Decision–Making and Implementation in Teams*

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Abstract

We use a mechanism design approach to study a team whose members choose a joint project and exert individual efforts to execute it. Members have private information about the qualities of alternative projects. We find that information sharing is potentially obstructed by the trade–off between *adaptation* and *motivation*, and determine the conditions under which first best project and effort choices are implementable. We find that these conditions can become weaker as the team grows in size, which contrasts with the common argument (based on free–riding) that efficiency is harder to achieve in larger teams. We also characterize the optimal (second best) mechanism. Depending on the relative importance of motivation and adaptation, this requires distorting effort, committing to an ex post inefficient project choice or failing to induce the revelation of information.

JEL *classification*: D02, D23, L2 .
Keywords: Teams, adaptation, motivation, decision–making, incentives.

*We thank Ricardo Alonso, Antonio Cabrales, Wouter Dessein, Luis Garicano, Thomas Kittsteiner, Kristof Madarasz, Eiichi Miyagawa, Ignacio Palacios-Huerta and participants at various seminars and conferences for valuable discussions and suggestions. The second author acknowledges financial support by the Spanish Ministry of Education grants RYC-200 -033 1 and ECO-200 -02 3 .

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"The members of an organization may be seen as providing two kinds of services: they supply inputs for production and process information for decision–making." Bengt Holmstrom (1982)

1 Introduction

This paper examines joint decision–making in teams where members exert individual efforts to execute an agreed decision. Such situations are ubiquitous. For example, members of government cabinets choose policy and then spend political capital ensuring its success. In joint ventures firms determine the characteristics of their common product and invest into its development and marketing. Parents agree on an upbringing approach and then struggle to impose it on their children. Within organizations the prevalence of self–managed teams is reportedly growing over time (Manz and Sims, 1993).

In the above examples execution efforts are arguably non–contractible and it is well known that moral hazard leads to free–riding. However, when team members have a common interest in choosing the best project, one might think that they should be able to share information efficiently and reach the best possible decision. And yet, teams with largely aligned incentives often fail to communicate valuable information and end up with sub–optimal decisions [1].

Our starting point is the observation that the desire to keep 'morale' high at the execution stage may hinder information–sharing and lead to sub–optimal choices at the decision–making stage. Consider for instance two co–authors choosing between two alternative scientific projects. Suppose that ex ante both authors expect project A to be more likely to be successful. Further suppose that one author receives information, e.g. feedback in a seminar, indicating that project B is more likely to be successful than A but less likely than project A was expected to be ex ante. In this situation the author faces a trade–off. By concealing the news and working on project A, he can maintain his co–author's high level of motivation, based on the optimistic (but incorrect) prior expectations. Instead, by sharing his information, the team can adapt to the news by adopting

[1] A classic example of a cohesive team making wrong–headed decisions is the Kennedy administration during the Bay of Pigs invasion (Janis, 1 2). Similar behavior has been documented using firm (Perlow, 2003) and laboratory studies (Stasser and Titus, 1 5, Gigone and Hastie, 1 3).

the more promising project B.

This trade–off between *motivation* and *adaptation* has long been recognized by scholars of group decision–making as critical to the understanding of why information questioning the prevailing consensus frequently remains unshared (Perlow and Williams 2003). It is often most dramatic in military settings, where maintaining morale is key. For instance, President George W. Bush admitted that, while privately aware throughout 2006 of the increasing likelihood of failure in Iraq, he continued to produce upbeat public assessments, thereby easing public pressure to correct his existing strategy, in order to avoid hurting troops' morale[2]. The view that an initially preferred alternative represents a threat to the frank exchange of information also resonates with lessons from social psychology (Stasser, 1999) and political science (T'Hart, 1990), as well as with views expressed by practitioners[3].

To examine the above trade–off formally, Section 2 develops a model of team production in which two team members work on one out of two feasible projects. A project's likelihood of success depends positively on the team members' unobservable execution efforts and the project's state dependent 'quality'. Decision–making and efforts are complementary in that returns to effort are increasing in the project's quality. Ex ante one project is expected to be better than the other, but team members may receive private information about the projects' qualities. In the first best benchmark, team members select the project which has the highest quality (given their aggregate information) and exert efficient levels of effort.

We use a mechanism design approach to determine the conditions under which the first best benchmark is implementable. Under the assumptions of limited liability and budget balance, Section 3 shows that the benchmark fails to be implementable when the value of adapting the decision to the available information is low relative to the value of motivating one's colleague. We find that the mechanism implementing the benchmark

[2]Interview with Martha Raddat, ABC News on April 11, 200 , transcript available at http://abcnews.go.com/Politics/story?id=463421 &page=1.

[3]Alfred P. Sloan once terminated a GM senior executive meeting with the following statement: "Gentlemen, I take it we are all in complete agreement on the decision here. Then I propose we postpone further discussion on this matter until our next meeting to give ourselves time to develop disagreement, and perhaps gain some understanding of what the decision is all about." Taken from http://www.economist.com/businessfinance/management/displaystory.cfm?story_id=1304 0 .

in the widest range of parameters rewards the (unilateral) disclosure of information in conflict with the team's initially preferred alternative. Thus, while it has been suggested that those willing to challenge the status quo should be protected from retaliation by other team members (Janis, 1982, T'Hart, 1990), we argue that they should be actively rewarded.

Section 4 characterizes the optimal collusion-proof mechanism when the benchmark cannot be implemented. In a first step we characterize the optimal revelation mechanism, i.e. the one which induces team members to reveal their information at the lowest cost to their overall surplus. In our setup there are two ways that agents can be discouraged from concealing their information: by inducing suboptimal effort levels upon concealment and by inducing an ex post suboptimal project choice. We find that the first approach is always cheaper in terms of foregone surplus, but not always collusion-proof. Intuitively, when the value of motivation is high, it becomes more attractive for the agents to undo the mechanism-induced effort distortion through the use of side-contracts. Thus, for low values of motivation, the optimal revelation mechanism induces sub–optimal effort choices while for high values of motivation, project selection differs from the first best.

Due to the co-existence of asymmetric information and moral hazard, the revelation principle fails to hold in our model. Since the decision cannot be adapted to the agents' private information when such information is concealed, a non-revealing mechanism will be more attractive when the value of adaptation is low relative to the value of motivation. We find that a non-revealing mechanism, which selects the initially preferred project regardless of the agents' information, is indeed optimal when information has little value. Depending on the relative importance of motivation and adaptation, the second best mechanism therefore requires distorting effort, committing to an ex post inefficient project choice or failing to induce the revelation of information.

We extend our model in Section 5 to include an arbitrary number of team members. In larger teams, the value of increasing colleagues' motivation is obviously higher. Despite this, we find that in larger teams it can be easier to induce members to disclose their private information. The reason is that larger teams provide a richer set of tools to reward the disclosure of unpopular evidence, and this effect can dominate the mechanical motivation effect. Therefore, larger teams do not only have better information but they

may also use their information better. In Section 5 we also introduce heterogeneity in our setting, and find that members who are less productive or more likely to be informed have a stronger incentive to conceal information. The optimal mechanism must therefore account for this asymmetry by giving these members a smaller stake in the initially preferred project.

Our basic model assumes that (a) information is verifiable and either perfect or non-existent, (b) efforts are independent inputs of team production and (c) messages to the mechanisms designers are public information. In Section 6 we show that the benchmark fails to be implementable even when we relax these assumptions. Section 7 concludes.

Related literature. This paper is related to and draws upon a number of literatures. Attempts to explain why groups often fail to aggregate information efficiently have largely focused on the importance of conflicting preferences (Li, Rosen, and Suen, 2001; Dessein 2007), the existence of career concerns (Ottaviani and Sorensen, 2001; Levy, 2007; Visser and Swank, 2007) and the distortions generated by voting rules (Feddersen and Pesendorfer, 1998). In our model, team members share the common goal of selecting the best project and voting rules and career concerns play no role. Our focus is instead on the trade–off between adaptation and motivation. To the best of our knowledge, this emphasis is novel to the literature on group decision–making and hence complementary to existing work. Persico (2004) and Gerardi and Yariv (2007) also combine decision–making and incentives but their focus is on incentives to acquire information rather than on incentives to implement a common decision.

The trade–off between adaptation and motivation is at the core of a few recent papers, but mostly in settings where decision–making and implementation lie at different levels of the organizational hierarchy (Zabojnik, 2002; Blanes i Vidal and Möller, 2007; Landier et al., 2009).[4] An exception in this respect is Banal-Estañol and Seldeslachts (2009), who study merger decisions and show that the incentive to free ride on a potential partner's post–merger efforts may hinder decision–making at the pre–merger stage. We differ from

[4] A related literature studies organizations where di erent divisions need to be encouraged to exert e ort and to take decisions that are both coordinated and adapted to local circumstances (Dessein et al., 200 ; Rantakari, 200). We assume a common project choice, and so coordination is not an issue.

them in that we use a general team framework and a mechanism design approach.

The finding that the concealment of information about some underlying productivity parameter can be optimal in the presence of moral hazard is related to the work by Teoh (1997) and Hermalin (1998). Teoh studies a social planner restricting access to information at an ex ante stage, while Hermalin considers a setting where one of the members holds private information and is able to signal high productivity via the exertion of high effort. These models differ from ours in that they focus on settings where the choice between alternative projects is absent.

Our result that commitment to an ex post inefficient decision can improve the communication of information is related to Gerardi and Yariv (2007) who show that such commitment can induce a committee to acquire costly information. In our model commitment is achieved by delegating decision–making to an outsider, an argument that is reminiscent of Holmstrom's (1982) well known budget breaking solution and Dessein's (2007) finding that decision making can be improved through "leadership".

Finally, a very different notion of group morale is employed by Benabou's (2008) model of collective delusion, where agents decide whether to engage in "reality denial" about an exogenously given productivity parameter.

2 The model

We consider a team with two homogeneous members $i = 1, 2$.[5] The team's purpose is to choose and implement one out of two mutually exclusive projects $x \in X \equiv \{A, B\}$. A project may be either successful or unsuccessful. If a project is successful it creates a revenue normalized to $R = 1$, otherwise its revenue is $R = 0$. Project x's likelihood of success depends on the team members' implementation efforts e_i and a state variable $y \in Y \equiv \{A, B\}$. We assume that it takes the following form:

$$Pr(R = 1|x, y, e_1, e_2) = p_{xy} \cdot f(e_1, e_2). \tag{1}$$

The parameter $p_{xy} \geq 0$ denotes project x's state dependent "quality". We denote one project as better (worse) than the other if it has a higher (lower) quality. The assumption

[5]The issues of team size and heterogeneity are the subject of Section 5.

that project choice and effort are complementary inputs of production is standard in the literature on organizations (for empirical support see Rosen, 1982). We assume that information is valuable, i.e. $p_{AA} > p_{BA}$ and $p_{BB} > p_{AB}$. If one of these inequalities was reversed, one project would be better independently of the state. We give sense to the notion that it is important to adapt the project choice to the state of the world by assuming that project x has a higher quality if it matches the state y, i.e. $p_{AA} > p_{AB}$ and $p_{BB} > p_{BA}$.

