Project Selection and Execution in Teams*

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Abstract

We use a mechanism-design approach to study a team whose members select a joint project and exert individual efforts to execute it. Members have private information about the qualities of alternative projects. Information sharing is obstructed by a trade-off between *adaptation* and *motivation*. We determine the conditions under which first-best project and effort choices are implementable and show that these conditions can become relaxed as the team grows in size. This contrasts with the common argument (based on free-riding) that efficiency is harder to achieve in larger teams. We also characterize the second-best mechanism and find that it may include a 'motivational bias', that is, a bias in favor of the team's initially preferred project, and higher-than-optimal effort by uninformed team members.

JEL *classification*: D02, D23, L29.
Keywords: teams, adaptation, motivation, decision-making, incentives.

*We thank Ricardo Alonso, Antonio Cabrales, Wouter Dessein, Luis Garicano, Thomas Kittsteiner, Kristof Madarasz, Ignacio Palacios-Huerta, Joaquin Poblete Lavanchy, David Rahman, Luis Rayo, Roland Strausz and participants at various seminars and conferences for valuable discussions and suggestions.

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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 sub-optimal effort choices. 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 an optimal decision. Nevertheless, teams with largely aligned incentives often fail to communicate valuable information and end up with sub-optimal decisions. A classic example of a cohesive team making wrong-headed decisions is the Kennedy administration during the Bay of Pigs invasion. Its failure is commonly attributed to a lack of communication as several members of the administration claimed to have failed to express their opinion that the operation was flawed (Janis, 1982). Similar behavior has been documented using firm (Perlow, 2003) and laboratory studies (Stasser and Titus, 1985, Gigone and Hastie, 1993). In this paper, we argue that less-than-full communication and biased decision-making can be rationalized as a team's optimal institutional arrangement in settings where decisions must not only be taken but also executed.

Our starting point is the observation that the desire to keep 'morale' high at the execution stage may hinder information-sharing between the members of a team. Consider for instance two co-authors choosing between two alternative scientific projects. Suppose that, ex ante, both authors expect that project A is 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 selecting project A he can benefit from 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 the ex post 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 which questions 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 diminishing troops' morale.[1] The view that a commitment to 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.[2]

Building on the above example, Section 2 presents a tractable model of team decision-making characterized by two main features: (1) project selection and project execution are complementary; and (2) each team member (privately) obtains (with some probability) verifiable information about the projects' qualities. In the first-best benchmark, team members select the project with the highest (expected) quality, conditional on their aggregate information, and exert efficient levels of effort. We use a mechanism design approach to examine the conditions under which the first best is implementable and to determine the characteristics of the team's optimal institutional arrangement.[3] In our model, team members decide whether or not to disclose their evidence to a mechanism

[1]Interview with Martha Raddat, ABC News on April 11, 2008, transcript available at http://abcnews.go.com/Politics/story?id=4634219&page=1.

[2]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=13047099.

[3]An alternative approach would be to assume a *specific* institutional arrangement and to derive the conditions under which team members are willing to communicate their private information. We pursue this approach in Blanes i Vidal and Möller (2013) for a setting in which team members receive a constant share of revenue and project-choice can be delegated to a manager. In this paper, we adopt a mechanism design approach to show that less-than-full communication and biased decision-making can persist even in the most general contracting environment.

which, based on the disclosed information, selects a project, recommends individual effort levels and specifies the team members' outcome-contingent compensation.[4] We allow the mechanism's project selection and effort recommendation to be random and impose only limited liability and budget balance.

The paper provides two main results. First, we show that the first-best benchmark is implementable if and only if the value of adaptation (i.e. the value of adapting the decision to the state of the world) is sufficiently large in comparison to the value of motivation (i.e. the value of inducing high execution effort). The optimal mechanism rewards disclosing members with the revenue-shares of non-disclosing members in order to improve the team's ability to share information in conflict with its prior. It is worth emphasizing that, in our setting, inefficiencies arise exclusively from the team's failure to aggregate information. In fact, we find that, contrary to settings where inefficiencies arise from free-riding, an increase in team size has a *positive* effect on the team's ability to aggregate information and hence on the implementability of the first best.

Our second result characterizes the optimal mechanism when the first-best benchmark fails to be implementable. We show that, when the value of motivation is sufficiently high, the second-best mechanism exhibits three features. First, the mechanism sometimes transmits no information between the team's members. In particular, team members are unable to improve on their information from observing the mechanism's project choice, effort recommendation, and revenue allocation. This contrasts with the first-best mechanism under which information observed by one member is fully mediated to the other. Second, the mechanism inefficiently selects the team's initially preferred alternative even when some (but not all) members have reported evidence documenting its inferior quality. Finally, the mechanism recommends high effort to uninformed team members even in situations when low effort would be more efficient. These findings show that the apparent failure to communicate information in the above examples can be explained as a feature of a team's optimal institutional arrangement.

[4] In our setting of an autonomous team, the mechanism should be understood as a mechanical device or contract rather than a third party. For examples, see our formal description of a mechanism in Section 2. The use of a mechanism requires a certain degree of commitment. The effects of limiting this commitment are discussed in Section 7.

Related literature

This paper is related to a body of work explaining why groups often fail to aggregate information efficiently. Previous contributions have 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 contrast to existing work, this paper highlights the consequences of a group's desire to maintain high morale at the execution stage, for the communication of information at the decision-making stage.[5] Moreover, in the literature on group decision-making, effort typically refers to the acquisition of decision-relevant information (Persico 2004, Gerardi and Yariv 2007, Gershkov and Szentes 2009, Campbell et al. 2013), rather than the execution of a joint decision. Some of these papers (Gershkov and Szentes 2009, Campbell et al. 2013), share with us the feature that group members fail to communicate their information in order to affect their colleagues' beliefs about the marginal return of effort.

Our model also ties in with a small literature examining organizational responses to the existence of a trade-off between efficiency at the decision-making stage and motivation at the execution stage. Banal-Estañol and Seldeslachts (2009), for instance, study mergers and show that the incentive to free-ride on a potential partner's post-merger effort may hinder decision-making at the pre-merger stage. Zabojnik (2002), Blanes i Vidal and Möller (2007), and Landier et al. (2009) instead focus on settings where decision-making and execution lie at different levels of the organizational hierarchy. We contribute to this literature by determining the optimal organizational arrangement in a general team framework.

Lastly, a key feature of our model is that the choice of mechanism determines how much of a team member's information is transmitted to her colleagues. This role of a mechanism as a mediator of information is shared by the literature on Bayesian persuasion (e.g. Rayo and Segal (2010), Kamenica and Gentzkow (2011)). A similar role is played by the intermediaries in the two-sided market models of Ostrovsky and Schwarz (2010)

[5]Benabou (2008) also emphasizes the importance of group-morale, but does so in a very different model where individuals decide whether to engage in "reality denial" about an exogenously given productivity parameter.

and Hagiu and Jullien (2011). A key difference between these papers and our model is that our second-best mechanism coarsens information, not because it is ex-ante beneficial to (one of) the parties, but instead to convince the parties to reveal their information to the mechanism. More related are therefore Goltsman and Pavlov (2014) and Hörner et al. (2011) where a mediator is used to improve communication between two competing players who are privately informed about their "aggressiveness". The mediator needs to convince the parties to reveal their types and determines how much information is transmitted from one party to the other. In our setting, the mechanism not only acts as a mediator of information but also performs the task of selecting the team's project.

2 The model

We consider a team with two identical members $i \in \{1, 2\}$.[6] The team's purpose is to choose and execute 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 one, otherwise its revenue is zero. Project x's likelihood of success is increasing in the team members' efforts $\mathbf{e} = (e^1, e^2) \in E$. Individual efforts are unobservable and non-contractible and can be either high or low, $e^i \in \{e_L, e_H\}$. We set $e_L = 0$ and $e_H = 1$ and let member i's effort costs be ce^i with $c > 0$. Project x's likelihood of success also increases in its "quality" $p_{xy} \geq 0$ which depends on a state variable $y \in Y \equiv \{a, b\}$. We assume that the probability of success takes the following form:

$$\Pr(\text{success}|x, y, \mathbf{e}) \equiv p_{xy} \cdot f(\mathbf{e}). \tag{1}$$

According to (1), project quality and effort are complementary inputs of production. This assumption is standard in the literature on organizations and empirical support has been provided by Rosen (1982). Since team members are identical and efforts are binary, the function f can take only three values. Indexing f by the number of team members who exert high effort, these values are denoted as $0 < f_0 < f_1 < f_2$. To simplify the analysis,

[6]In Section 6 we extend our model to allow for an arbitrary number of members.

we assume that efforts are independent, i.e. $f_2 - f_1 = f_1 - f_0 \equiv \Delta f$.[7]

We give sense to the notion that it is important to adapt the project choice to the state of the world by assuming that in state $y = a$ project A has higher quality than B whereas in state $y = b$ project B has higher quality than A. More specifically, we assume that

$$p_{Aa} > p_{Ba} \quad \text{and} \quad p_{Bb} > p_{Ab}. \tag{A1}$$

To simplify the exposition we set $p_{Aa} = 1$ and $p_{Ba} = 0$ and consider the case where both states are equally likely. For other priors and general values of p_{xa} our results remain qualitatively unchanged. Without loss of generality, we choose A to be the project that is expected to have a higher quality ex ante, i.e.

$$\bar{p}(A) \equiv \frac{1}{2}(1 + p_{Ab}) > \frac{1}{2}p_{Bb} \equiv \bar{p}(B). \tag{A2}$$

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.[8]

Our final assumption is concerned with the productivity of effort. While for large vales of Δf, team members can be induced to exert high effort on both projects, for small values of Δf, high effort cannot be induced for any project. In both cases, project choice would have no influence on efforts. For a trade-off between adaptation and motivation to exist, team members must be willing to exert high effort on one project but not on the other. Our analysis therefore focuses on the non-trivial case where

$$\Delta f^{min} \equiv \frac{2c}{\bar{p}(A)} \leq \Delta f < \frac{c}{p_{Bb}} \equiv \Delta f^{max}. \tag{A3}$$

[7]We have verified that our result about the non-implementability of the first best extends to the case where efforts are complementary. Details are available on request.

