1+\alpha)/(2+\alpha)$, one player may block decision 1 under the quiet protocol. For all $a \leq \bar{\alpha}^{-1}(\alpha, p)$ this outcome is inefficient. This inefficiency can be overcome by a strict rule. A mechanism leads to the same state contingent decision but yields an extra delay.

At $a = \bar{\alpha}^{-1}(\alpha, p)$ the strict rule and a Bayesian mechanism yield identical payoffs $E\left(u_1(x, s_1) + u_2(x, s_2)\right)$ to both players. The fact that the boundary value $\hat{a}$ satisfies $\hat{a} > \bar{\alpha}^{-1}(\alpha, p)$ follows from the continuity of all equilibrium payoffs in α, a, and p and from the fact that communication protocols generate an extra delay with positive cost. *Q.E.D.*

Strict rules do not react to new information. Such inflexible rules can sometimes be found in practice. One example in the context of international relations is the norm of non-intervention which guarantees state sovereignty in internal matters (United Nations, 1981). The rule which plays a major role in the UN charter is problematic in circumstances under which the international community may unanimously wish an intervention. However, in most of the relevant historical examples some major countries opposed an intervention while some other countries favored it. In such a situation there may be some rationale for an inflexible and cost-saving rule.

6.3 Intermediate conflict: Bayesian mechanisms

So far we have seen that informed agents with opposing interests choose simple rules while agents with similar preferences either act non-cooperatively or communicate. Is there scope for contractual protocols that replicate Bayesian mechanisms in between? In order to answer this question, I first compare the payoff under a mechanism with the one under a quiet protocol. The expected payoff (excluding the cost of delay) under a mechanism is given by the following expression.

$$\begin{aligned} E\left(u\left(x,s_i\right)\right) &= \\ & prob\left(s_i=1,\theta_j=1,\theta_i=0\right)\cdot 1 \\ & +prob\left(s_i=0,\theta_j=0,\theta_i=0\right)\cdot 1 \\ & +prob\left(s_i=1,\theta_j=0,\theta_i=0\right)\cdot(-\alpha) \\ & +prob\left(s_i=0,\theta_j=1,\theta_i=0\right)\cdot 0 \\ & +prob\left(s_i=1,\theta_j=1,\theta_i=1\right)\cdot 1 \\ & +prob\left(s_i=0,\theta_j=0,\theta_i=1\right)\cdot 0 \\ & +prob\left(s_i=1,\theta_j=0,\theta_i=1\right)\cdot 1 \\ & +prob\left(s_i=0,\theta_j=1,\theta_i=1\right)\cdot 0 \end{aligned} \tag{19}$$

The expected payoff difference with respect to a truthtelling equilibrium of the quiet protocol is:

$$\begin{aligned} \Delta \quad & E\left(u\left(x,s_i\right)\right)= \\ & prob\left(s_i=1,\theta_j=1,\theta_i=0\right)\cdot(1+\alpha)+prob\left(s_i=0,\theta_j=0,\theta_i=0\right)\cdot 0 \\ & +prob\left(s_i=1,\theta_j=0,\theta_i=0\right)\cdot 0+prob\left(s_i=0,\theta_j=1,\theta_i=0\right)\cdot(-1) \\ & +prob\left(s_i=1,\theta_j=1,\theta_i=1\right)\cdot 0+prob\left(s_i=0,\theta_j=0,\theta_i=1\right)\cdot(-1) \\ & +prob\left(s_i=1,\theta_j=0,\theta_i=1\right)\cdot(1+\alpha)+prob\left(s_i=0,\theta_j=1,\theta_i=1\right)\cdot 0. \end{aligned} \tag{20}$$

Taking into account the cost of delay $f\left(3\right)$, the mechanism is strictly superior if:

$$\begin{aligned} & \left(prob\left(s_i=1,\theta_j=1,\theta_i=0\right)+prob\left(s_i=1,\theta_j=0,\theta_i=1\right)\right)\cdot(1+\alpha) \\ > \; & prob\left(s_i=0,\theta_j=1,\theta_i=0\right)+prob\left(s_i=0,\theta_j=0,\theta_i=1\right)+f\left(3\right). \end{aligned} \tag{21}$$

$$\Leftrightarrow \left(\frac{1}{2}\left(\left(1-p\right)\left(ap+\left(1-a\right)\left(1-p\right)\right)\right)+\frac{1}{2}\left(p\left(\left(1-a\right)p+a\left(1-p\right)\right)\right)\right)\cdot\left(1+\alpha\right) \tag{22}$$

$$> \frac{1}{2}\left(p\left(\left(1-a\right)p+a\left(1-p\right)\right)\right)+\frac{1}{2}\left(\left(1-p\right)\left(ap+\left(1-a\right)\left(1-p\right)\right)\right)+f\left(3\right).$$

$$\Leftrightarrow \alpha > \frac{f\left(3\right)}{\left(2a-1\right)\left(p-p^{2}\right)+\frac{1-a}{2}}. \tag{23}$$

The derivative of the RHS with respect to a is $-\left(2p-1\right)^{2}<0$. Hence, a larger value of a makes the mechanism less attractive.

Comparing the mechanism to a strict rule we find that the advantage of the mechanism increases with the correlation parameter a because it becomes more likely that both players simultaneously prefer the outcome $x=0$. The Bayesian mechanism is chosen when $f(3)$ is small enough. Summarizing the previous results one can state the following Proposition.