Team members have a common prior about the state y. To simplify the exposition we consider the case where both states are equally likely. Our results remain qualitatively unchanged when this assumption is relaxed. Without loss of generality we choose A to be the project that is expected to be better ex ante, i.e.

$$\bar{p}_A = \frac{1}{2}(p_{AA} + p_{AB}) > \frac{1}{2}(p_{BA} + p_{BB}) = \bar{p}_B. \tag{2}$$

Team members may hold private information about the state. In particular, we assume that member i observes verifiable evidence for y with probability $q \in (0, 1)$ while with probability $1 - q$ he observes nothing.[6]

Team member i chooses an effort level $e_i \in \{0, 1\}$ incurring the cost $C(e_i)$ with $C(0) = 0 < c = C(1)$. Efforts are unobservable and non–contractible. Since team members are identical and efforts are binary, the production function f can take three values. Indexing f by the number of team members who exert effort, these values are denoted as f_0, f_1, and f_2 respectively. Effort increases the project's likelihood of success, i.e. $0 < f_0 < f_1 < f_2$. To simplify the analysis, we assume that efforts are independent, i.e. $f_2 - f_1 = f_1 - f_0 \equiv \Delta f$.[7]

Note that for high Δf, team members can be induced to exert effort on both projects, while for low Δf, effort cannot be induced for any of the two. In both cases, project choice would have no influence on the team members' incentive to provide effort. We focus on the non–tivial case where effort can be induced for one project but not for the other. As we will see, a trade–off between adaptation and motivation exists, when team members

[6]The assumption that private information is either perfect or non–existent simplifies Bayesian updating in models of joint decision–making and is shared by Visser and Swank (2007). See Section 6 for the case of unverifiable and imperfect signals.

[7]In Section 6 we show that our main result extends to the case where efforts are complementary.

are willing to provide effort on the initially favoured project A but not on project B. We capture this by restricting attention to the case where

$$\frac{2c}{\bar{p}_A} < \Delta f < \frac{c}{p_{BB}}. \tag{3}$$

The first inequality guarantees that, even when the identity of the best project is uncertain, both team members can be induced to exert effort on project A by receiving half of its revenue. The second inequality implies that a team member is not willing to exert effort on project B even when he knows that it is the best project and receives its entire revenue.

Finally, in order to simplify the exposition, we normalize by setting $p_{AA} = 1$ and $p_{BA} = 0$. Allowing these values to be general leaves our results qualitatively unchanged. We will discuss the problem in a two dimensional parameter space. The x-axis will measure the value of motivation Δf. The y-axis will measure the value of adaptation $\frac{p_{BB}}{p_{AB}}$. The trade–off between adaptation and motivation exists in the subset

$$T = \{(\Delta f, \frac{p_{BB}}{p_{AB}}) | \frac{2c}{\bar{p}_A} < \Delta f < \frac{c}{p_{BB}}, \frac{p_{BB}}{p_{AB}} > 1\} \tag{4}$$

of the parameter space. To guarantee that T is non–empty and that $Pr(R = 1) \leq 1$ for all $(\Delta f, \frac{p_{BB}}{p_{AB}}) \in T$ the following parametric restrictions are necessary and sufficient:[8]

$$f_0 < 1, \quad c < \frac{1 - f_0}{6}, \quad p_{AB} \in [\frac{2c}{1 - f_0}, \frac{1}{3}). \tag{5}$$

A mechanism design approach

We use a mechanism design approach to determine the team's optimal institution. For this purpose it is necessary to define some basic notions. Let $s_i \in \{A, B, \emptyset\}$ denote member i's private information or *type*. The set of possible types is then given by

$$S = \{(A, A), (A, \emptyset), (\emptyset, A), (\emptyset, \emptyset), (B, \emptyset), (\emptyset, B), (B, B)\}. \tag{6}$$

[8] $T \neq \emptyset$ if and only if $\Delta f^{min} \equiv \frac{2c}{\bar{p}_A} < \frac{c}{p_{AB}} \equiv \Delta f^{max} \Leftrightarrow p_{AB} < \frac{1}{3}$. $Pr(R = 1) \leq 1$ for all $(\Delta f, \frac{p_{BB}}{p_{AB}}) \in T$ if and only if $f_0 + 2\Delta f^{max} \leq 1 \Leftrightarrow f_0 < 1$ and $p_{AB} \geq \frac{2c}{1-f_0}$. $[\frac{2c}{1-f_0}, \frac{1}{3}) \neq \emptyset$ if and only if $c < \frac{1-f_0}{6}$.

A *project allocation* is a mapping $\hat{\sigma} : S \to X$ where $\hat{\sigma}(s_1, s_2)$ is the project allocated to a team that observed evidence (s_1, s_2). Similarly, an *effort allocation* is a mapping $\hat{e}_i : S \times X \to \{0, 1\}$ where $\hat{e}_i(s_1, s_2, x)$ is the effort allocated to member i in a team that observed evidence (s_1, s_2) and was allocated project x. The collection of project and effort allocations, $(\hat{\sigma}, \hat{e}_1, \hat{e}_2)$, will be simply denoted as an *allocation*.

In a mechanism, members send *messages* $m_i(s_i)$ conditional on their types. Since information is assumed to be verifiable evidence, message spaces are type–dependent. More specifically, type $s_i = y \in Y$ chooses $m_i \in M_i(y) = \{y, \emptyset\}$ whereas type $s_i = \emptyset$ can only issue $m_i \in M_i(\emptyset) = \{\emptyset\}$.[9] A *mechanism* (σ, w_1, w_2) consists of a project selection rule σ and compensation schemes w_1, w_2. A *project selection rule* is a mapping $\sigma : M_1 \times M_2 \to [0, 1]$ where $\sigma(m_1, m_2)$ is the probability with which project A is selected when members have issued the messages (m_1, m_2). A *compensation scheme* $w_i : M_1 \times M_2 \times X \times \{0, 1\} \to [0, 1]$ determines member i's compensation, $w_i(m_1, m_2, x, R)$, in dependence of the messages m_1, m_2, the selected project x and the realized revenue R. Implicit in the definition of a compensation scheme is the assumption that team members are protected by *limited liability*, i.e. $w_i \geq 0$. We also require *budget balance*, i.e. $w_1 + w_2 = R$.[10]

A mechanism (σ, w_1, w_2) induces a game defined by the following sequence of events. (1) Members observe information $(s_1, s_2) \in S$. (2) Members send messages $m_i(s_i) \in M_i(s_i)$ simultaneously. Messages are public, i.e. team members observe the message sent by their colleague.[11] (3) Project A is selected with probability $\sigma(m_1, m_2)$, otherwise project B is chosen. (4) Members choose unobservable efforts $e_i(s_i, m_1, m_2, x) \in \{0, 1\}$. (5) Revenue $R \in \{0, 1\}$ is realized and member i receives compensation $w_i(m_1, m_2, x, R) \in$

[9] While message spaces are typically part of the designer's choice, in the presence of verifiable information, the disclosure of evidence has to be seen as the members' inalienable action. Bull and Watson (200[illegible]) show that this restriction has no influence on the set of implementable allocations if type s_i can declare his type to be s_i' if and only if all of the evidence available to type s_i' is also available to type s_i. In our setting this condition is satisfied since type $s_i = y$ can declare to be type $s_i = \emptyset$ but not vice versa.

[10] While budget balance can be relaxed, limited liability is necessary for our results. With unlimited liability, the disclosure of information can be induced by the threat of sufficiently severe punishments. For a detailed discussion, see end of Section 3.

[11] The need to specify whether messages are public or private derives from the fact that team members condition their effort choices on their beliefs about the project's quality. When messages are private our main results remain valid since members can deduce all necessary information from their knowledge of the mechanism and the observation of the project choice. For details, see Section 6.

$[0, 1]$.

Following Levitt and Snyder (1997), we assume that team members have a zero reservation utility. Since $w_i \geq 0$ and $C(0) = 0$ this implies that participation is not an issue, neither at the ex ante nor at the interim stage. We also require the mechanism to be *interim collusion–proof*. In particular, after the project has been selected by the mechanism, and before team members exert effort, the compensation scheme (w_1, w_2) has to be such that no other compensation scheme (w_1', w_2') would be preferred by both team members. Otherwise team members would sign a side–contract rendering void the original agreement.[12]

The mechanism (σ, w_1, w_2) *implements* the allocation $(\hat{\sigma}, \hat{e}_1, \hat{e}_2)$ if the induced game has an equilibrium (m_1, m_2, e_1, e_2) such that:

1. $\sigma(m_1(s_1), m_2(s_2)) = 1$ for all $(s_1, s_2) \in S$ s.t. $\hat{\sigma}(s_1, s_2) = A$ and $\sigma(m_1(s_1), m_2(s_2)) = 0$ for all $(s_1, s_2) \in S$ s.t. $\hat{\sigma}(s_1, s_2) = B$.

2. $e_i(s_i, m_i(s_i), m_j(s_j), x) = \hat{e}_i(s_i, s_j, x)$ for all $(s_i, s_j) \in S$ and all $x \in X$.

An allocation $(\hat{\sigma}, \hat{e}_1, \hat{e}_2)$ is said to be *implementable* if there exists a mechanism that implements it.

In standard models of mechanism design under asymmetric information, the *revelation principle* guarantees that any allocation that is implementable can be implemented by a *revelation mechanism*, i.e. one for which truthtelling, $m_i(s_i) = s_i$, constitutes an equilibrium. Green and Laffont (1986) show that with type–dependent message spaces, the revelation principle remains valid when message spaces satisfy a so called *Nested Range Condition*. In our setting this condition is trivially satisfied. Nevertheless, in the present setup the revelation principle fails to hold due to the coexistence of asymmetric information and moral hazard. To see this note that any allocation requiring $\hat{e}_1(\emptyset, B, A) = 1$ cannot be implemented with a revelation mechanism since a team member cannot be induced to exert effort on project A when he knows that $y = B$. However, as we will see below, such an allocation is implementable with a mechanism in which members conceal their information by choosing $m_i(s_i) = \emptyset$.

[12] Collusion–proofness a ects the optimal (second best) mechanism but has no influence on the implementability of the benchmark. See Section 4 for details.

The first best benchmark

As a benchmark consider the case where all information is observed publicly, i.e. by both team members. Let us determine the allocation $(\hat{\sigma}^*, \hat{e}_1^*, \hat{e}_2^*)$ that maximizes the team members' aggregate surplus. For this purpose, let $S^y = \{(y,y),(y,\emptyset),(\emptyset,y)\}$ denote the event where the state $y \in \{A, B\}$ has been observed. $p_{AA} > p_{BA}$ implies that $\hat{\sigma}^*(s_1,s_2) = A$ for all $(s_1,s_2) \in S^A$. Similarly $p_{BB} > p_{AB}$ implies that $\hat{\sigma}^*(s_1,s_2) = B$ for all $(s_1,s_2) \in S^B$. Finally, since project A is expected to have a higher quality ex ante, i.e. $\bar{p}_A > \bar{p}_B$, it has to hold that $\hat{\sigma}^*(\emptyset,\emptyset) = A$. In summary, the efficient project allocation requires project A to become selected unless evidence in favor of project B has been observed.