[8]The assumption that private information is verifiable has a long tradition in information economics (see e.g. Milgrom, 1981). 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). While these assumptions represent a useful benchmark, we do not pretend that they are without loss of generality. They imply, for instance, that information is substitutable. We have verified that our result about the non-implementability of the first best extends to the case of unverifiable and complementary signals. Details are available on request.

The first inequality implies that, even in the absence of evidence, both team members can be induced to exert high effort on project A by receiving half of its revenue. The second inequality implies that a team member cannot be induced to exert high effort on project B even when he knows the state to be $y = b$.

We discuss the problem in a two-dimensional parameter space. The horizontal axis measures the value of motivation Δf corresponding to an increase in effort. The vertical axis measures the value of adaptation $\frac{p_{Bb}}{p_{Ab}}$. The trade-off between adaptation and motivation exists in the subset

$$T = \{(\Delta f, \frac{p_{Bb}}{p_{Ab}}) | \Delta f^{min} \leq \Delta f < \Delta f^{max}, \frac{p_{Bb}}{p_{Ab}} > 1\} \quad (2)$$

of the parameter space (see Figure 1). T is non-empty if and only if $p_{Ab} < p_{Bb} < \frac{\bar{p}(A)}{2}$, i.e. when project B's quality in state b is higher than project A's quality but relatively small compared to the quality project A is expected to have ex ante. This in turn requires project A to be relatively unattractive when it fails to match the state, i.e. $p_{Ab} < \frac{1}{3}$.[9]

Benchmark

As a benchmark consider the case where all information is observed publicly, i.e. by both team members. It follows immediately from our assumptions (A1) and (A2) that efficiency requires project A to be selected unless evidence for $y = b$ has been observed.

With respect to the efficient choice of effort, it follows from assumption (A3) that efforts on project B should be low independently of the team's observation. In contrast, efforts on project A should be high unless the team has observed evidence for $y = b$.

Note that 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.[10] This means that in the symmetric-information benchmark, surplus is equal

[9] For our technology to be well defined we further require that the probability of a success is smaller or equal to 1 for all $(\Delta f, \frac{p_{Bb}}{p_{Ab}}) \in T$. This holds if and only if $f_0 + 2\Delta f^{max} \leq 1 \Leftrightarrow f_0 < 1$ and $p_{Ab} \geq \frac{2c}{1-f_0}$. The last inequality is compatible with $p_{Ab} < \frac{1}{3}$ if and only if $c < \frac{1-f_0}{6}$.

[10] For $\Delta f < \frac{2c}{\bar{p}(A)}$, free-riding represents a second source of inefficiency, since receiving half of project A's revenue is not sufficient to induce efficient effort levels.

to its first-best value given by

$$W^* = \frac{1}{2}(f_2 - 2c) + \frac{1}{2}[(1-q)^2(p_{Ab}f_2 - 2c) + (1-(1-q)^2)p_{Bb}f_0]. \quad (3)$$

In Section 4 we determine the conditions under which this value can be achieved in the presence of asymmetric information about the projects' qualities.

A mechanism design approach

Following Myerson (1982), we use a mechanism design approach to determine the team's optimal institution. In a mechanism, each team member sends a (private) message conditional on his information. Depending on these messages, the mechanism selects a project, recommends (privately) to each member an individual effort level, and specifies the team members' outcome-contingent compensation. In our example of a joint venture, the mechanism could be interpreted as a contract that, on the basis of the individual firms' market research, selects from a set of potential products, recommends each firm a certain level of (non-contractible) "investment", and determines the allocation of profits. For a government cabinet, a mechanism could be thought of as a voting protocol which, contingent on individual (confidential) "votes", selects a policy, recommends actions to its members, and assigns political capital arising from the policy's potential success. We determine the mechanism which maximizes the team's total surplus subject to several constraints specified below.

For this purpose, let $s^i \in \{a, b, \emptyset\}$ denote member i's private information or *type*. Here we use $\emptyset$ to denote the event in which member i has failed to observe evidence. We denote the set of possible type profiles $\mathbf{s} = (s^1, s^2)$ as S. According to the *revelation principle*, we can restrict attention to direct mechanisms in which each member i simply sends a *message*, m^i, to the mechanism. Since information is assumed to be verifiable, message spaces are type-dependent. More specifically, type $s^i = y \in Y$ chooses a message $m^i \in \{y, \emptyset\}$ whereas type $s^i = \emptyset$ can only issue the message $m^i = \emptyset$.[11]

[11] While message spaces are typically part of the mechanism, in the presence of verifiable information, the disclosure of evidence has to be seen as the members' inalienable action. Bull and Watson (2007) show that this restriction is innocuous if type s^i can declare his type to be $\tilde{s}^i$ if and only if all of the evidence available to type $\tilde{s}^i$ is also available to type s^i. In our setting this condition is satisfied since

The exposition of the mechanism design problem is rather complicated. However, two observations help to simplify the exposition significantly. First, given assumption (A3), a recommendation to exert high effort on project B would never be followed. Hence we can restrict attention to mechanisms that recommend both members to exert low effort when project B becomes selected. Second, it is easy to see that in our setting, the disclosure of evidence *in favor of* the initially preferred project A is never an issue. This is because the disclosure of $y = a$ is beneficial for *both* adaptation *and* motivation.[12] As a consequence we can ignore the corresponding disclosure constraint in our description of the mechanism design problem.

For every message profile $\mathbf{m} = (m^1, m^2) \in S$ a *mechanism* (α, β, ω) specifies three objects: (1) the probability $\alpha_{\mathbf{m}} \in [0, 1]$ with which project $x = A$ becomes selected; (2) the probabilities $\beta_{\mathbf{m}}(\mathbf{e}) \in [0, 1]$ with which members are recommended to exert efforts $\mathbf{e} \in E$ when working on project A; and (3) the allocation of revenue in case of success, $\omega_{\mathbf{m}}(x, \mathbf{e}) \in [0, 1]^2$, as a function of the selected project and the recommended efforts.

A mechanism induces a (Bayesian) game defined by the following sequence of events: (1) Each member observes his type. (2) Members send messages $\mathbf{m}$ (privately) to the mechanism. (3) The mechanism chooses a project x and effort recommendations $\mathbf{e}$ in accordance with $\alpha_{\mathbf{m}}$ and $\beta_{\mathbf{m}}$. It announces (publicly) the selected project x and communicates (privately) to each member his individual effort recommendation e^i and his compensation $\omega^i_{\mathbf{m}}(x, \mathbf{e})$ in case of success. (4) Members choose unobservable efforts. (5) Finally, when the project turned out to be successful member i receives the revenue $\omega^i_{\mathbf{m}}(x, \mathbf{e})$.

We assume that team members have a zero reservation utility. Since payments are non-negative and exerting zero effort is costless this implies that participation is not an issue, neither at the ex ante nor at the interim stage. Implicit in our definition of a mechanism is the assumption that team members are protected by *limited liability*, i.e.

type $s^i = y$ can declare to be type $s^i = \emptyset$ but type $s^i = \emptyset$ cannot declare to be type $s^i = y$. 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.

[12]For the formal argument see Step 1 of the proof of Proposition 1.

$\omega^i_{\mathbf{m}} \geq 0$.[13] In addition, we require the mechanism to satisfy three constraints. First, since the team is autonomous, revenue must be shared amongst its members. In particular, the mechanism should satisfy the following *budget constraint* (BC): For all $\mathbf{m} \in S$, $x \in X$, and $\mathbf{e} \in E$, it must hold that

$$\omega^1_{\mathbf{m}}(x, \mathbf{e}) + \omega^2_{\mathbf{m}}(x, \mathbf{e}) = 1. \tag{BC}$$

Second, since efforts are unobservable and non-contractible, each member must have an incentive to follow the mechanism's effort recommendation. In particular, the mechanism should satisfy the following *incentive constraint* (IC): For all members $i \in \{1, 2\}$ and type profiles $\mathbf{s} \in S$, and all effort recommendations $\mathbf{e} \in E$ (for project A) that are given with positive probability, $\beta_{\mathbf{s}}(\mathbf{e}) > 0$, it holds that

$$\omega^i_{\mathbf{s}}(A, \mathbf{e})\hat{p}(A)\Delta f \geq c \quad \text{if and only if} \quad e^i = e_H. \tag{IC}$$

Here $\hat{p}(A)$ denotes the member's expectation about project A's quality given his information and his knowledge of the mechanism. The compensation ω^i is written as a function of the observed evidence $\mathbf{s}$ rather than the members' messages $\mathbf{m}$ since we require (IC) to hold only on the equilibrium path.