Proposition 6 *(Bayesian mechanisms) For $p=1$ and a sufficiently low cost of delay $f(3)$ there is a nonempty interval $[\underline{a},\bar{a}]$ such that (i) in the interior of $[\underline{a},\bar{a}]\subset(0,1)$ a Bayesian mechanism is the unique best institution (ii) below $\underline{a}$, a strict rule is uniquely optimal and (iii) above $\bar{a}$ protocols with or without communication are optimal. The interval extends in both directions as $f(3)$ decreases.*

Proof For $p=1$ both agents choose a truthful action under any protocol without enforcement. The mechanism yields a higher sum of payoffs $E\left(u_{1}\left(x,s_{1}\right)+u_{2}\left(x,s_{2}\right)\right)$ for any $a<1$, the difference decreases with a. For a sufficiently small cost $f(3)$ the mechanism is socially preferred to the quiet protocol (condition 23). The lower bound on a is determined in comparison to the strict rule. The welfare gain of the mechanism decreases in a, it is zero at $a=0$. *Q.E.D.*

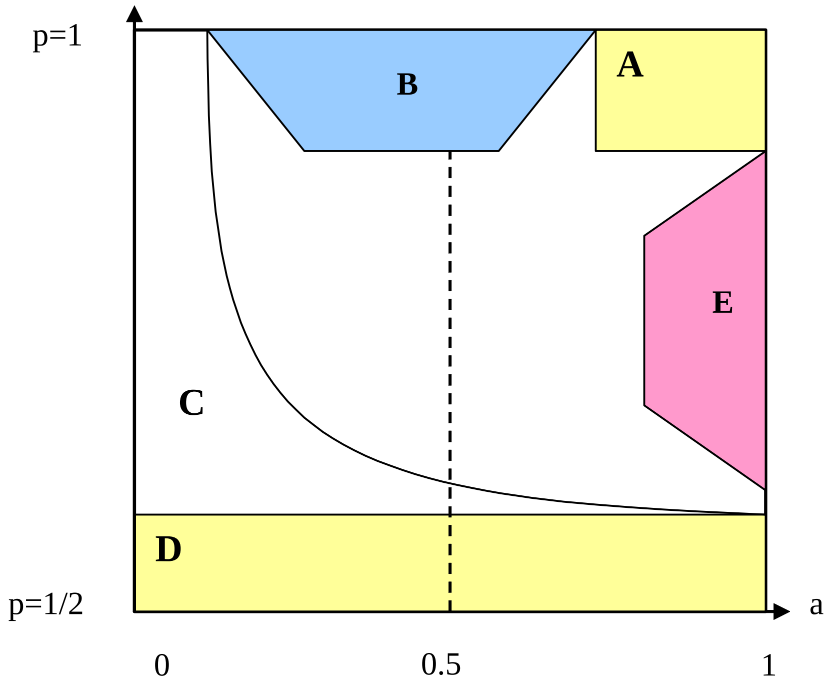


Figure 2. Main results. A quiet protocol is optimal in areas A and D. A strict rule is chosen in area C, the Bayesian mechanism in area B, and one sided communication in area E.

7 Information quality, conflict and delay

One of the fundamental assumptions underlying the revelation principle is that conflict-resolution in a centralized mechanism is costless. In the present paper, I instead assumed that communication is time consuming and therefore costly. Different communication protocols emerged as optimal depending on a number of key parameters.

The main results of this paper are summarized in Figure 1. One key parameter is the likelihood of a conflict of interest among the agents, $(1-a)$. A mechanism that makes use of verifiable signals of both players is superior to decentralized and immediate action only if the correlation of agents' preferences is sufficiently small and if agents' information is sufficiently good (area B). When preferences are highly correlated, communication functions well and outperforms the mechanism on the dimension of delay (area E). If, in addition, information quality is very good neither a Bayesian mechanism nor communication are needed (area A). The same holds when the quality of information is very low (area D). In this case the gain from more informed decision making is too small to justify the extra delay. A negative correlation demands either a strict rule or decentralized and immediate activity (area C or D).

A surprising result of the present analysis is that centralization - in form of binding agreements that include sanctions for certain actions - is more desirable when agent's preferences differ. This is at odds with the conventional wisdom according to which only similar individuals or states should be part of an institution or a club. The conventional wisdom seems to rely on a different, broader view of decision procedures, one that encompasses participants' willingness to support and commit to the collective decision procedure itself.

Interestingly, there is no monotonous relationship between the probability of conflict $(1-a)$ and delay. While, for high enough values of p, conflict $(a = 0)$ and aligned interests $(a = 1)$ both go along with fast decision procedures, intermediate values of the correlation parameter are associated with more time consuming Bayesian mechanisms (area B). Similarly, informedness and delay are not monotonously related, with intermediate degrees of informedness leading to a higher delay in collective decision making (area E).

The present paper extends previous work that studies the role of incentives in organizations with costly delay. I studied a common values case with imperfectly correlated preferences and a superadditive decision technology. The study of other environments such as auctions or committee voting along similar lines may help to better understand the role of time constraints in other areas of economic design. It is likely that a similar trade-off between decision delay and efficiency plays a role in those setups.

Table 1: Timing

Period	Quiet protocol	One-way communication	Two-way communication	Bayesian mechanism	Rule
0	Information	Information	Information	Information	Information
0	Choice of (x_1, x_2)				Choice of (x_1, x_2)
1		Player 1 sends m_1; Choice of (x_1, x_2)	Player 1 sends m_1	Player 1 sends m_1 to planner.	
2			Player 2 sends m_2; Choice of (x_1, x_2)	Player 2 sends m_2 to planner.	
3				Planner sends x to both players; Choice of (x_1, x_2)	

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