With respect to the efficient allocation of efforts our assumptions imply that $p_{BB}\Delta f < c < \bar{p}_A\Delta f$. Hence effort on project B should be $\hat{e}_i^*(s_1,s_2,B) = 0$ independently of the team's observation. In contrast, effort on project A should be $\hat{e}_i^*(s_1,s_2,A) = 1$ unless the team has observed evidence in favor of project B.

It is a well established fact that team production may suffer from underprovision of effort. Indeed, for $\frac{2c}{\bar{p}_A} > \Delta f > \frac{c}{\bar{p}_A}$, efficiency would require both team members to exert effort, but only one team member could be induced to do so by receiving a sufficiently high share of revenue. We focus on the case where $\Delta f > \frac{2c}{\bar{p}_A}$ in order to study the trade–off between adaptation and motivation in a setting where it represents the *unique* source of inefficiency. This means that in the symmetric information benchmark, surplus is equal to its first best value given by

$$W^* = \frac{1}{2}(f_2 - 2c) + \frac{1}{2}[(1-q)^2(p_{AB}f_2 - 2c) + (1-(1-q)^2)p_{BB}f_0]. \tag{7}$$

In the next section we determine the conditions under which this value can be achieved in the presence of asymmetric information.

3 Implementability of the first best

Consider a mechanism that selects the project according to the first best rule σ^* defined by $\sigma^*(m_1,m_2) = 1$ for all $(m_1,m_2) \in S^A \cup \{(\emptyset,\emptyset)\}$ and $\sigma^*(m_1,m_2) = 0$ for all $(m_1,m_2) \in S^B$. We need to find compensation schemes w_1, w_2, such that the benchmark allocation $(\hat{\sigma}^*, \hat{e}_1^*, \hat{e}_2^*)$ is implemented by the mechanism (σ^*, w_1, w_2). Since budget balance and

limited liability imply that $w_i(m_1, m_2, x, 0) = 0$ we can simplify notation by defining $w_i^x(m_1, m_2) \equiv w_i(m_1, m_2, x, 1)$.

The first best allocation makes project choice contingent on the team members' observations when $y = B$. Hence the mechanism (σ^*, w_1, w_2) has to induce the disclosure of evidence for B. Disclosure of evidence for B is optimal for member 1 if and only if

$$qp_{BB}f_0 w_1^B(B,B) + (1-q)p_{BB}f_0 w_1^B(B,\emptyset) \geq qp_{BB}f_0 w_1^B(\emptyset,B) + (1-q)p_{AB}f_1 w_1^A(\emptyset,\emptyset). \quad (8)$$

An analog condition needs to be satisfied by w_2. Moreover, since the benchmark requires member i to exert effort on project A, w_i has to satisfy the following incentive constraints:

$$\bar{p}_A \Delta f w_i^A(\emptyset,\emptyset) > c \quad \text{and} \quad p_{AA}\Delta f w_i^A(m_1,m_2) > c \quad \text{for all} \quad (m_1,m_2) \in S^A. \quad (9)$$

Condition (8) can be relaxed by increasing $w_1^B(B,B)$ or by decreasing $w_1^A(\emptyset,\emptyset)$. However, due to budget balance, such changes make the analog condition for w_2 harder to satisfy. Since team members are identical and implementability requires both conditions to be satisfied, it is therefore optimal to set $w_1^B(B,B) = w_1^A(\emptyset,\emptyset) = \frac{1}{2}$. For the same reason $w_1^B(B,\emptyset) = w_2^B(\emptyset,B)$ and $w_1^B(\emptyset,B) = w_2^B(B,\emptyset)$. The conditions that guarantee the disclosure of evidence for B thus become:

$$w_1^B(B,\emptyset) = w_2^B(\emptyset,B) \geq \frac{1}{2}[q + (1-q)\frac{p_{AB}}{p_{BB}}\frac{f_1}{f_0}]. \quad (10)$$

The incentive constraints in (9) are satisfied by setting $w_i^A(m_1,m_2) = \frac{1}{2}$ in all remaining cases. Note that the lower bound in (10) is strictly larger than $\frac{1}{2}$ whenever $p_{AB}f_1 > p_{BB}f_0$, i.e. when motivation is favoured over adaptation. The implementability of the benchmark then requires a reward for the unilateral revelation of evidence for B. Since rewards cannot exceed the team's revenue, the benchmark is implementable if and only if

$$1 \geq \frac{1}{2}[q + (1-q)\frac{p_{AB}}{p_{BB}}\frac{f_1}{f_0}] \quad \Leftrightarrow \quad \frac{p_{BB}}{p_{AB}} \geq \frac{1-q}{2-q}(1 + \frac{\Delta f}{f_0}) \equiv t^*(\Delta f). \quad (11)$$

In the Appendix we prove the following:

Proposition 1 *The set of parameters for which the first best benchmark fails to be implementable is given by* $T^0 = \{(\Delta f, \frac{p_{BB}}{p_{AB}}) \in T | \frac{p_{BB}}{p_{AB}} < t^*(\Delta f)\}$. $T^0 \neq \emptyset$ *if and only if*

$p_{AB} < \frac{c}{f_0}$ *and* $q < q^* \equiv 1 - \frac{p_{AB} f_0}{c} \in (0,1)$. *For* $(\Delta f, \frac{p_{BB}}{p_{AB}}) \in T^* \equiv T - T^0$ *the benchmark is implementable by a mechanism that can require a reward for the unilateral disclosure of evidence for* B, $w_1^B(B, \emptyset) = w_2^B(\emptyset, B) \geq \frac{1}{2}[q + (1-q)\frac{p_{AB}(f_0+\Delta f)}{p_{BB} f_0}]$, *and equal revenue sharing,* $w_i = \frac{1}{2}$, *in all other cases.*

Figure 1 depicts the case where the conditions of Proposition 1 are satisfied.[13] The

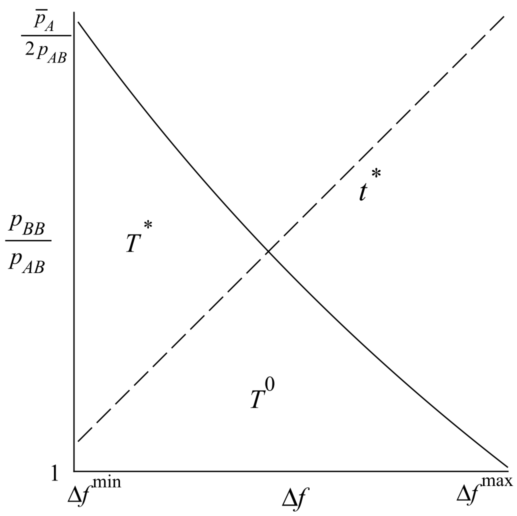


Figure 1: Implementability of the Benchmark: The benchmark is implementable in T^* but fails to be implementable in T^0. $\Delta f^{min} = \frac{2c}{\bar{p}_A}$, $\Delta f^{max} = \frac{c}{p_{AB}}$. Solid line: $\frac{p_{BB}}{p_{AB}} = \frac{c}{p_{AB}\Delta f}$.

parameter space T, where a trade-off between adaptation and motivation exists, is the area below the solid line. The benchmark is implementable in T^* but fails to be implementable below the dashed line in the area denoted as T^0.

The intuition for this result is as follows. When team members favour motivation over adaptation, i.e. $p_{AB} f_1 > p_{BB} f_0$, then the reward in (10) is necessary to induce the disclosure of B. A decrease in q leads to an increase in the necessary reward since team members are more tempted to raise their colleagues' motivation via the concealment of evidence. When q becomes sufficiently small, the necessary reward will exceed the upper

[13] Given the parametric restrictions on p_{AB} contained in (5), the requirement $p_{AB} < \frac{c}{f_0}$ of Proposition 1 can be satisfied if and only if $\frac{2c}{1-f_0} < \frac{c}{f_0} \Leftrightarrow f_0 < \frac{1}{3}$.

limit, 1, which is implied by budget balance and limited liability. To understand the condition on p_{AB}, note that the necessary reward is at its maximum when the value of motivation is maximal, $\Delta f \to \Delta f^{max}$, the value of adaptation is minimal $\frac{p_{BB}}{p_{AB}} \to 1$, and $q \to 0$. The maximum necessary reward is $\frac{1}{2} + \frac{c}{2p_{AB}f_0}$ and exceeds the maximum feasible reward, 1, if and only if $p_{AB} < \frac{c}{f_0}$.

In this section we have shown that the benchmark is implementable in T^* by use of a mechanism that rewards the (unilateral) disclosure of evidence in conflict with the team's initially preferred alternative. In the next section we determine the optimal mechanism for the remaining case where the benchmark fails to be implementable. However, before doing so, we discuss the importance of the budget balance and limited liability on the implementability of the benchmark.

The role of budget balance

Suppose we relax the requirement that the team's budget be balanced by letting $w_1+w_2 \leq R$. In other words, we assume that the mechanism designer can commit to "burn money". Since we maintain limited liability, relaxing budget balance only affects the case where $R = 1$.

We now ask whether, in the absence of budget balance, the mechanism designer can implement the benchmark in a larger range of the parameter space. It follows from (8) that the mechanism designer might want to "burn money" only in the case where no information is disclosed and project A is chosen. However, in this case, w_i cannot be reduced below $\frac{c}{\bar{p}_A \Delta f}$ in order to guarantee the provision of effort. We can therefore substitute $w_1^A(\emptyset, \emptyset) = \frac{c}{\bar{p}_A \Delta f}$ in (8) to obtain the minimum value of $\frac{p_{BB}}{p_{AB}}$ compatible with the implementability of the benchmark. Without budget balance the benchmark is implementable if and only if

$$\frac{p_{BB}}{p_{AB}} \geq \frac{1-q}{2-q}\left(\frac{1}{\Delta f} + \frac{1}{f_0}\right)\Delta f^{min}. \tag{12}$$

This threshold is decreasing in Δf and becomes identical to t^* for $\Delta f = \Delta f^{min}$. It follows that the benchmark fails to be implementable in a non–empty subset of T if and only if

$t^*(\Delta f^{min}) > 1$ which is equivalent to

$$\frac{\bar{p}_A}{2} < \frac{c}{f_0} \quad \text{and} \quad q < 1 - \frac{\bar{p}_A f_0}{2c}. \tag{13}$$

Since $\bar{p}_A > 2p_{AB}$ these conditions are stronger than the corresponding conditions under budget balance specified in Proposition 1.[14] Relaxing budget balance therefore enlargens the parameter set for which the benchmark is implementable. However, even in the absence of budget balance, the benchmark fails to be implementable for some parameter values.