Finally, each member must find it optimal to disclose his evidence. In order to derive the corresponding constraint, consider member i's expected payoff if he observed $s^i = b$ and messages $\mathbf{m}$ were sent:

$$u^i_{\mathbf{m}} = (1 - \alpha_{\mathbf{m}})\omega^i_{\mathbf{m}}(B)p_{Bb}f_0 + \alpha_{\mathbf{m}} \sum_{\mathbf{e} \in E} \beta_{\mathbf{m}}(\mathbf{e})\omega^i_{\mathbf{m}}(A, \mathbf{e})p_{Ab}f(e_L, e^j). \tag{4}$$

The two terms refer to the potential selection of project B or project A respectively. For project B, low efforts are recommended (and chosen) with certainty. For this reason we are able to suppress the argument (e_L, e_L) in $\omega^i_{\mathbf{m}}(B)$. In contrast, the mechanism may randomize over effort recommendations $\mathbf{e} \in E$ for project A. Knowing the state to be $y = b$, member i will choose low effort e_L, independently of his effort recommendation. In

[13] Limited liability is necessary for our results. With unlimited liability, the disclosure of evidence can be induced by threatening a member with a sufficiently severe punishment whenever he turns out to be the only member who fails to disclose evidence.

order to make it optimal for member i to reveal evidence for $y = b$, the following *disclosure constraint* (DC) has to be satisfied:

$$qu^i_{b,b} + (1-q)u^i_{m^i=b,m^j=\emptyset} \geq qu^i_{m^i=\emptyset,m^j=b} + (1-q)u^i_{\emptyset,\emptyset}. \tag{DC}$$

Note that these inequalities reflect the fact that each member decides whether to disclose his evidence without knowing whether the other member has obtained (and disclosed) such evidence.

The team's objective is to determine the mechanism which maximizes (expected) surplus amongst all mechanisms satisfying the budget, incentive, and disclosure constraints. To write down this problem formally, denote by $\bar{p}_{\mathbf{s}}(x)$ project x's (expected) quality given type profile $\mathbf{s} \in S$. In particular, $\bar{p}_{\mathbf{s}}(x) = p_{xy}$ if the state was observed to be y and $\bar{p}_{\mathbf{s}}(x) = \bar{p}(x)$, as defined in (A2), if the state was not observed. Moreover, let $\kappa_{\mathbf{s}}$ be the likelihood with which type profile $\mathbf{s} \in S$ occurs. In particular, $\kappa_{\emptyset,\emptyset} = (1-q)^2$, $\kappa_{a,a} = \kappa_{b,b} = \frac{1}{2}q^2$, and $\kappa_{\mathbf{s}} = \frac{1}{2}q(1-q)$ for profiles $\mathbf{s}$ in which the state is observed by exactly one member. The mechanism design problem can then be written as:

$$\max_{(\alpha,\beta,\omega)} \sum_{\mathbf{s}\in S} \kappa_{\mathbf{s}} \left\{ (1-\alpha_{\mathbf{s}})\bar{p}_{\mathbf{s}}(B) f_0 + \alpha_{\mathbf{s}} \sum_{\mathbf{e}\in E} \beta_{\mathbf{s}}(\mathbf{e})[\bar{p}_{\mathbf{s}}(A) f(\mathbf{e}) - ce^1 - ce^2] \right\} \tag{5}$$
$$\text{subject to (BC), (IC), and (DC).}$$

The following lemma simplifies the derivation of the optimal mechanism substantially:

Lemma 1 *Without loss of generality we can restrict attention to symmetric mechanisms. Formally,* $\alpha_{m,\tilde{m}} = \alpha_{\tilde{m},m}$, $\beta_{m,\tilde{m}}(e,\tilde{e}) = \beta_{\tilde{m},m}(\tilde{e},e)$ *and* $\omega^1_{m,\tilde{m}}(x,e,\tilde{e}) = \omega^2_{\tilde{m},m}(x,\tilde{e},e)$.

The reasoning is straightforward. Given any optimal asymmetric mechanism, one can construct an optimal symmetric mechanism by combining it with the mechanism that is obtained by merely switching the identities of team members. An immediate consequence of Lemma 1 is that, conditional on messages and effort recommendations being identical, the mechanism must distribute revenue equally across members, i.e.

$$\omega^i_{m,m}(x, e_L, e_L) = \omega^i_{m,m}(x, e_H, e_H) = \frac{1}{2}. \tag{6}$$

3 Characterization of the optimal mechanism

In this section we characterize the optimal mechanism. Proposition 1 describes its main features, leaving only two degrees of freedom: (1) the probability with which project A is selected after the unilateral disclosure of evidence for state b; and (2) the probability that the mechanism recommends only one rather than two high efforts on project A in the absence of evidence.

Proposition 1 *Surplus is maximized by a mechanism with the following features:*

- *The probability with which project A is selected is:* $\alpha_{a,a} = \alpha_{a,\emptyset} = \alpha_{\emptyset,\emptyset} = 1$ *when no evidence for b is disclosed;* $\alpha_{b,\emptyset} \in [0,1]$ *when b is disclosed unilaterally, that is, by only one member; and* $\alpha_{b,b} = 0$ *if b is disclosed by both members.*

- *High effort (on project A) is recommended to all members when* $y = a$ *is disclosed,* $\beta_{a,a}(e_H, e_H) = \beta_{a,\emptyset}(e_H, e_H) = 1$*, but only to the uninformed member when* $y = b$ *is disclosed unilaterally,* $\beta_{b,\emptyset}(e_L, e_H) = 1$*. When no evidence is disclosed, high effort is recommended to both members with probability* $\beta_{\emptyset,\emptyset}(e_H, e_H) \in [0,1]$ *and to only one member (picked at random) with probability* $1 - \beta_{\emptyset,\emptyset}(e_H, e_H)$*.*

- *The unilateral disclosure of evidence is rewarded with the maximum share of revenue that is consistent with the uninformed member's incentive to follow his effort recommendation:* $w^1_{a,\emptyset}(A, e_H, e_H) = w^1_{b,\emptyset}(A, e_L, e_H) = 1 - \frac{c}{\hat{p}(A)\Delta f}$*, and* $w^1_{b,\emptyset}(B) = w^1_{\emptyset,\emptyset}(A, e_H, e_L) = 1$*.*

The mechanism described in Proposition 1 leaves only the values of $\alpha_{b,\emptyset}$ and $\beta_{\emptyset,\emptyset}(e_H, e_H)$ unspecified. In the remainder, we denote these values as α and β respectively in order to simplify notation. The corresponding mechanism will be denoted as the (α, β)-mechanism. We now briefly explain the main intuition for this result. Its formal proof can be found in the Appendix.

The challenge faced by the mechanism is a tension between surplus maximization and individual disclosure incentives when evidence for $y = b$ is observed unilaterally. In this case, surplus-maximization requires the selection of project B and the recommendation of low efforts. However, the informed member might be tempted to raise his colleague's effort by concealing his evidence and invoking the selection of project A. In this case (DC) might therefore be binding, requiring the optimal mechanism to strengthen the members' incentive to disclose $y = b$. This should be done in a way that minimizes the resulting loss of surplus.

In the proof of Proposition 1, we show that there exist only three methods to improve the disclosure incentive for $y = b$ that are potentially optimal. The first one is to reward the unilateral disclosure of $y = b$ with a higher share of revenue. Since it consists of a simple reallocation of revenue, such a reward entails no loss of surplus. However, while for project B the disclosing member can be rewarded with the entire revenue, for project A the disclosing member's reward has to be consistent with the non-disclosing member's incentive to exert high effort. This is why for project A the maximum feasible reward is given by $1 - \frac{c}{\hat{p}(A)\Delta f}$ with $\hat{p}(A)$ denoting the project's expected quality from the viewpoint of the non-disclosing member.[14]

The second method is to increase a member's payoff from the unilateral disclosure of $y = b$ by biasing the team's decision-making via the selection of project A rather than B. The selection of project A together with the recommendation of high effort to the uninformed member mimics the outcome that the informed member could obtain by concealing his evidence. However, this comes at a loss of surplus, since project A's quality, p_{Ab}, is lower than project B's quality p_{Bb} and not sufficient to compensate for the uninformed member's cost of high effort, c. The surplus-loss is given by $(p_{Bb} - p_{Ab})f_0 + (c - p_{Ab}\Delta f)$ and is incurred whenever evidence for $y = b$ is observed unilaterally (with probability $q(1-q)$) and the bias in decision-making results in the selection of project A rather than project B (with probability α).

Finally, the third method is to decrease a member's payoff from the concealment of $y = b$ as follows: In the absence of evidence, the mechanism recommends high effort (on project A) to only one member, picked at random, together with the assignment of the project's entire revenue. In this case, a concealment of $y = b$ by member 1 either fails to induce member 2 to exert high effort or results in zero revenue for member 1. The resulting surplus loss is given by $\bar{p}(A)\Delta f - c$ and is incurred when no evidence is observed

[14]For $\alpha \neq 0$ the non-disclosing member is uncertain whether it was $y = a$ or $y = b$ that was disclosed. The precise expression for $\hat{p}(A)$ is derived in Section 5.