The role of limited liability

Suppose we relax limited liability by assuming that $w_i \geq -L$ where $L > 0$. Then the mechanism designer can punish the unilateral non–disclosure of B and increase the reward for the unilateral disclosure of B by choosing $w_1(B, \emptyset, B, 1) = 1 + L$ and $w_1(\emptyset, B, B, 1) = -L$. Moreover, he can reward the unilateral disclosure of B not only when the project has been successful but also in the absence of a success by setting $w_1(B, \emptyset, B, 0) = L$ and $w_1(\emptyset, B, B, 0) = -L$. Substitution of these compensations into (8) shows that the benchmark is implementable if and only if

$$\frac{p_{BB}}{p_{AB}} \geq \frac{1-q}{2-q}(1 + \frac{\Delta f}{f_0}) - \frac{2L}{(2-q)p_{AB} f_0} \equiv t_L^*(\Delta f). \tag{14}$$

An increase in L leads to a (parallel) downward shift of the implementability threshold $t_L^*(\Delta f)$. Following the argument of the proof of Proposition 1 one can show that the benchmark fails to be implementable in a non–empty subset of T if and only if $p_{AB} < \frac{c-2L}{f_0}$ and $q < 1 - \frac{p_{AB} f_0 + 2L}{c}$. When L is sufficiently large, these conditions can no longer be satisfied. This shows that limited liability is essential for our result. When the unilateral non–disclosure of B can be punished and the potential punishment is sufficiently large then the first best benchmark becomes implementable in the entire parameter space.

[14] Given the parametric restrictions on p_{AB} contained in (5), $\frac{\bar{p}_A}{2} < \frac{c}{f_0} \Leftrightarrow p_{AB} < \frac{4c}{f_0} - 1$ is possible if and only if $\frac{2c}{1-f_0} < \frac{4c}{f_0} - 1 \Leftrightarrow f_0 < \frac{1}{3}$ and $c \in (\frac{f_0(1-f_0)}{4-6f_0}, \frac{1-f_0}{6})$.

4 Second best

of revenue are assigned to each member, i.e. $w_1^A(\emptyset,\emptyset) = w_2^A(\emptyset,\emptyset) = \frac{1}{2}$. With probability $\frac{1-\beta}{2}$ member $i = 1, 2$ is assigned the entire revenue, i.e. $w_i^A(\emptyset,\emptyset) = 1$, $w_j^A(\emptyset,\emptyset) = 0$. Under this mechanism, agent i will choose to disclose B if and only if

$$(1 - \frac{1}{2}q)p_{BB}f_0 \geq \frac{1}{2}(1-q)\left[\alpha\left(\beta\frac{f_1}{2} + \frac{1-\beta}{2}f_0\right) + (1-\alpha)p_{BB}f_0\right]. \quad (16)$$

Note that this condition is satisfied when $\alpha = 0$. When project B is selected (with certainty) in the absence of evidence, member j will provide zero effort. As a consequence, member i is no longer able to motivate member j by concealing B. Condition (16) is also satisfied when $\beta = 0$. This is for two reasons. Either member i finds himself without revenue after concealing B or, as in the case where $\alpha = 0$, he is unable to motivate member j.

Obviously, providing incentives to disclose information comes at the cost of inefficient project and/or effort choices. Relative to the first best value W^*, the generic revelation mechanism leads to the following welfare loss:

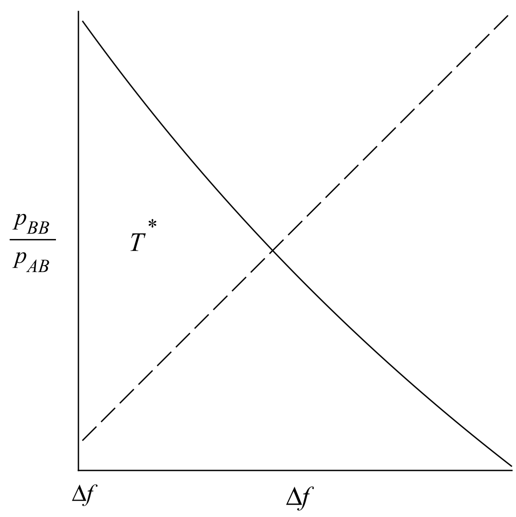
$$\Delta W = (1-q)^2[(1-\alpha)(\bar{p}_A f_2 - 2c - \bar{p}_B f_0) + \alpha(1-\beta)(\bar{p}_A \Delta f - c)]. \quad (17)$$

The optimal revelation mechanism minimizes this welfare loss subject to the disclosure constraint (16). In the Appendix we prove the following:

Proposition 2 *In T^0 the optimal revelation mechanism is identical to the one implementing the benchmark (with maximum rewards) except that, in the absence of evidence, it selects project B with probability $1-\alpha$ and assigns project A's entire revenue to one member with probability $1-\beta$.*

1. *If $\Delta f > \Delta f^{**}$ then $\beta = 1$ and $\alpha = \frac{p_{BB}f_0}{(1-q)[p_{AB}f_1 - p_{BB}f_0]} \in (0,1)$ (Sub–optimal Adaptation).*
2. *If $\Delta f \leq \Delta f^{**}$ then $\alpha = 1$ and $\beta = \frac{f_0}{\Delta f}(\frac{2-q}{1-q}\frac{p_{BB}}{p_{AB}} - 1) \in (0,1)$ (Sub–optimal Motivation)*

Proposition 2 is depicted in Figure 2. It shows that the optimal revelation mechanism never requires the distortion of both decision–making *and* effort. This is because distorting effort is less costly (in terms of welfare) but not always feasible (i.e. interim collusion–proof). To see the first point, note that the welfare loss of distorting effort, $\bar{p}_A\Delta f - c$, is


$\frac{p_{BB}}{p_{AB}}$
T^*
Δf
Δf

Sub–optimal Motivation and Sub–optimal Adaptation constitute the optimal revelation mechanism for some parameter values. This follows from the fact that $\Delta f^{**} > \Delta f^{min}$ and $\lim_{f_0 \to 0} \Delta f^{**} = \Delta f^{min}$. Secondly, relaxing limited liability increases the area for which Sub–optimal Adaptation represents the optimal mechanism since it improves the members' ability to collude at the interim stage.[15] Lastly, there is a link between the Sub–optimal Motivation mechanism and the work of Teoh (1997) and Hermalin (1998). These authors find that, in a team setting, the reduction in the availability of information can help to bring the equilibrium level of effort closer to its efficient level. In our model the converse is true, as distorting effort below its efficient level allows the team to share their private information with the mechanism designer.

Non–revealing mechanisms

Proposition 2 characterizes the optimal revelation mechanism. However, our setting combines asymmetric information and moral hazard and, as a result, the optimal mechanism need not induce the disclosure of evidence. In this section we characterise the conditions under which the optimal mechanism is non-revealing. The key lesson from this section is that it can be optimal to induce team members to conceal their private information by committing the team to stick with its initially preferred alternative.

Consider a mechanism which always selects project A and gives equal revenue shares, independently of messages. It is clear that under this mechanism, team members will fail to disclose any evidence and will exert effort unless they have observed evidence for B. This is because the disclosure of B can only decrease motivation without improving adaptation.[16] We denote this mechanism as Non–Adaptation, to emphasize the fact that

[15] If the side–contract requires member j to pay a transfer t to member i (independently of the project's outcome) then both members would sign the contract if $t \in [\frac{cf_2}{\Delta f} - \bar{p}_A \Delta f, \frac{cf_2}{\Delta f} - c]$. This interval is non–empty since effort is efficient. If limited liability is relaxed to $w_i \geq -L$, $L > 0$, then side–contracting rules out Sub–optimal Motivation if $L \geq \frac{cf_2}{\Delta f} - \bar{p}_A \Delta f$. Substitution of Δf^{min} into this condition shows that Sub–optimal Motivation is not feasible (and Sub–optimal Adaptation is optimal) in the entire T^0 if $L \geq \frac{f_0 \bar{p}_A}{2}$.

[16] Agents are indifferent between disclosing and concealing A. If agents disclosed A but concealed B, then Bayesian updating implies that in the absence of evidence members would expect project A's quality to be below $\bar{p}_A$. This could harm the members' incentive to provide effort. In order to avoid this problem, the concealment of A should be made *strictly* optimal by setting $w_1^A(A, \emptyset) = w_2^A(\emptyset, A) = \frac{1}{2} - \epsilon$, i.e. by punishing (slightly) the unilateral disclosure of A.

the choice of project is never adapted to the information held by the team members.

Relative to the benchmark allocation, Non–Adaptation leads to a welfare loss if and only if evidence for B has been observed. In this case Non–Adaptation fails to select the best project and induces inefficiently high effort by any member who failed to observe B. The welfare loss under Non–Adaptation is given by

$$\Delta W = \frac{1}{2}[(1-(1-q)^2)(p_{BB}-p_{AB})f_0 + 2q(1-q)(c-p_{AB}\Delta f)]. \quad (19)$$

While Non–Adaptation leads to a welfare loss when B is observed, it implements the first best allocation in the absence of evidence. The opposite is true for the optimal revelation mechanism charaterized in Proposition 2. It can easily be shown that no other non–revealing mechanism is able to dominate the optimal revelation mechanism from Proposition 2. For example, a mechanism which always selects project B is clearly dominated by the optimal revelation mechanism. The overall optimum can therefore be determined by comparing Non–Adaptation with the optimal revelation mechanism. In the Appendix we prove the following:

Proposition 3 *There exists a threshold $t^{**}(\Delta f) < t^*(\Delta f)$ such that in T^0 the optimal mechanism can be characterized as follows:*

1. *If the value of adaptation is high, i.e. $\frac{p_{BB}}{p_{AB}} \geq t^{**}(\Delta f)$, then surplus is maximized by Sub–optimal Motivation or Sub–optimal Adaptation and team members are induced to reveal their private information.*

2. *If the value of adaptation is low, i.e. $\frac{p_{BB}}{p_{AB}} \leq t^{**}(\Delta f)$, then surplus is maximized by Non–Adaptation and team members are induced to conceal their private information.*

The threshold t^{**} is strictly increasing in the value of motivation Δf.

Proposition 3 is depicted in Figure 3. To understand the intuition, consider the case where the value of adaptation is minimal, i.e. $\frac{p_{BB}}{p_{AB}} \to 1$, and the value of motivation is maximal, i.e. $\Delta f \to \Delta f^{max}$. In the presence of evidence for B, surplus then becomes independent of project and effort choices. As a result, surplus under Non–Adaptation converges to the first best value W^*. Hence Non–Adaptation is optimal in the lower right

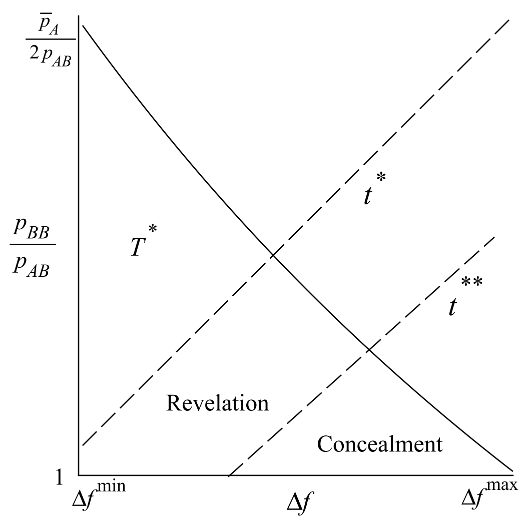


Figure 3: Information sharing under the optimal (second best) mechanism.

corner of T^0. If instead the value of adaptation is maximal, i.e. $\frac{p_{BB}}{p_{AB}} \to t^*(\Delta f)$, then the parameters α and β of the optimal revelation mechanism converge to 1 and surplus under this mechanism converges to the first best value, W^*. The reason is that project or effort choices need to be distorted only just enough to induce disclosure. The distortion required is minimal (and surplus close to optimal) when the value of motivation is low and the value of adaptation is high. Hence, close to $t^*(\Delta f)$ the optimal revelation mechanism constitutes the overall optimum.

We conclude this Section with two comments regarding Proposition 3. Firstly, the ex ante level of effort provided by the team is non–monotonic in Δf and $\frac{p_{BB}}{p_{AB}}$. As Δf increases (or $\frac{p_{BB}}{p_{AB}}$ decreases) effort initially decreases (in the Sub–optimal Motivation and Sub–optimal Adaptation areas) and then increases above its efficient level (in the Non–Adaptation area). Secondly, the ex ante likelihood that project B will be chosen is also non–monotonic in Δf and $\frac{p_{BB}}{p_{AB}}$. As Δf increases (or $\frac{p_{BB}}{p_{AB}}$ decreases) the team selects project B with a higher likelihood (in the Sub–optimal Adaptation area). Beyond a certain level, however, the likelihood of selecting project B drops down to zero (in the Non–Adaptation area).

5 Extensions

In this section we consider two extensions of our model. In the first part we allow for a general number N of (homogeneous) team members. We obtain the surprising result, that, although potentially detrimental for the incentive to provide effort, an increase in team size can make the first best become implementable, due to a positive effect on the members' incentive to share information. In the second part we allow for heterogeneities, by considering two team members who differ in their productivity and the likelihood with which they become informed. Our results show that the incentive to conceal evidence is stronger for the member who is less productive or more likely to be informed and we determine how the optimal mechanism should account for this difference.

Team size

Consider a team with an arbitrary number $N > 2$ of members.[17] The objective is to generalize Proposition 1 and to understand how an increase in N affects the implementability of the benchmark allocation in the set T of parameters for which a trade–off between motivation and adaptation exists.

N team members can be induced to exert effort on project A in the absence of evidence if and only if $\Delta f \geq \frac{Nc}{\bar{p}_A}$. Free–riding prevents the benchmark from being implementable for all $\Delta f \in (\frac{2c}{\bar{p}_A}, \frac{Nc}{\bar{p}_A})$. This negative effect of team size on incentives is standard in models of team production.[18]

In the present setup team size also affects the ability to share information. In a larger team, increasing motivation via the concealment of evidence is potentially more rewarding but less likely to succeed. In particular, if member i conceals evidence for B, then $N-1$ team members can be motivated to exert effort on project A. However, this only happens if all $N-1$ members failed to observe evidence, i.e. with probability $(1-q)^{N-1}$. Whether the incentive to disclose evidence is increasing or decreasing in N is therefore not clear.

A more subtle effect is that, in a larger team, a wider range of possibilities exists

[17] $Pr(R=1) \leq 1$ in T if and only if $f_0 + N\Delta f^{max} \leq 1$. It is therefore necessary to strengthen the parametric restrictions in (5) to $f_0 < 1$, $c < \frac{1-f_0}{N(2N-1)}$, and $p_{AB} \in [\frac{Nc}{1-f_0}, \frac{1}{3})$.

[18] An exception is Adams (2006) who shows that the e ect can be positive when team production exhibits su ciently strong complementarities.

to reward the disclosure of information. In particular, evidence for B can not only be rewarded when it is disclosed unilaterally but also whenever *some* member(s) failed to disclose. The incentive to disclose B is maximized by sharing the team's revenue (equally) amongst all members who happened to disclose such evidence. Substitution of this reward schedule into the generalized version of condition (8) shows that team members can be induced to disclose evidence for B if and only if

$$p_{BB}f_0\sum_{k=0}^{N-1}\binom{N-1}{k}q^k(1-q)^{N-1-k}\frac{1}{1+k} \geq p_{AB}(f_0+(N-1)\Delta f)(1-q)^{N-1}\frac{1}{N}$$

$$\Leftrightarrow \frac{p_{BB}}{p_{AB}} \geq \frac{q(1-q)^{N-1}}{1-(1-q)^N}(1+(N-1)\frac{\Delta f}{f_0}) \equiv t_N^*(\Delta f). \qquad (20)$$

In the Appendix we prove the following:

Proposition 4 *For a team with $N > 2$ members, the benchmark is implementable in $T_N^* = \{(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T | \Delta f \geq \frac{Nc}{\bar{p_A}}, \frac{p_{BB}}{p_{AB}} \geq t_N^*(\Delta f)\}$. The benchmark fails to be implementable due to free–riding in $T_N^F = \{(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T | \Delta f < \frac{Nc}{\bar{p_A}}\} \neq \emptyset$, and due to a lack of information sharing in $T_N^I = \{(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T | \Delta f \geq \frac{Nc}{\bar{p_A}}, \frac{p_{BB}}{p_{AB}} < t_N^*(\Delta f)\}$. $T_N^I \neq \emptyset$, if and only if $p_{AB} < \min(\frac{1}{2N-1}, \frac{c}{f_0})$ and $q < q_N^*$. The threshold $q_N^* \in (0,1)$ is decreasing in N.*

Proposition 4 extends Proposition 1 to the case of $N > 2$ team members. As before, there exists a nonempty subset of T, denoted as T_N^I, for which the benchmark fails to be implementable due to the team's inability to share information.[19] There also exists a subset of T, denoted as T_N^F, for which free–riding hinders the benchmark to become implementable. For $N = 2$ this set was empty due to our focus on the parameter values for which free–riding was *not* a source of inefficiency. The sets T_N^I and T_N^F are depicted in Figure 4. Since the conditions under which $T_N^I \neq \emptyset$ become stricter as N increases, there may exist a subset of the parameter space T for which an increase in team size improves the team's ability to share information. In the Appendix we prove the following:

Corollary 1 *Increasing the team size from $N \geq 2$ to $N + 1$ has two effects:*

[19]Given the parametric restrictions on p_{AB} contained in footnote 17, $p_{AB} < \min(\frac{1}{2N-1}, \frac{c}{f_0})$ is possible if and only if $\frac{Nc}{1-f_0} < \min(\frac{1}{2N-1}, \frac{c}{f_0}) \Leftrightarrow f_0 < \frac{1}{N+1}$.

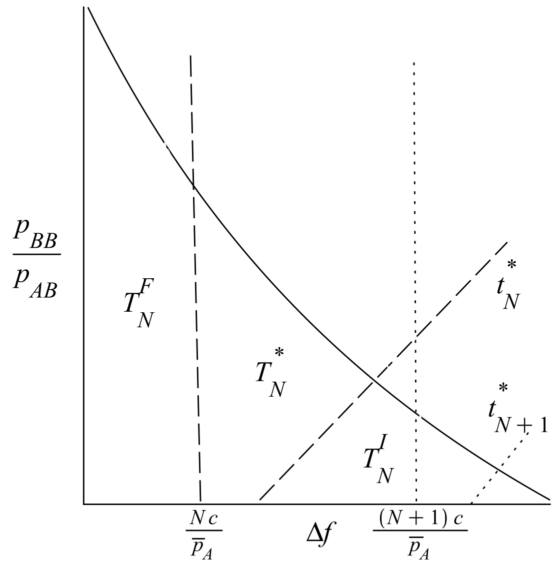


Figure 4: Team size $N > 2$: The benchmark is implementable in T_N^*. It fails to be implementable due to free riding in T_N^F and due to a lack of information sharing in T_N^I. Increasing team size to $N+1$ makes the benchmark implementable in the area between the dotted lines.

1. *If $p_{AB} < \frac{1}{2N-1}$, then the benchmark ceases to be implementable due to more free–riding in $T_{N+1}^F \backslash T_N^F \neq \emptyset$.*

2. *If $p_{AB} < \min(\frac{1}{2N+1}, \frac{c}{f_0})$ and $q_{N+1}^* \leq q < q_N^*$, then the benchmark becomes implementable due to better information sharing in $T_N^I \backslash T_{N+1}^I \neq \emptyset$.*

The novel feature of Corollary 1 is its second part. It provides sufficient conditions under which an increase in team size *raises efficiency* by making the benchmark become likely to be implementable. As can be seen from Figure 4, this happens for parameter values between the disclosure threshold t_{N+1}^* and the free–riding threshold at $\frac{(N+1)c}{\bar{p}_A}$, i.e. when the value of motivation is relatively large and the value of adaptation is relatively small.

An increase in team size has the effect that it improves the team's potentially available information (due to the private information of the added team member). Corollary 1 shows that the team may benefit from this added source of information not only marginally. The new member also changes the existing members' incentives to disclose

their private information, resulting in a decision based now on the aggregated information of *all* team members.

Note that for this result to hold, it is crucial that the team rewards the disclosure of evidence for B. If instead, members received a fixed share $\frac{1}{N}$ of the team's revenue, independently of messages, then condition (20) would change to

$$\frac{p_{BB}}{p_{AB}} \geq 1 + (N-1)\frac{\Delta f}{f_0}. \tag{21}$$

In this case, a member's message affects his payoff only when he is pivotal, i.e. the only one who observed evidence. The incentive to conceal evidence is then stronger in a larger team since, conditional on being pivotal, more colleagues can be motivated by concealing B. Hence,if rewards cannot be conditioned on the issued messages, an increase in team size affects the team's ability to share information negatively.

Heterogeneity

We now introduce heterogeneity in our framework. Team members may differ in their 'productivities', i.e. their influence Δf_i on the project's chances of success. They may also differ in the likelihood q_i with which they observe evidence. In the following we assume that member 1 is either less productive ($\Delta f_1 < \Delta f_2$, $q_1 = q_2$) or more likely to be informed ($q_1 > q_2$, $\Delta f_1 = \Delta f_1$) than member 2. We maintain our assumption that $\Delta f_i > \Delta f^{min}$ for $i \in \{1, 2\}$. In order to minimize the team members' incentive to conceal evidence for B it is still optimal to employ maximum rewards for the (unilateral) disclosure of B. From (8) it therefore follows that both team members disclose evidence for B if and only if $\max(g_1, g_2) \leq p_{BB} f_0$ where

$$g_i = p_{AB}(f_0 + \Delta f_j) w_i^A(\emptyset, \emptyset) - \frac{q_j}{1-q_j} p_{BB} f_0 w_i^B(B, B) \tag{22}$$

can be interpreted as member i's incentive to conceal B. Note that for $w_i^A(\emptyset, \emptyset) = w_i^B(B, B) = \frac{1}{2}$, it holds that $g_1 > g_2$, i.e. member 1 has a stronger incentive to conceal evidence for B. This is because for him, concealment is either more likely to motivate the colleague (since member 2 is less likely to be informed) or the resulting increase in effort has a stronger effect on the probability of success (since member 2 is more productive).