(with probability $(1-q)^2$) and low effort is recommended (with probability $1-\beta$).

In order to attain the first-best level of surplus, the (α, β)-mechanism specified in Proposition 1 must set $\alpha^* = 0$ and $\beta^* = 1$. For any other combination $(\alpha, \beta) \neq (0, 1)$, the mechanism incurs a total (expected) welfare loss of size

$$\Delta W(\alpha, \beta) = \alpha q(1-q)[(p_{Bb} - p_{Ab})f_0 + (c - p_{Ab}\Delta f)] + (1-\beta)(1-q)^2[\bar{p}^A \Delta f - c]. \quad (7)$$

Since the (α, β)-mechanism satisfies (BC) and (IC) by definition, the only remaining constraint is the disclosure constraint (DC). Substituting the features of the (α, β)-mechanism into (DC) this constraint simplifies to:

$$\begin{aligned} & q\frac{1}{2}p_{Bb}f_0 + (1-q)[(1-\alpha)p_{Bb}f_0 + \alpha(1 - \frac{c}{\hat{p}(A)\Delta f})p_{Ab}f_1] \quad (8) \\ & \geq q\alpha\frac{c}{\hat{p}(A)\Delta f}p_{Ab}f_0 + (1-q)[\beta\frac{1}{2}p_{Ab}f_1 + \frac{1-\beta}{2}p_{Ab}f_0]. \end{aligned}$$

The left hand side represents a member's expected payoff from disclosing evidence for $y = b$. With probability q the other member also observed (and discloses) evidence, resulting in the selection of project B and equal shares of revenue. With probability $1-q$ the other member failed to observe evidence. In this case the mechanism either selects project B and rewards the disclosing member with its entire revenue or it selects project A and recommends the uninformed worker to exert high effort.

The right hand side represents a member's expected payoff from concealing evidence for $y = b$. When the other member observed (and discloses) such evidence, the mechanism either selects project B and punishes the non-disclosing member with a zero share of revenue, or it selects project A and recommends high effort only to the non-disclosing member. Finally, when both members fail to disclose evidence the mechanism selects project A and either recommends high effort to both members (with equal revenue shares) or it recommends high effort to only one of the members (together with the assignment of the project's entire revenue).

In order to complete the characterization of the optimal mechanism it remains to determine the combination (α, β) that solves the following linear program:

$$\min_{\alpha,\beta\in[0,1]} \Delta W(\alpha, \beta) \quad \text{subject to} \quad (8). \quad (9)$$

In the next section we determine the set of parameters for which the first-best level of surplus can be implemented. In the subsequent section we then characterize the (second) best mechanism for the remaining set of parameters.

4 First best

In this section we determine the set of parameters for which the first-best level of surplus can be implemented. For the welfare loss in (7) to be zero it must hold that $(\alpha, \beta) = (0, 1)$. The first-best mechanism selects project B if and only if evidence for $y = B$ is disclosed, recommends high effort to both members whenever project A is selected, and rewards a member who discloses evidence unilaterally with a higher share of revenue.

Note that under the first-best mechanism, information is shared amongst team members. More precisely, an uninformed team member can perfectly infer the other member's information from the outcome of the mechanism. In particular, if member i observed $s^i = \emptyset$ then from the selection of project B he infers that member j must have observed $s^j = b$. Instead, if project A is selected, member i can infer whether $s^j = a$ or $s^j = \emptyset$ from whether or not he is awarded a smaller share of revenue than member j. This implies that under the first-best mechanism uninformed team members have correct expectations about the projects' quality, i.e. $\hat{p}(A) = \bar{p}_{\mathbf{s}}(A)$.

It remains to derive the conditions under which the first-best mechanism satisfies the disclosure constraint in (8). Setting $\alpha = 0$ and $\beta = 1$ this constraint further simplifies to

$$q\frac{1}{2}p_{Bb}f_0 + (1-q)p_{Bb}f_0 \geq (1-q)\frac{1}{2}p_{Ab}f_1. \tag{10}$$

The intuition for this condition is as follows. With probability q, member j has also observed $y = b$ and a concealment by member i lowers i's revenue share from one half to zero. With probability $1-q$, member j has failed to observe $y = b$ and a concealment by member i decreases i's revenue share from one to one half and the project's quality from p_{Bb} to p_{Ab} in exchange for an increase in member j's effort. The disclosure of $y = b$ is guaranteed as long as the drop in the project's quality is sufficiently large in comparison to the return to effort:

$$\frac{p_{Bb}}{p_{Ab}} \geq t^*(\Delta f) \equiv \frac{1-q}{2-q}\left(1 + \frac{\Delta f}{f_0}\right). \tag{11}$$

Proposition 2 *The first best fails to be implementable in a non-empty subset of the parameter space given by*

$$T^{**} = \{(\Delta f, \frac{p_{Bb}}{p_{Ab}}) \in T | \frac{p_{Bb}}{p_{Ab}} < t^*(\Delta f)\} \tag{12}$$

if and only if $p_{Ab} < \frac{c}{f_0}$ *and* $q < q^* \equiv 1 - \frac{p_{Ab} f_0}{c} \in (0, 1)$.

Figure 1 depicts the case where the conditions of Proposition 2 are satisfied.[15] The first

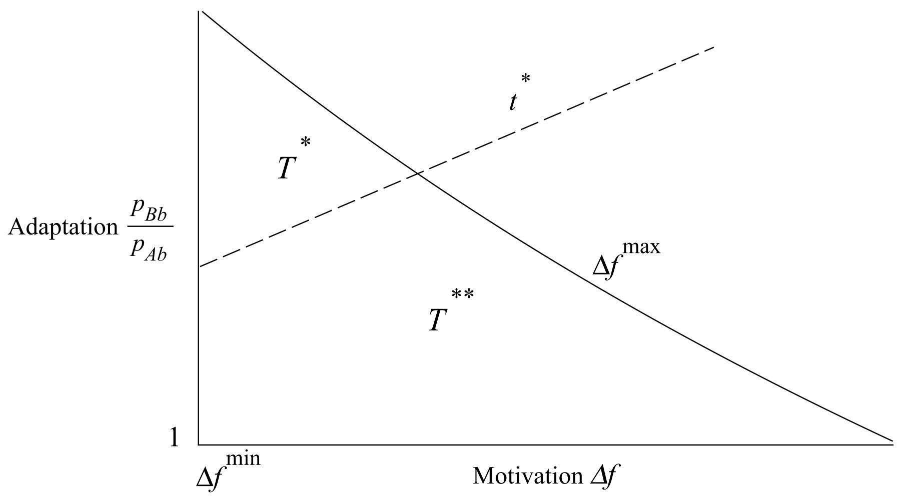

Figure 1: Implementability of the first best: The parameter space T is the area below Δf^{max}. The first best is implementable in T^* but fails to be implementable in T^{**}.

best is implementable in T^* but fails to be implementable below the dashed line in the area denoted as T^{**}. The intuition for this result is as follows. When team members favor motivation over adaptation, i.e. $p_{Ab} f_1 > p_{Bb} f_0$, then a reward for unilateral disclosure is necessary to induce the revelation of evidence for $y = b$. 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 exceeds the maximum feasible reward of obtaining the project's *entire* revenue. As a result, the first best is no longer implementable.

[15] Given the parametric restriction on p_A contained in footnote 9, the requirement $p_{Ab} < \frac{c}{f_0}$ of Proposition 2 can be satisfied if and only if $\frac{2c}{1-f_0} < \frac{c}{f_0} \Leftrightarrow f_0 < \frac{1}{3}$.

To understand the condition on p_{Ab}, note that the necessary reward is at its maximum when the value of motivation is highest, $\Delta f \to \Delta f^{max}$, the value of adaptation is lowest $\frac{p_{Bb}}{p_{Ab}} \to 1$, and members are most likely not to have observed evidence, $q \to 0$. 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 the remainder of this section we discuss which of the constraints are responsible for the non-implementability of the first best in T^{**}. To answer this question, we consider the effect of relaxing (BC) or (IC). (BC) can be relaxed to $\omega^1 + \omega^2 \leq 1$ by the introduction of a third party, a so-called budget-breaker, who absorbs the revenue that fails to be allocated to one of the team's members. (IC) can be eliminated by the introduction of a monitor, who enforces the mechanism's effort recommendations.

If effort recommendations are enforceable through a monitor, a team member who decides to conceal $y = b$ will be forced to exert high effort when project A becomes selected. Hence the term $\frac{1}{2}p_{Ab}f_1$ in (10) becomes substituted by the smaller term $\frac{1}{2}p_{Ab}f_2 - c$, i.e. (DC) becomes relaxed. In fact, the concealment of $y = b$ becomes unappealing in the entire parameter set.[16] Hence, when efforts are enforceable through a monitor, the first best is implementable in the entire parameter space. This shows that (IC) is (partly) responsible for the non-implementability of the first best in the entire T^{**}.

Now reinstate (IC) but relax (BC) by assuming the existence of a budget-breaker. It follows from (10) that "breaking the budget" is useful only in the case where no information is disclosed and both members are recommended to exert high effort on project A. In this case, team members can be punished *collectively* for the absence of evidence by the transfer of revenue to the budget-breaker. In particular, *both* members can be allocated the minimal revenue share consistent with their incentive to exert high effort. Substituting the term $\frac{1}{2}p_{Ab}f_1$ in (10) by the smaller term $\frac{c}{\bar{p}(A)\Delta f}p_{Ab}f_1$ relaxes (DC) maximally without violating (IC). From (10) it is then straightforward to determine a new threshold for the implementability of the first best. This threshold divides the original T^{**} into two areas. In one area the first best fails to be implementable because (DC),

[16]To see this, note that the payoff from concealment $(1-q)(\frac{1}{2}p_{Ab}f_2 - c)$ is increasing in the value of motivation, Δf, and, for $\Delta f \to \max_T \Delta f = \frac{c}{p_{Ab}}$, converges to $(1-q)\frac{1}{2}p_{Ab}f_0$ which is strictly smaller than the payoff from disclosure $q\frac{1}{2}p_{Bb}f_0 + (1-q)p_{Bb}f_0$.

(IC), *and* (BC) cannot be satisfied simultaneously. In the other area, the first best is not implementable even in the presence of a budget breaker, that is, inefficiencies arise solely due to the incompatibility of (DC) and (IC).

5 Second best

In the introduction we described examples for team behavior characterized by a motivational bias. The defining features were: (1) a failure to share evidence in conflict with prior information; (2) a bias in decision-making in favor of the initially preferred alternative; and (3) a boost to morale. In this section we provide a rationale for this behavioral pattern by determining the conditions under which it constitutes (part of) the team's (second) best mechanism.

The optimal mechanism characterized in Section 3 induces each team member to disclose $y = b$ to the mechanism. However, information may not be transmitted across members. In particular, when a member discloses $y = b$ unilaterally and project A becomes selected, the uninformed member can deduce from his low share of revenue, $\frac{c}{\hat{p}(A)\Delta f}$, that his colleague must have disclosed evidence. However, the uninformed member can *not* infer whether the evidence was for $y = a$ or for $y = b$. From Bayesian updating, the uninformed member's belief about the quality of project A is given by

$$\hat{p}(A) = \frac{1}{1+\alpha} \cdot 1 + \frac{\alpha}{1+\alpha} \cdot p_{Ab} = \frac{1+\alpha p_{Ab}}{1+\alpha}. \tag{13}$$

For $\alpha < 1$, project A is less likely to become selected after a unilateral observation of $y = b$ than after a unilateral observation of $y = a$. Hence, the selection of project A constitutes positive news with respect to its chances of success. By pooling the information that one member has observed $y = a$ or $y = b$, the mechanism increases the other member's morale beyond his prior expectations, i.e. $\hat{p}(A) > \bar{p}(A)$. Moreover, for $\alpha > 0$, the team's project choice is biased in the direction of the initially preferred alternative and an uninformed member is induced to exert high effort on project A even when the other member has observed the state to be b. Hence for $\alpha \in (0, 1)$, information fails to be shared, decision-making is biased, and morale is increased. It is therefore reasonable to make the following:

Definition 1 *The optimal mechanism exhibits a motivational bias if* $\alpha \in (0, 1)$.

In the Appendix we determine the conditions under which $\alpha^{**} \in (0,1)$ in the (second) best mechanism. Our results can be summarized as follows:

Proposition 3 *There exists an increasing threshold $t^+(\Delta f)$ and a non-empty subset of T^{**} given by*

$$T^+ = \{(\Delta f, \frac{p_{Bb}}{p_{Ab}}) \in T^{**} | \frac{p_{Bb}}{p_{Ab}} < t^+(\Delta f)\} \tag{14}$$

in which the (second) best mechanism exhibits a motivational bias. In $T^{**} \setminus T^+$ the second best mechanism features first best project selection but induces inefficiently low effort in the absence of evidence.

The set T^+ is depicted in Figure 2. The second best mechanism exhibits a motivational bias in the area to the right of the dotted line $t^+(\Delta f)$. To the left of this line, the second best mechanism is characterized by an efficient project selection ($\alpha = 0$) but inefficiently low effort. These two potential outcomes reflect the underlying trade-off between adaptation and motivation.

Proposition 3 rationalizes the behavior described in the introduction as the (second) best mechanism for a team in a situation where the value of adaptation is relatively low in comparison to the value of motivation. In such a situation, the value of maintaining high morale outweighs the value of adapting the team's project to the information that may potentially be received by its members. The mechanism prevents such information from being shared. Concealment of evidence in conflict with the initially preferred alternative is not only optimal from the perspective of the individual team member but also from the perspective of the team as a whole. Our model thus provides a rationale for the observation of an apparently irrational bias in group decision making.

6 Team size

In this section, we extend our analysis to a team with an arbitrary number of members, $N > 2$, in order to consider how the implementability of the first best depends on the

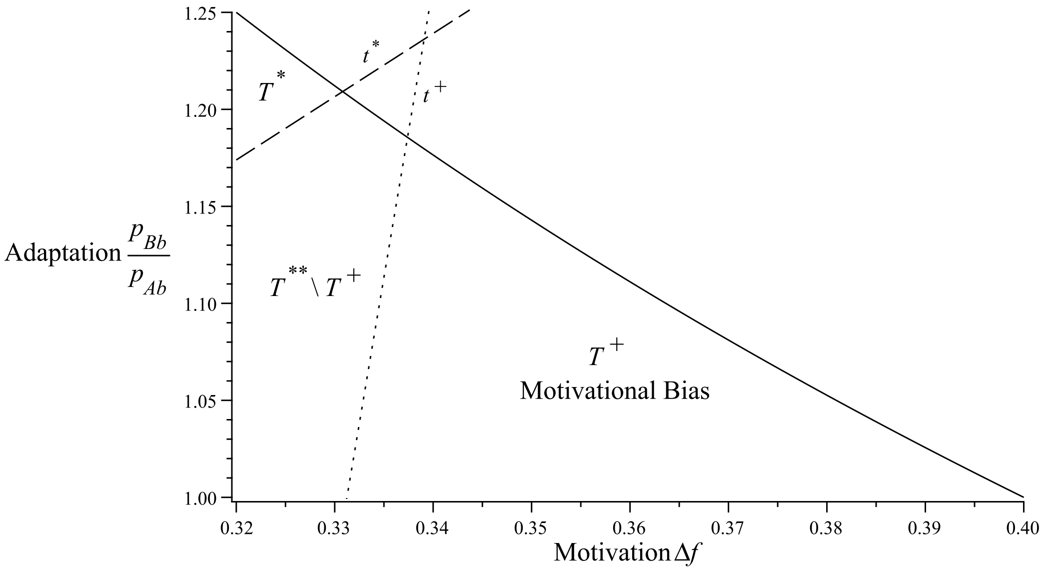

Figure 2: Motivational bias: The subset T^+ of the parameter space, for which the second best mechanism exhibits a motivational bias, is the area to the right of the dotted line t^+. T^+ may consist of the entire set T^{**}, for which the first best fails to be implementable, or be a non-empty subset as depicted. In the (potentially empty) remaining area $T^{**} \setminus T^+$ the second best mechanism induces first best project choices but sub-optimal efforts. Parameters chosen are $f_0 = 0.04$, $c = 0.1$, $p_{Ab} = 0.25$, and $q = 0.85$.

team's size.[17] Intuitively, two countervailing effects can arise when a team increases in size. On the one hand, the concealment of evidence is potentially more rewarding since it can boost the motivation of a higher number of colleagues. On the other hand, the concealment of evidence is less likely to succeed in a bigger team. In this Section, we show that the latter effect dominates. In contrast to settings where moral hazard constitutes the only source of inefficiency, we therefore obtain the surprising result that, in the presence of informational asymmetries, an increase in team size can have a *positive* effect on the implementability of the first best.

Below, we first extend Proposition 2 to an arbitrary number of members and then

[17]The results in this section are not driven by the fact that our technology exhibits decreasing returns to scale. They are valid for arbitrarily small $f_0 > 0$ and therefore remain true when returns to scale become (approximately) constant.

show the effects of an increase in team size. As in Section 2, we restrict attention to the subset of parameters for which equal revenue sharing is sufficient to induce first-best efforts in a team of size N by adjusting assumption (A3) to

$$\Delta f_N^{min} \equiv \frac{Nc}{\bar{p}(A)} < \Delta f < \frac{c}{p_{Bb}} \equiv \Delta f^{max}. \tag{A3'}$$

The set of parameters for which a trade-off between adaptation and motivation exists in a team of size N becomes

$$T_N = \{(\Delta f, \frac{p_{Bb}}{p_{Ab}}) | \Delta f_N^{min} < \Delta f < \Delta f^{max}, \frac{p_{Bb}}{p_{Ab}} > 1\} \tag{15}$$

in analogy to before.[18] The parameter space under consideration now depends on the team's size N. Below we will compare a team of size N with a team of size $N+1$, restricting attention to parameters in T_N. For this purpose, it is important to note that T_{N+1} is a subset of T_N and that for parameters outside T_N, the first best is either implementable ($\Delta f > \Delta f^{max}$) or non-implementable ($\Delta f < \Delta f_N^{min}$) independently of whether the team has N or $N+1$ members.