As a consequence, $w_i^A(\emptyset,\emptyset) = w_i^B(B,B) = \frac{1}{2}$ cannot be optimal. Instead $w_i^A(\emptyset,\emptyset)$ and $w_i^B(B,B)$ should be used to give both members an equal incentive to disclose. This can be achieved either by decreasing $w_1^A(\emptyset,\emptyset)$ or by increasing $w_1^B(B,B)$. Lowering member 1's incentive to conceal by decreasing $w_1^A(\emptyset,\emptyset)$ comes at a lower cost, i.e. a smaller increase in member 2's incentive to conceal.[20] In order to implement the benchmark for the largest range of parameters it is therefore necessary to set $w_1^A(\emptyset,\emptyset) < \frac{1}{2}$. However, this decrease in $w_1^A(\emptyset,\emptyset)$ could potentially alter the incentives to disclose evidence for A. One way to guarantee that A is disclosed is to make the allocation of project A's revenue independent of messages. We summarize these findings as follows:

Proposition 5 *If member* 1 *is less productive or more likely to be informed than member* 2*, then member* 1 *has a stronger incentive to conceal evidence for* B*. The benchmark is implemented in the largest range of parameters by a mechanism which offers maximum rewards for the unilateral disclosure of* B *(*$w_1^B(B,\emptyset) = w_2^B(\emptyset,B) = 1$*) and provides member* 1 *with a smaller share of project* A*'s revenue (*$w_1^A < \frac{1}{2}$*).*

The optimal compensation scheme is characterized in more detail in the proof of Proposition 5. Proposition 5 contrasts with the effect that heterogeneity has in results of a standard model of team production. To see this note that, in the absence of informational asymmetries, it may be necessary to give a larger share of revenue to the member with the lower productivity if both members are to exert (discrete) effort. Indeed, when $\Delta f_1 < \Delta f^{min}$, member 1 would exert effort on project A only if $w_1^A(\emptyset,\emptyset) \geq \frac{c}{\bar{p}_A \Delta f_1} > \frac{c}{\bar{p}_A \Delta f^{min}} = \frac{1}{2}$. While in such a standard model member 1 may need to receive a higher share of revenue in order to exert effort (when $\Delta f_1 < \Delta f^{min}$), in our model with asymmetric information member 1 may need to receive a lower share in order to share information (when $\Delta f > \Delta f^{min}$).

Interpreting project A as the status quo and project B as the adoption of changes, Proposition 5 has the following implication. It suggests that teams more effectively adapt to a changing environment when those members who are more likely to be informed about the necessity of changes own smaller shares in the status quo. Moreover, teams are more

[20]For $\Delta f_1 < \Delta f_2$, $q_1 = q_2$, decreasing g_1 by one unit can be achieved by decreasing $w_1^A(\emptyset,\emptyset)$ by $[p_{AB}(f_0+\Delta f_2)]^{-1}$ units or by increasing $w_1^B(B,B)$ by $[\frac{q}{1-q} p_{BB} f_0]^{-1}$ units. This increases g_2 by $\frac{f_0+\Delta f_1}{f_0+\Delta f_2} < 1$ or 1 units respectively. Similar for the case $q_1 > q_2$, $\Delta f_1 = \Delta f_1$.

adaptive if they reward opinions in conflict with the status quo. Unfortunately, better information often goes hand in hand with higher stakes and dissenting voices are often punished rather than rewarded. Teams can therefore be expected to be less effective in the adoption of necessary changes than they could be.

6 Robustness

Our model assumes that information is verifiable and that individual efforts are independent inputs of production and messages are public. In this section we show that Proposition 1 remains qualitatively unchanged when we relax these assumptions. We first consider the case where team members receive unverifiable signals. Secondly, we allow for complementarities. The main insight is that in these cases an increase in the signals' precision or in the strength of complementarities makes the set of parameters for which the benchmark fails to be implementable become smaller without reducing it to $\emptyset$. At the end of the section we argue that our results are robust to not change members observe the messages sent by their colleague.

Non–verifiable information

So far, our analysis has focussed on the team's ability to share *verifiable* evidence. Suppose instead that member i observes an unverifiable signal $s_i \in \{A, B\}$. Conditional on the state of the world being y, $s_i = y$ with probability $\tilde{q} \in (\frac{1}{2}, 1)$. The parameter $\tilde{q} \in (\frac{1}{2}, 1)$ denotes the precision of the team members' information and is the analog of the parameter q in the baseline model. In both models, the parameter represents the likelihood with which a team member is correctly informed.

In the baseline model it was neccessary to assume that $p_{AB} > 0$. Otherwise, team members would have always preferred adaptation over motivation. When team members receive soft signals this assumption is no longer necessary for a trade–off between adaptation and motivation to exist. In the following we therefore simplify the exposition by assuming that $p_{AB} = 0$.

As before we assume that information is valuable. In particular, we suppose that project A is (expected to be) better when both signals point towards A, while project B

is better when both signals point towards B. Without loss of generality, we let project A be better when signals differ from each other. These assumptions require that

$$1 > p_{BB} > \frac{(1-\tilde{q})^2}{\tilde{q}^2}. \tag{23}$$

The mechanism and the induced game are as before, with the obvious difference that message spaces are no longer type dependent. More specifically, type $s_i \in \{A, B\}$ chooses $m_i \in \{A, B\}$.

In order to match the assumptions of the original model, we assume that both team members can be induced to exert effort on project A even when their beliefs are identical to the prior (which happens when $s_1 \neq s_2$). As before, we also assume that it is inefficient to exert effort on project B even when both signals point towards B. This require that

$$4c < \Delta f < \frac{\tilde{q}^2 + (1-\tilde{q})^2}{\tilde{q}^2} \frac{c}{p_{BB}}. \tag{24}$$

In summary, the set

$$\tilde{T} = \{(\Delta f, p_{BB}) | 4c < \Delta f < \frac{q^2 + (1-q)^2}{q^2} \frac{c}{p_{BB}}, 1 > p_{BB} > \frac{(1-q)^2}{q^2}\} \tag{25}$$

represents the analog to the set T in our baseline model.[21] The benchmark allocation is similar to before. In particular, project B should be selected if and only if $s_1 = s_2 = B$, $\hat{e}_i^*(s_1, s_2, B) = 0$ for all (s_1, s_2), and $\hat{e}_i^*(s_1, s_2, A) = 1$ unless $s_1 = s_2 = B$.
We now proceed to examine whether this benchmark allocation can be implemented. Reasoning as in Section 3, truth–telling incentives are maximized by setting $w_i^B(B, B) = w_i^A(A, A) = \frac{1}{2}$ and it remains to consider the potential reward $w_1^A(B, A)$ for issuing $m_1 = B$ unilaterally.

Let $I_1(B, B)$ denote member 1's incentive to issue $m_1 = B$ after observing $s_1 = B$. $I_1(B, B)$ is given by the difference in (expected) payoffs from issuing $m_1 = B$ and $m_1 = A$ respectively. Member 1 reports $s_1 = B$ truthfully if and only if $I_1(B, B) \geq 0$. We have

$$I_1(B, B) = \tilde{q}^2 p_{BB} f_0 \frac{1}{2} - (1-\tilde{q})^2 f_1 [1 - w_1^A(B, A)] + \tilde{q}(1-\tilde{q}) f_2 [w_1^A(B, A) - \frac{1}{2}]. \tag{26}$$

[21]To guarantee that $\tilde{T}$ is non–empty and that $Pr(R = 1) \leq 1$ for all $(\Delta f, p_{BB}) \in \tilde{T}$ the following parametric restrictions are necessary and su cient: $f_0 < 1$, $\tilde{q} > \frac{3}{2} - \frac{1}{2}\sqrt{3}$, and $c < \frac{1}{2}(1 - f_0)\frac{(1-\tilde{q})^2}{\tilde{q}^2 + (1-\tilde{q})^2}$.

While in the original model, the incentive to disclose evidence for A was never an issue, here we have to be concerned also with the team members' incentive to truthfully reveal the signal A. This is because the prospect of a potential reward for issuing B (unilaterally) gives members a reason to issue B rather than A. To take account of this possibility, let $I_1(B, A)$ denote member 1's incentive to issue $m_1 = B$ after observing $s_1 = A$. Member 1 will misrepresent his information by issuing $m_1 = B$ if and only if $I_1(B, A) \geq 0$. We have

$$I_1(B, A) = 2\tilde{q}(1 - \tilde{q}) \left[\frac{1}{4} p_{BB} f_0 - \frac{1}{2} f_2[1 - w_1^A(B, A)] + c\right] + \tilde{q}^2 f_2[w_1^A(B, A) - \frac{1}{2}]. \quad (27)$$

To induce truth–telling the mechanism has to choose a $w_1^A(B, A)$ such that $I_1(B, B) \geq 0$ and $I_1(B, A) < 0$. Moreover, in order to induce efficient effort levels for project A, $w_1^A(B, A)$ has to satisfy the following incentive constraints:

$$\frac{2c}{\Delta f} \leq w_1^A(B, A) \leq 1 - \quad 2c$$

Remark 1 *When team members receive unverifiable signals, the benchmark fails to be implementable in* $\tilde{T}^0 = \{(\Delta f, p_{BB}) \in \tilde{T} | p_{BB} < \tilde{t}^*(\Delta f)\} \neq \emptyset$. *Increasing the signals' precision makes* $\tilde{T}^0$ *smaller.*

As in the baseline model, the implementability of the benchmark becomes more feasible when team members are better informed about the projects' qualities. The reason is that the misrepresentation of information is then less likely to result in an increase in motivation.

In comparison to the baseline model, the model with unverifiable signals has an additional feature which is similar to the subordinates' incentive to conform with the views of their superiors in Prendergast (1993), or to the leader's propensity to pander his followers' opinion in Blanes i Vidal and Möller (2007). Each team member has an incentive to issue a message that reinforces rather than contradicts the other member's signal. Since messages are issued simultaneously and signals are more likely to coincide than to contradict each other, members have an additional incentive to tell the truth. It is reassuring that our main result remains unchanged even in the presence of such a *propensity to agree.*

Complementarities

Our model assumes that individual efforts are independent inputs of the team's production function. In this section we generalize Proposition 1 by allowing for the existence of complementarities. For this purpose suppose that, as before, $f_1 - f_0 = \Delta f$ but let $f_2 - f_1 = (1+\gamma)\Delta f$. The parameter $\gamma > 0$ measures the strength of complementarities. As before we assume that efficiency requires zero effort on project B, i.e. $p_{BB}(2+\gamma)\Delta f < 2c$, while equal revenue sharing is sufficient to induce both team members to exert effort on project A, i.e. $\frac{1}{2}\bar{p}_A \Delta f > c$.[22] In the presence of complementarities assumption (3) therefore becomes

$$\frac{2c}{(2+\gamma)p_{BB}} > \Delta f > \frac{2c}{\bar{p}_A}. \tag{31}$$

[22]Note that in the presence of complementarities, an equilibrium $e_1 = e_2 = 1$ may coexist with an equilibrium $e_1 = e_2 = 0$. Our assumption guarantees that $e_1 = e_2 = 1$ constitutes the *unique* equilibrium.