The generalization of the optimal mechanism characterized in Section 3 to the case of N team members is straightforward. The only novelty is that with more than two members, there exists a wider range of possibilities to reward the disclosure of information. In particular, disclosure can not only be rewarded when it happens unilaterally but whenever *at least one other* member failed to disclose. The incentive to disclose is then maximized by allocating to all uninformed members the minimal revenue share that is consistent with their effort incentives and by sharing the remaining revenue (equally) amongst all members who disclosed evidence. With this revenue sharing rule, the generalized version of the disclosure constraint (10) becomes

$$p_{Bb} f_0 \sum_{k=0}^{N-1} \binom{N-1}{k} q^k (1-q)^{N-1-k} \frac{1}{1+k} - p_{Ab}(f_0 + (N-1)\Delta f)(1-q)^{N-1} \frac{1}{N} \geq 0 \tag{16}$$

which is equivalent to

$$\frac{p_{Bb}}{p_{Ab}} \geq t_N^*(\Delta f) \equiv \frac{q(1-q)^{N-1}}{1-(1-q)^N}(1 + (N-1)\frac{\Delta f}{f_0}). \tag{17}$$

[18] The parametric restrictions in footnote 9 generalize to $f_0 < 1$, $c < \frac{1-f_0}{N(2N-1)}$, and $p_{Ab} > \frac{Nc}{1-f_0}$.

In the Appendix we prove the following:

Proposition 4 *For a team with $N > 2$ members, the first best fails to be implementable in a non-empty subset of the parameter space*

$$T_N^{**} = \{(\frac{p_{Bb}}{p_{Ab}}, \Delta f) \in T_N | \frac{p_{Bb}}{p_{Ab}} < t_N^*(\Delta f)\} \tag{18}$$

if and only if $p_{Ab} < \frac{c}{f_0}$ and $q < q_N^*$. The thresholds t_N^* and $q_N^* \in (0,1)$ are decreasing in N.

Proposition 4 extends Proposition 2 to the case of $N > 2$ team members by showing that the first best is implementable only in a subset of the parameter space. In Figure 3, this is the area to the left of the dashed line t_N^*.

We now consider how the implementability of the first best is affected by an increase in team size from N to $N+1$. As can be seen from Figure 3 there are two effects. Firstly, the incentive constraint Δf^{min}, which ensures the implementability of the optimal effort levels, moves to the right. There are parameter values, depicted as the area $T_N^* \setminus T_{N+1}^*$ in Figure 3, for which the first best is therefore implementable in a team of size N but not in a team of size $N+1$. In $T_N^* \setminus T_{N+1}^*$, an increase in team size has a negative effect on the implementability of the first best, due to the emergence of free-riding. The first best is no longer implementable, since the assignment of a $\frac{1}{N+1}$ share rather than a $\frac{1}{N}$ share of revenue is not sufficient to induce members to exert high effort on project A in the absence of evidence. This negative effect of team size on the implementability of the first best is well known at least since the seminal work of Holmstrom (1982).

However, there exists a second effect. As team size increases from N to $N+1$, the disclosure threshold t^*, which guarantees the disclosure of private information in favor of project B, also moves to the right. Hence there may exist parameter values, depicted as the area $T_{N+1}^* \setminus T_N^*$ in Figure 3, for which the first best can be implemented in a team of size $N+1$ but not in a team of size N. In $T_{N+1}^* \setminus T_N^*$, an increase in team size has a positive effect on the implementability of the first best. The first best becomes implementable since the disclosure of information can be induced (without loss of surplus) in a team of size $N+1$ but not in a team of size N. Our last result states sufficient conditions under which the area $T_{N+1}^* \setminus T_N^*$ is non-empty:

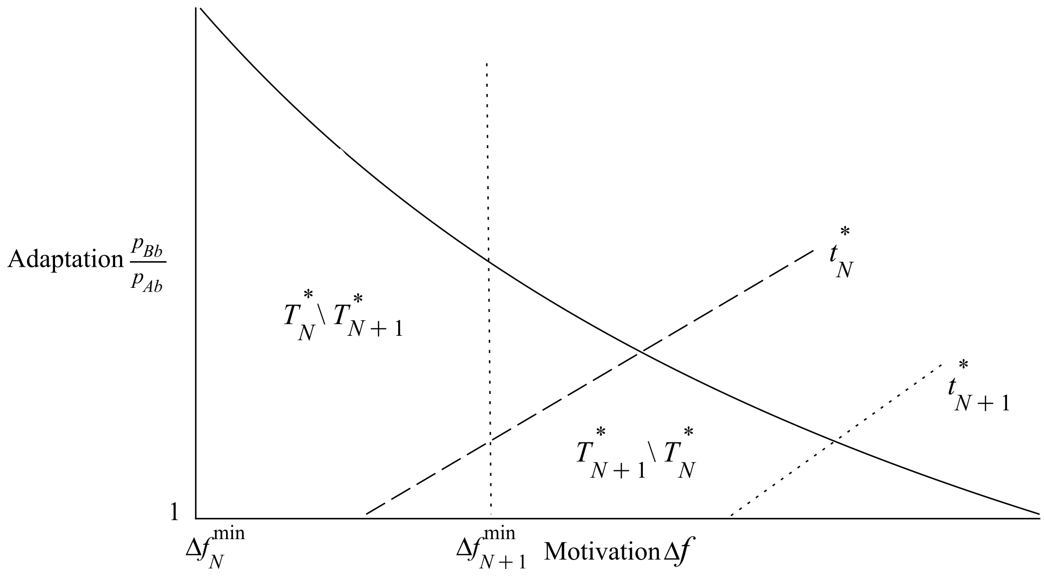

Figure 3: Team size: Increasing team size from N to $N+1$ moves *both*, Δf^{min} and t^*, to the right, i.e. it tightens the incentive constraints but relaxes the disclosure constraints. In the area $T^*_N \setminus T^*_{N+1} = \{(\frac{p_{Bb}}{p_{Ab}}, \Delta f) \in T_N | \Delta f < \Delta f^{min}_{N+1}, \frac{p_{Bb}}{p_{Ab}} > t^*_N\}$ the first best is implementable in a team of size N but fails to be implementable in a team of size $N+1$ (due to free-riding). The opposite holds in the area $T^*_{N+1} \setminus T^*_N = \{(\frac{p_{Bb}}{p_{Ab}}, \Delta f) \in T_N | \Delta f > \Delta f^{min}_{N+1}, t^*_{N+1} < \frac{p_{Bb}}{p_{Ab}} < t^*_N\}$. Here the first best is implementable in a team of size $N+1$ but fails to be implementable in a team of size N (due to a lack of information-sharing).

Corollary 1 *If $p_{Ab} < \min(\frac{1}{2N+1}, \frac{c}{f_0})$ and $q^*_{N+1} \leq q < q^*_N$, then there exists a non-empty subset of the parameter space, given by $\{(\frac{p_{Bb}}{p_{Ab}}, \Delta f) \in T_N | \Delta f > \Delta f^{min}_{N+1}, t^*_{N+1}(\Delta f) < \frac{p_{Bb}}{p_{Ab}} < t^*_N(\Delta f)\}$, for which the first best is implementable in a team of size $N+1$ but not in a team of size N.*

Corollary 1 provides conditions under which an increase in team size *increases efficiency* by making the first best become implementable.[19] This contrasts with the common view, based on free-riding alone, that efficiency is harder to achieve in larger teams.[20]

[19] Given the parametric restrictions on p_{Ab} contained in footnote 18, $p_{Ab} < \min(\frac{1}{2N+1}, \frac{c}{f_0})$ is possible if and only if $\frac{(N+1)c}{1-f_0} < \min(\frac{1}{2N+1}, \frac{c}{f_0}) \Leftrightarrow f_0 < \frac{1}{N+2}$.

[20] In order to display this result in its starkest version, we have focused on the case in which free–riding matters in a team of size $N+1$ but not in a team of size N. It is worth emphasizing that the conditions

Corollary 1 shows that a team may benefit not only marginally, from the added evidence of an extra member, but also in aggregate, from the improved incentives to share information. It underlines the importance of rewarding the disclosure of information in a team setting. If instead, members received a fixed share $\frac{1}{N}$ of the team's revenue, independently of their messages, then condition (17) would become

$$\frac{p_{Bb}}{p_{Ab}} \geq 1 + (N-1)\frac{\Delta f}{f_0}, \tag{19}$$

i.e. the disclosure threshold would be increasing rather than decreasing in N. Intuitively, a member's message would affect his payoff only when he is pivotal, i.e. the only one to observe evidence. The incentives for concealment would then be stronger in a larger team since, conditional on being pivotal, more colleagues could be motivated with the concealment of evidence in favor of $y = b$. Hence, if compensation could not be conditioned on messages, an increase in team size would affect the team's ability to share information *negatively*. Without rewards for disclosure, an increase in team size cannot have a positive effect on the implementability of the first best.

7 Limited commitment

In our model, the mechanism provides the team members with two types of commitment. Firstly, the mechanism allows the team to commit to a project selection rule. Secondly, the mechanism also chooses the allocation of revenue on the members' behalf. In this section we return to the case of a team with two members in order to discuss the likely consequences of limiting these two kinds of commitment. In particular, we allow members to renegotiate the outcome of the mechanism at the interim stage, that is, after the project has been selected and revenue shares have been announced but before effort recommendations are executed.

in Corollary 1 are sufficient but not necessary. In particular, we expect the positive effect of team size on disclosure to be beneficial also in situations in which the team suffers from free-riding independently of its size. A thorough investigation of this issue requires a setting with continuous effort choices and is left for future research.

Allocation of Revenue

We start by considering how the optimal mechanism would be affected if the team members were able to renegotiate revenue shares. This renegotiation could take many forms, so instead of modeling it explicitly, we adopt a reduced form approach by requiring the mechanism's revenue allocation to be such that no other allocation would be preferred by both members at the interim stage.

In the area $T^{**} \setminus T^{+}$, there is, indeed, scope for renegotiation to make both agents better off, and to unravel the feasibility of the mechanism characterized in Proposition 3. Remember that, in this area, project selection is efficient and that, when no evidence is disclosed, (inefficiently) low effort is sometimes recommended to one of the members. When this is the case, the favored member could induce the other member to exert high rather than low effort by offering to him a share $\frac{c}{\hat{p}(A)\Delta f}$ of revenue. He will offer such a side-contract, thereby rendering the original mechanism void, if and only if the reduction in his share of revenue is more than compensated by the increased effort of his colleague, that is if:

$$\hat{p}(A) f_2 \left[1 - \frac{c}{\hat{p}(A)\Delta f}\right] > \hat{p}(A) f_1. \tag{20}$$

Hence, when revenue–commitment is limited, an unbiased project selection may no longer be feasible for (some) parameter values in $T^{**} \setminus T^{+}$.

In contrast, the optimal mechanism would remain unchanged in the area T^{+}. In this area, the only inefficient outcome arises when evidence for b is observed unilaterally, project A is chosen, and the uninformed member exerts high effort. This outcome is preferred by the informed member over any other in which the uninformed member exerts no effort. Similarly, the implementability of the first best in T^{*} would not be affected by the possibility of renegotiation, as there is no extra surplus available to make both agents better off.

We can therefore conclude that a limitation of revenue-commitment has no effect on the implementability of the first best and can only extend the set of parameters for which the second-best mechanism exhibits a motivational bias.

Project Selection

We now discuss how the optimal mechanism would be affected by a limitation of the commitment to a project selection rule. As above, we consider the possibility that the team members overrule the mechanism's project choice at the interim stage if they agree that it is in both of their interests to do so.

In the areas T^* and $T^{**} \setminus T^+$, project selection is efficient, so there is no potential for increasing both agents' utility by choosing a different project. In the area T^+, project selection is biased in the direction of A when b is unilaterally observed and the uninformed member exerts inefficiently high effort. Any agreement to change the chosen project from A to B would reduce the effort of the uninformed member. Since in T^{**} and hence in T^+ it holds that $p_{Ab}f_1 > p_{Bb}f_0$, it would not be in the interest of the informed member to switch to the higher quality project at the cost of a reduction in effort. We therefore expect the optimal mechanism to remain unchanged when project-commitment is limited.

8 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 has been the one between adaptation and motivation, making team members reluctant to disclose information in conflict with prior expectations, especially in situations where maintaining the colleagues' morale is more important than choosing the best project.

We have shown that to overcome this trade-off, the optimal mechanism offers rewards for the disclosure of information. Perhaps surprisingly, we have found that an increase in team-size can be good for efficiency, as it allows for a richer set of rewards. We have also shown that for high values of motivation the optimal (second-best) mechanism is characterized by three features: (a) information fails to be transmitted across team members, (b) project-selection is biased in the direction of the initially preferred alternative, and (c) efforts (sometimes) exceed the level that is optimal, given the team's aggregate information.

While we have kept the analysis at a fairly abstract level, it is worth pointing out that the features of our optimal mechanism have counterparts in real organizations. Regarding (a), note that it is fairly common for decision-makers to meet separately with the members of their teams, so as to induce more candid exchanges. They may then take a decision and communicate it to the team without fully revealing the information transmitted in the one-to-one meetings. Janis (1982), for instance, argues that moving from public meetings to private exchanges was one of the key innovations by the Kennedy administration that allowed it to navigate the Cuban Missile Crisis better than it had the Bay of Pigs invasion.

Similarly, one could interpret (b) as a 'status-quo bias', i.e. a reluctance to deviate from the initially preferred alternative unless there is overwhelming consensus to do so. The academic management literature has traditionally emphasized the virtues of continuous innovation (Christensen, 1997), and criticized the tendencies of organizations to resist change (March, 1991). Instead, our model emphasizes the potential benefits of a status-quo bias from encouraging team members to reveal their private information without undermining their colleagues' morale.

An important limitation of our model is that information is exogenous. Persico (2004) and Gerardi and Yariv (2007) show that in committees, the incentives to acquire information can be affected by the decision-making rule. In our setting, this could imply that it is difficult (and perhaps even undesirable) to encourage the acquisition of information when project-selection is only partially responsive to the team's information. We leave to future work a comprehensive analysis of the interactions between the effort to acquire decision-relevant information and the effort to execute a decision.

Appendix

Proof of Lemma 1

Suppose (α, β, ω) is an optimal (asymmetric) mechanism. Let $(\tilde{\alpha}, \tilde{\beta}, \tilde{\omega})$ denote the mechanism which can be obtained from (α, β, ω) by exchanging the members' identities. Construct a new mechanism $(\hat{\alpha}, \hat{\beta}, \hat{\omega})$ by setting $\hat{\alpha}_{\mathbf{m}} = \frac{1}{2}\alpha_{\mathbf{m}} + \frac{1}{2}\tilde{\alpha}_{\mathbf{m}}$ and $\hat{\beta}_{\mathbf{m}} = \frac{1}{2}\beta_{\mathbf{m}} + \frac{1}{2}\tilde{\beta}_{\mathbf{m}}$ and by defining the revenue allocation $\hat{\omega}_{\mathbf{m}}$ as follows: If for a given message profile $\mathbf{m}$, both of the original mechanisms select $(x, \mathbf{e})$ with positive probability then let $\hat{\omega}_{\mathbf{m}}(x, \mathbf{e}) =$

$\frac{1}{2}\omega_{\mathbf{m}}(x,\mathbf{e}) + \frac{1}{2}\tilde{\omega}_{\mathbf{m}}(x,\mathbf{e})$. Otherwise, let $\hat{\omega}_{\mathbf{m}}(x,\mathbf{e})$ be identical to the revenue allocation of the mechanism that selects $(x,\mathbf{e})$.

The mechanism $(\hat{\alpha},\hat{\beta},\hat{\omega})$ is symmetric by definition and, due to the symmetry of the problem, leads the same surplus as (α,β,ω) and $(\tilde{\alpha},\tilde{\beta},\tilde{\omega})$. It satisfies (BC) and (DC) since these constraints hold separately for (α,β,ω) and $(\tilde{\alpha},\tilde{\beta},\tilde{\omega})$. The only non-trivial step is to show that $(\hat{\alpha},\hat{\beta},\hat{\omega})$ satisfies (IC). This is because a member's incentives to exert effort depend on his believes about the state which may be different under $(\hat{\alpha},\hat{\beta},\hat{\omega})$ than under (α,β,ω) and $(\tilde{\alpha},\tilde{\beta},\tilde{\omega})$. However, Bayesian updating implies that under $(\hat{\alpha},\hat{\beta},\hat{\omega})$, i's expectation about project A's quality must lie between his expectations under (α,β,ω) and $(\tilde{\alpha},\tilde{\beta},\tilde{\omega})$. Since (IC) must hold for both (α,β,ω) and $(\tilde{\alpha},\tilde{\beta},\tilde{\omega})$ it must therefore hold for $(\hat{\alpha},\hat{\beta},\hat{\omega})$. ■

Proof of Proposition 1

Step 1: $\alpha_{a,a} = \alpha_{a,\emptyset} = \beta_{a,a}(e_H,e_H) = \beta_{a,\emptyset}(e_H,e_H) = 1.$

Suppose that conditional on evidence for $y = a$ being disclosed, the mechanism's project selection and effort recommendations are such that surplus is maximized, i.e. $\alpha_{a,a} = \alpha_{a,\emptyset} = \beta_{a,a}(e_H,e_H) = \beta_{a,\emptyset}(e_H,e_H) = 1$. Then member 1 will disclose $y = a$ if

$$qf_2[\frac{1}{2} - w^1_{\emptyset,a}(A,e^H,e^H)] + (1-q)[f_2 w^1_{a,\emptyset}(A,e^H,e^H) - c - u^1_{\emptyset,\emptyset}(a)] \geq 0, \tag{21}$$

where $u^1_{\emptyset,\emptyset}(a)$ denotes member 1's expected payoff conditional on no evidence being disclosed. Due to symmetry, member 1 cannot expect to obtain more than half of the maximum attainable surplus when both members send identical messages, i.e. $u^1_{\emptyset,\emptyset}(a) \leq \frac{1}{2}f_2 - c$. Hence (21) holds as long as the unilateral disclosure of $y = a$ is (weakly) rewarded by setting $w^1_{a,\emptyset}(A,e^H,e^H) \geq \frac{1}{2} \Leftrightarrow w^1_{\emptyset,a}(A,e^H,e^H) \leq \frac{1}{2}$. This holds under the mechanism specified in Proposition 1 since $w^1_{a,\emptyset}(A,e_H,e_H) = 1 - \frac{c}{\hat{p}(A)\Delta f} > \frac{1}{2}$. Here we have used (A3) and the fact that $\hat{p}(A) \geq \bar{p}(A)$. Under the mechanism specified in Proposition 1, a member who observed $s^i = \emptyset$, $x = A$, $e^i = e_H$ and $\omega^i = \frac{c}{\hat{p}(A)\Delta f}$ might not be able to deduce whether the other member has (unilaterally) disclosed $y = a$ or $y = b$. However, since the former is (weakly) more likely than the latter ($\alpha_{a,\emptyset} = 1 \geq \alpha_{b,\emptyset}$) member i's observation means positive news with respect to the prospects of project A. This shows that conditional on evidence for $y = a$ being disclosed, surplus can be maximized without harm to the members' incentive to disclose such evidence.