The parametric restrictions which guarantee the possibility of a trade–off between adaptation and motivation are modified to

$$f_0 < 1, \quad c < \frac{1-f_0}{6+4\gamma}, \quad p_{AB} \in [\frac{2c}{1-f_0}, \frac{1}{3+\gamma}). \tag{32}$$

The existence of complementarities has no influence on the threshold t^*, since a team member who conceals evidence for B will refrain from exerting effort on project A. However, the condition under which the benchmark fails to be implementable in a non–empty subset of T, $t^*(\Delta f^{max}) > 1$, now depends on the parameter γ through $\Delta f^{max} = \frac{2c}{(2+\gamma)p_{AB}}$. It holds if and only if

$$p_{AB} < \frac{2c}{(2+\gamma)f_0} \quad \text{and} \quad q < 1 - \frac{(2+\gamma)p_{AB}f_0}{2c}. \tag{33}$$

The upper bound on p_{AB} in (33) is larger than the lower bound in (32) if and only if $f_0 < \frac{1}{3+\gamma}$. The fact that these upper bounds are positive and decreasing in γ implies the following:

Remark 2 *Even in the presence of complementarities, the benchmark fails to be implementable in a non–empty subset of the parameter space. Increasing the strength of complementarities reduces the parameter space for which the benchmark fails to be implementable.*

Private Messages

Throughout this paper, we have assumed that team members observe the messages sent by their colleague. In an alternative setting, messages could be sent to the mechanism designer *privately*. This distinction matters since team members may want to condition their effort choices on the message sent by their colleague. We now argue that our results remain unchanged when messages are assumed to be private.

Since team members never exert effort on project B, the observability of messages can only be an issue when project A is selected. Moreover, under any revelation mechanism which selects project A only in the absence of evidence for B, member i learns that $s_j \in \{A, \emptyset\}$ from his observation of project A being selected. Furthermore, under our assumptions, member i will exert effort on project A if he receives a share of at least $\frac{c}{\bar{p}_A \Delta f}$

independently of whether $s_j = A$ or $s_j = \emptyset$. Hence neither the mechanism implementing the benchmark, nor the optimal revelation mechanism are affected by the observability of messages. Since under Non–Adaptation, the only message that is sent is $\emptyset$, this mechanism is unaffected trivially. We therefore conclude that our results remain unchanged when messages are allowed to be private.

7 Conclusion

In private and public organizations, teams are often allocated the dual task of taking *and* implementing a decision. In this paper we have investigated the link between the incentive to share decision-relevant information and the motivation to exert effort in this type of team setting. Our key trade–off makes team members reluctant to disclose information in favour of the initially least preferred alternative in situations where maximising the colleagues' motivation is more important that ensuring the best project is chosen. To overcome this, the optimal mechanism always includes rewards for the disclosure of evidence favouring the ex ante least preferred project. Somewhat counterintuitively, we show that an increase in team size makes the benchmark more likely to be implementable, and hence leads to a gain in surplus, if the value of motivation is relatively high and the value of adaptation is relatively low.

If the first best is not implementable, three alternative (second best) mechanisms emerge. For low (relative) values of motivation, the optimal mechanism requires treating identical agents differently, thus introducing arbitrary inequality in the organization. As the value of motivation increases equality is restored among members, but a project selection rule, biased in favour of the ex ante least preferred project, becomes part of the optimal mechanism. When the value of motivation is very large, the optimal mechanism is biased in favour of the *other* project (the ex ante preferred), which prevents information revelation from taking place.

What specific institutional form could these mechanisms take? One such form would be the delegation of the decision–making rights to an outsider to the team, e.g. a manager. Consider for instance a manager who neither obtains any private information nor exerts effort. To implement the Suboptimal Adaptation mechanism, the manager would select

the team's preferred project in the presence of evidence, but project B (rather than A) in its absence[23]. This mechanism could then be interpreted as delegating the project choice to the manager in a fraction $1-\alpha \in [0,1)$ of all cases. This is reminiscent of Garicano's (2000) principle of 'management by exception', where parameter α can be interpreted as the team's level of autonomy. Since α is increasing in p_{BB} but decreasing in Δf (Proposition 2), the team's optimal level of autonomy is then increasing in the value of adaptation but decreasing in the value of motivation[24].

Appendix

Proof of Proposition 1

We have already shown that the benchmark is implementable if and only if $\frac{p_{BB}}{p_{AB}} \geq \frac{1-q}{2-q}(1+\frac{\Delta f}{f_0})$. Moreover, by definition, for all $(\Delta f, \frac{p_{BB}}{p_{AB}}) \in T$ it holds that $\frac{p_{BB}}{p_{AB}} < \frac{c}{p_{AB}\Delta f}$. While the lower bound on $\frac{p_{BB}}{p_{AB}}$ is increasing in Δf, the upper bound is decreasing. The benchmark therefore fails to be implementable in a non–empty subset of T if and only if the lower bound exceeds the upper bound at $\Delta f^{max} = \max_T \Delta f = \frac{c}{p_{AB}}$, i.e.

$$\frac{1-q}{2-q}(1+\frac{\Delta f^{max}}{f_0}) > \frac{c}{p_{AB}\Delta f^{max}} = 1 \quad \Leftrightarrow \quad p_{AB} < \frac{c(1-q)}{f_0}. \tag{34}$$

This holds if and only if

$$p_{AB} f_0 < c \quad \text{and} \quad q < 1 - \frac{p_{AB} f_0}{c}. \tag{35}$$

Proof of Proposition 2

In order to minimize (17) subject to (16) the constraint has to be binding. Solving (16) for β and substituting into (17) gives

$$\frac{\Delta W}{(1-q)^2} = (1-\alpha)(\bar{p}_A f_2 - 2c - \bar{p}_B f_0) + (\bar{p}_A \Delta f - c)(\alpha \frac{f_1}{\Delta f} - (\frac{1}{1-q} + \alpha)\frac{p_{BB}}{p_{AB}}\frac{f_0}{\Delta f}). \tag{36}$$

[23] This may be motivated in two ways. First, as in Landier et al. (200), the manager's preferences may differ from the team's. For example, when A represents the status quo and B the introduction of changes, a manager who has been hired from outside may be more inclined to implement changes. Second, as in Ferreira and Rezende (2007), the manager's position may allow him to commit to an ex post inefficient project selection rule by publicly announcing his plans or "vision".

[24] Interpreting the mechanism as delegation to a manager resonates with Holmstrom (1 2). While in his paper the principal provides optimal incentives to exert effort by allowing the team to *break the budget*, in our model the manager provides optimal incentives to share information by enabling the team to *take unpopular decisions*.

For the derivative we get

$$\begin{aligned}\frac{\partial}{\partial \alpha} &= -(\bar{p}_A f_2 - 2c - \bar{p}_B f_0) + (\bar{p}_A \Delta f - c)(\frac{f_1}{\Delta f} - \frac{p_{BB}}{p_{AB}}\frac{f_0}{\Delta f}) \\ &< -(\bar{p}_A \Delta f - c) - (\bar{p}_A - \bar{p}_B) f_0 < 0\end{aligned} \tag{37}$$

where the first inequality follows from $p_{BB} > p_{AB}$ and the second from (2) and (3). In the optimum it therefore has to hold that $\alpha = 1$. Given $\alpha = 1$, ΔW is decreasing in β, and the optimal β makes (16) binding, i.e.

$$\beta = \frac{f_0}{\Delta f}(\frac{2-q}{1-q}\frac{p_{BB}}{p_{AB}} - 1). \tag{38}$$

If $\Delta f > \Delta f^{**}$ then Sub–optimal Adaptation is not feasible due to side–contracting and the minimization is further constrained by the requirement that $\beta = 1$. In this case, α is optimally chosen to make (16) binding, i.e.

$$\alpha = \frac{p_{BB} f_0}{(1-q)[p_{AB} f_1 - p_{BB} f_0]}. \tag{39}$$

It is straightforward to see that both α and β are increasing in $\frac{p_{BB}}{p_{AB}}$ and converge to 1 when $\frac{p_{BB}}{p_{AB}} \to t^*(\Delta f)$.

Finally, note that under the (random) compensation scheme of the optimal revelation mechanism, each member expects to obtain half of the revenue when messages $m_1 = m_2 = \emptyset$ have been issued. This means that, as before, the provision of incentives to disclose A is not an issue.

Proof of Proposition 3

Proposition 2 has shown that the optimal revelation mechanism is given by Sub–optimal Adaptation when $\Delta f > \Delta f^{**}$ and Sub–optimal Adaptation when $\Delta f \leq \Delta f^{**}$. Sub–optimal Adaptation leads to a smaller welfare loss than Non–Adaptation if and only if

$$(1-\alpha)(\bar{p}_A f_2 - 2c - \bar{p}_B f_0) < \frac{1-(1-q)^2}{2(1-q)^2}(p_{BB} - p_{AB}) f_0 + \frac{q}{(1-q)}(c - p_{AB}\Delta f). \tag{40}$$

For $\frac{p_{BB}}{p_{AA}} \to t^*(\Delta f)$, the inequality is satisfied since α tends to 1. For $\frac{p_{BB}}{p_{AB}} \to 1$ and $\Delta f \to \Delta f^{max}$ the inequality fails to hold since both terms on the RHS tend to zero. Since α is increasing in p_{BB} and decreasing in Δf, the LHS is decreasing in p_{BB} and increasing in Δf while for the RHS the opposite holds. Hence there exists an increasing threshold $t^{SA}(\Delta f)$ such that Sub–optimal Adaptation leads to higher welfare than Non–Adaptation if and only if $\frac{p_{BB}}{p_{AB}} > t^{SA}(\Delta f)$ and t^{SA} has the following properties: $t^{SA}(\Delta f) < t^*(\Delta f)$ for all $\Delta f \in [\Delta f^{min}, \Delta f^{max}]$ and $t^{SA}(\Delta f) > 1$ for all $\Delta f \in (\Delta f^{SA}, \Delta f^{max}]$ where $\Delta f^{SA} < \Delta f^{max}$.

For the comparison between Sub–optimal Adaptation and Non–Adaptation the LHS in the above inequality is substituted by $(1-\beta)(\bar{p}_A\Delta f - c)$ and an analog argument implies that Sub–optimal Adaptation leads to higher welfare than Non–Adaptation if and only if $\frac{p_{BB}}{p_{AB}} > t^{SI}(\Delta f)$. The threshold t^{SI} has analog properties as the threshold t^{SA}, i.e. $t^{SI}(\Delta f) < t^*(\Delta f)$ for all $\Delta f \in [\Delta f^{min}, \Delta f^{max}]$ and $t^{SI}(\Delta f) > 1$ for all $\Delta f \in (\Delta f^{SI}, \Delta f^{max}]$ where $\Delta f^{SI} < \Delta f^{max}$. Moreover, since Sub–optimal Adaptation, when feasible, dominates Sub–optimal Adaptation, it holds that $t^{SI}(\Delta f) < t^{SA}(\Delta f)$ for all $\Delta f \in [\Delta f^{min}, \Delta f^{max}]$.

Finally, taking into account that Sub–optimal Adaptation is feasible only if $\Delta f \leq \Delta f^{**}$, let $t^{**}(\Delta) = t^{SI}(\Delta f)$ for all $\Delta f \leq \Delta f^{**}$ and $t^{**}(\Delta) = t^{SA}(\Delta f)$ for all $\Delta f > \Delta f^{**}$. Then the optimal revelation mechanism leads to higher surplus than concealment via Non–Adaptation if and only if $\frac{p_{BB}}{p_{AB}} > t^{**}(\Delta f)$. t^{**} is continously increasing in Δf with a possible upward jump at Δf^{**}.

Proof of Proposition 4

$T_N^I \neq \emptyset$ if and only if $\frac{Nc}{\bar{p_A}} < \Delta f^{max}$ and $t_N^*(\Delta f^{max}) > 1$. Since $\Delta f^{max} = \frac{c}{p_{AB}}$, the first condition is equivalent to

$$p_{AB} < \frac{1}{2N-1}. \tag{41}$$

The second condition is equivalent to

$$p_{AB} < \frac{c}{f_0}\frac{(N-1)q(1-q)^{N-1}}{1-(1-q)^{N-1}} = \frac{c}{f_0}(1-q)P(q,N) \tag{42}$$

where $P(q,N)$ denotes the probability that evidence is observed by exactly one out of $N-1$ members, conditional on evidence being observed by at least one out of $N-1$ members. $P(q,N)$ is strictly decreasing in q and in N with $\lim_{q\to 0} P(q,N) = 1$ and $\lim_{q\to 1} P(q,N) = 0$. Hence (42) holds if and only if

$$p_{AB} < \frac{c}{f_0} \quad \text{and} \quad q < q_N^* \tag{43}$$

for some $q_N^* \in (0,1)$ and q_N^* is decreasing in N.

Proof of Corollary 2

For the first part note that $p_{AB} < \frac{1}{2N-1} \Leftrightarrow \frac{Nc}{\bar{p_A}} < \Delta f^{max}$ implies that $T_N^F \neq T$. The result then follows from $\frac{Nc}{\bar{p_A}} < \frac{(N+1)c}{\bar{p_A}}$. For the second part, note that $q \geq q_{N+1}^*$ implies that $T_{N+1}^I = \emptyset$. Together with $p_{AB} < \frac{1}{2N+1} \Leftrightarrow \frac{(N+1)c}{\bar{p_A}} < \Delta f^{max}$ this implies that $(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T_{N+1}^*$ if $\Delta f \geq \frac{(N+1)c}{\bar{p_A}}$. Finally, since $p_{AB} < \frac{1}{2N+1} < \frac{1}{2N-1}$, $p_{AB} < \frac{c}{f_0}$, and $q < q_N^*$, there exist $(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T$ such that $\Delta f \geq \frac{(N+1)c}{\bar{p_A}}$ and $\frac{p_{BB}}{p_{AB}} < t_N^*(\Delta f)$. For all those parameter values, the benchmark is implementable with $N+1$ agents but fails to be implementable with N agents.

Proof of Proposition 5

Let $g_i(w_i^A(\emptyset,\emptyset), w_i^B(B,B))$ be defined as in (11). In the following we characterize the compensations $w_1^A(\emptyset,\emptyset)$ and $w_1^B(B,B)$ which minimize the members' "aggregate" incentive to conceal, $G \equiv \max(g_1, g_2)$, subject to budget balance, limited liability and incentive constraints. Starting from $w_1^A(\emptyset,\emptyset) = w_1^B(B,B) = \frac{1}{2}$, $w_1^A(\emptyset,\emptyset)$ should be reduced as long as $g_1(w_1^A(\emptyset,\emptyset), \frac{1}{2}) > g_2(1 - w_1^A(\emptyset,\emptyset), \frac{1}{2})$. However, for member 1 to provide e ort on project A we require that $w_1^A(\emptyset,\emptyset) \geq \frac{c}{\bar{p}_A \Delta f_1}$. If the degree of heterogeneity $\Delta f_2 - \Delta f_1$ is larger than some threshold h (to be determined below), then for $w_1^A(\emptyset,\emptyset) = \frac{c}{\bar{p}_A \Delta f_1}$ it will still hold that $g_1(w_1^A(\emptyset,\emptyset), \frac{1}{2}) > g_2(1 - w_1^A(\emptyset,\emptyset), \frac{1}{2})$. In this case $w_1^B(B,B)$ should be increased as long as $g_1(\frac{c}{\bar{p}_A \Delta f_1}, w_1^B(B,B)) > g_2(1 - \frac{c}{\bar{p}_A \Delta f_1}, 1 - w_1^B(B,B))$. In contrast, when the degree of heterogeneity is small, i.e. $\Delta f_2 - \Delta f_1 \leq h$, then there exists some $w_1^A(\emptyset,\emptyset) \in (\frac{c}{\bar{p}_A \Delta f_1}, \frac{1}{2})$ such that $g_1(w_1^A(\emptyset,\emptyset), \frac{1}{2}) = g_2(1 - w_1^A(\emptyset,\emptyset), \frac{1}{2}) = G$. In this case, G can be reduced further by simultaneously decreasing $w_1^A(\emptyset,\emptyset)$ and $w_1^B(B,B)$. To see this, note that a reduction in $w_1^A(\emptyset,\emptyset)$ decreases g_1 by more than it increases g_2. A reduction in $w_1^B(B,B)$ raises g_1 by the same amount as it lowers g_2 and can therefore be used to restore equality but at a lower level $g_1 = g_2 = G' < G$. Optimally $w_1^A(\emptyset,\emptyset)$ and $w_1^B(B,B)$ are therefore reduced until one of the two reaches its lower bound given by $\frac{c}{\bar{p}_A \Delta f_1}$ and 0 respectively. The threshold h can be determined from $g_1(\frac{c}{\bar{p}_A \Delta f_1}, \frac{1}{2}) = g_2(1 - \frac{c}{\bar{p}_A \Delta f_1}, \frac{1}{2})$ and is given by

$$h = 2(f_0 + \Delta f_1)(\frac{\bar{p}_A \Delta f_1}{2c} - 1) > 0. \tag{44}$$

It is increasing in Δf_1 and tends to 0 when $\Delta f_1 \to \Delta f^{min}$. In summary, we have shown that the optimal compensation scheme can be characterized as follows: If $\Delta f_2 - \Delta f_1 > h$, then $w_1^A(\emptyset,\emptyset) = \frac{c}{\bar{p}_A \Delta f_1}$ and $w_1^B(B,B) > \frac{1}{2}$. If $\Delta f_2 - \Delta f_1 < h$, then either $w_1^A(\emptyset,\emptyset) = \frac{c}{\bar{p}_A \Delta f_1}$ and $w_1^B(B,B) \in (0, \frac{1}{2})$ or $w_1^A(\emptyset,\emptyset) \in (\frac{c}{\bar{p}_A \Delta f_1}, \frac{1}{2})$ and $w_1^B(B,B) = 0$.

Proof of Remark 1

To abbreviate notation, let $w_1^A(B,A) = w$. To show that (30) is not only necessary but also su cient for the implementability of the benchmark, we prove that if w satisfies $I_1(B,B) = 0$ then $I_1(B,A) < 0$. If $w = 1 - \frac{2c}{\Delta f}$, then $I_1(B,A)$ simplifies to

$$I_1(B,A) = \tilde{q}(1-\tilde{q})[p_{BB} f_0 \frac{1}{2} - f_1(1-w)] + \tilde{q}^2 f_2(w - \frac{1}{2}). \tag{45}$$

This is because member 1 no longer values the opportunity to exert e ort on project A, given $s_1 = A \neq B = s_2$. If in addition $I_1(B,B) = 0$ then

$$f_2(w - \frac{1}{2}) = \frac{1-\tilde{q}}{\tilde{q}} f_1(1-w) - \frac{\tilde{q}}{1-\tilde{q}} f_0 p_{BB} \frac{1}{2} \tag{46}$$

can be substituted into (45) to get

$$I_1(B,A) = f_0 p_{BB} \frac{1}{2} \tilde{q}(1-\tilde{q}) \left(1 - \frac{\tilde{q}^2}{(1-\tilde{q})^2}\right) < 0. \tag{4 }$$

Hence if the maximum feasible reward is paid and the B-type is indifferent between $m_1 = A$ and $m_1 = B$ then the A-type strictly prefers $m_1 = A$ over $m_1 = B$. It remains to show that the same is true when $w < 1 - \frac{2c}{\Delta f}$. For this purpose, define $\Delta I_1 = I_1(B,B) - I_1(B,A)$. ΔI_1 measures the difference in the incentives to issue $m_1 = B$ between the B-type and the A-type. The B-type has a stronger incentive to issue B than the A-type if and only if $\Delta I_1 \geq 0$. Note

$$\frac{\partial \Delta I_1}{\partial w} = (1-\tilde{q})^2 f_1 - \tilde{q}^2 f_2 < 0. \tag{4 }$$

A decrease in the reward makes the A type become less inclined to issue $m_1 = B$ relative to the B-type. Also note that

$$\frac{\partial \Delta I_1}{\partial p_{BB}} = f_0 \tilde{q}(\tilde{q} - \frac{1}{2}) > 0. \tag{4 }$$

An increase in p_{BB} makes the A type become less inclined to issue $m_1 = B$ relative to the B-type. Now starting from the implementability threshold $p_{BB} = \tilde{t}^*(\Delta f)$ for which $w = 1 - \frac{2c}{\Delta f}$, an increase in p_{BB} lowers the w necessary to make the B-type indifferent. Both changes make the A type become even less inclined to issue $m_1 = B$ relative to the B-type. This shows that if $w < 1 - \frac{2c}{\Delta f}$ is chosen to make the B type indifferent between truth–telling and lying, then the A type will tell the truth. Hence (30) is necessary and sufficient for the implementability of the benchmark. Finally, to see that $\tilde{T}^0 \neq \emptyset$, note that $\tilde{t}^*(\Delta f)$ is decreasing in Δf. Hence $\tilde{T}^0 \neq \emptyset$ if and only if $\tilde{t}^*(\Delta f^{min}) > p_{BB}^{min}$. Substitution of $\Delta f^{min} = 4c$ and $p_{BB}^{min} = \frac{(1-\tilde{q})^2}{\tilde{q}^2}$ into this condition shows that the condition is equivalent to $\tilde{q} < 1$ which is satisfied by assumption.

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