Step 2: $\alpha_{b,b} = 0$.

Let

$$\Gamma = q[u^1_{b,b} - u^1_{\emptyset,b}] + (1-q)[u^1_{b,\emptyset} - u^1_{\emptyset,\emptyset}] \tag{22}$$

denote member 1's incentive to disclose $y = b$ with $u^1_{\mathbf{m}}$ as defined in (4). Consider how Γ depends on $\alpha_{b,b}$:

$$\frac{\partial \Gamma}{\partial \alpha_{b,b}} = \frac{1}{2} q f_0 (p_{Ab} - p_{Bb}). \tag{23}$$

Since $p_{Bb} > p_{Ab}$, decreasing $\alpha_{b,b}$ not only raises surplus but also relaxes (DC). Hence the optimal mechanism must set $\alpha_{b,b} = 0$.

Step 3: $\omega^1_{b,\emptyset}(B) = 1$.

Using symmetry and (BC) we have $\omega^1_{b,\emptyset}(B) = 1 - \omega^1_{\emptyset,b}(B)$ which gives

$$\frac{\partial \Gamma}{\partial \omega^1_{b,\emptyset}(B)} = [(1-q)(1-\alpha_{b,\emptyset}) + q(1-\alpha_{\emptyset,b})] f_0 p_{Bb} > 0. \tag{24}$$

Setting $\omega^1_{b,\emptyset}(B) = 1$ thus maximizes the members' incentive to disclose $y = b$. Since for project B effort and hence surplus are independent of the revenue-allocation, setting $\omega^1_{b,\emptyset}(B) = 1$ is therefore optimal.

Step 4: $\beta_{b,\emptyset}(e_L, e_H) = 1$ *and* $\omega^1_{a,\emptyset}(A, e^H, e^H) = \omega^1_{b,\emptyset}(A, e^L, e^H) = 1 - \frac{c}{\hat{p}(A)\Delta f}$.

Given $\mathbf{m} = (b, \emptyset)$, selecting $x = A$ and $\mathbf{e} = (e_L, e_L)$ leads to lower surplus *and* a lower Γ than choosing $x = B$ and $\mathbf{e} = (e_L, e_L)$. This follows immediately from $p_{Ab} < p_{Bb}$. Hence, selecting project A and recommending low effort to the uninformed member cannot be part of the optimal mechanism, implying $\beta_{b,\emptyset}(e_L, e_H) = 1$. In analogy to before, the disclosing member 1's share of revenue should be made as large as possible in order to maximize Γ. However, since the uninformed member 2 must be provided with an incentive to exert high effort, this choice is restricted by (IC):

$$[1-\omega^1_{b,\emptyset}(A,e^L,e^H)]\hat{p}(A)\Delta f \geq c \Rightarrow \omega^1_{b,\emptyset}(A,e^L,e^H) = 1-\frac{c}{\hat{p}(A)\Delta f}. \qquad (25)$$

Note that (IC) is relaxed and thus a larger share of revenue can be used to induce the disclosure of $y=b$ when $\hat{p}(A)$ is increased. In order to maximize $\hat{p}(A)$ the uninformed member should be unable to deduce (from his observation of project choice, effort recommendation and revenue assignment) whether the informed member observed (and reported) a or b. Hence it is optimal to set $\omega^1_{a,\emptyset}(A,e^H,e^H) = \omega^1_{b,\emptyset}(A,e^L,e^H)$.

Step 5: $\alpha_{\emptyset,\emptyset}=1$ *and* $\omega^1_{\emptyset,\emptyset}(A,e_H,e_L)=1$.

Conditional on $\mathbf{s}=(\emptyset,\emptyset)$, the surplus loss, $\bar{p}(A)\Delta f - c$, from inducing only one high effort on project A, is smaller than the surplus loss, $[\bar{p}(A)-\bar{p}(B)]\,f_0 + 2\,[\bar{p}(A)\Delta f - c]$, from selecting project B rather than A. Moreover, when project A is selected and only one member is recommended to exert high effort then the concealment of $y=b$ by member 1 gives him an expected payoff of $p_{Ab}[\frac{1}{2}\omega^1_{\emptyset,\emptyset}(A,e_H,e_L)f_0 + \frac{1}{2}\omega^1_{\emptyset,\emptyset}(A,e_L,e_H)f_1]$. This is because, by symmetry, both members are equally likely to be the one who is recommended a high effort. Setting $\omega^1_{\emptyset,\emptyset}(A,e_H,e_L)=1 \Leftrightarrow \omega^1_{\emptyset,\emptyset}(A,e_L,e_H)=0$ reduces this payoff to $p_{Ab}\frac{1}{2}f_0$ which is strictly smaller than the payoff $p_{Bb}\frac{1}{2}f_0$ that member 1 would expect from concealing $y=b$ under a mechanism which selects project B in the absence of evidence. This shows that distorting project choice by setting $\alpha_{\emptyset,\emptyset}<1$ is not only more costly in terms of surplus but also less effective with respect to the relaxation of (DC) than distorting effort.

Steps 1-5 characterize the optimal mechanism except for the likelihood $\alpha \equiv \alpha_{b,\emptyset}$ with which the mechanism selects project A when evidence for b is disclosed unilaterally, and the effort distribution $\beta_{\emptyset,\emptyset}(\mathbf{e})$ when project A is selected in the absence of evidence. Since the recommendation of (e_L,e_L) cannot be incentive compatible, it follows from symmetry that this distribution can be described by a single number $\beta=\beta_{\emptyset,\emptyset}(e^H,e^H)$ denoting the likelihood with which both members are recommended to exert high effort. ■

Proof of Proposition 2

The first best 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 first best therefore fails to be implementable in a non-empty subset of T if and only if the lower bound exceeds the upper bound for $\Delta f = \max_T \Delta f = \frac{c}{p_{Ab}}$, i.e.

$$\frac{1-q}{2-q}(1+\frac{\max_T \Delta f}{f_0}) > \frac{c}{p_{Ab}\max_T \Delta f} = 1 \quad \Leftrightarrow \quad p_{Ab} < \frac{c(1-q)}{f_0}. \tag{26}$$

This holds if and only if

$$p_{Ab}f_0 < c \quad \text{and} \quad q < 1 - \frac{p_{Ab}f_0}{c}. \quad \blacksquare \tag{27}$$

Proof of Proposition 3

We first show that $\alpha^{**} < 1$. If we set $\alpha = 1$ and $\beta = 0$ then the disclosure constraint (8) becomes:

$$q\frac{1}{2}p_{Bb}f_0 + (1-q)(1-\frac{c}{\hat{p}(A)\Delta f})p_{Ab}f_1 \geq q\frac{c}{\hat{p}(A)\Delta f}p_{Ab}f_0 + (1-q)\frac{1}{2}p_{Ab}f_1. \tag{28}$$

Since $p_{Bb} > p_{Ab}$ and $\frac{c}{\hat{p}(A)\Delta f} < \frac{1}{2}$ this inequality holds strictly. Hence we could decrease α below 1, thereby increasing surplus, without violating the disclosure constraint. This shows that setting $\alpha = 1$ cannot be optimal. To derive the conditions under which $\alpha^{**} > 0$, let Γ be given by (22) and define

$$L_\alpha(\alpha) = \frac{\frac{\partial \Delta W}{\partial \alpha}}{\frac{\partial \Gamma}{\partial \alpha}} = \frac{q[(p_{Bb}-p_{Ab})f_0 + c - p_{Ab}\Delta f]}{p_{Ab}\Delta f - (p_{Bb}-p_{Ab})f_0 - cp_{Ab}(1+\frac{f_0}{(1-q)\Delta f})\frac{1+2\alpha+p_{Ab}\alpha^2}{(1+p_{Ab}\alpha)^2}} \tag{29}$$

$$L_\beta = \frac{\frac{\partial \Delta W}{\partial \beta}}{\frac{\partial \Gamma}{\partial \beta}} = \frac{2(1-q)}{p_{Ab}}[\bar{p}(A) - \frac{c}{\Delta f}].$$

L_α and L_β measure how much welfare is lost if we relax the disclosure constraint (8) by one unit by increasing or decreasing(marginally) the probabilities α or β respectively.

When (8) needs to be relaxed, we should do so in the least costly way. Note that $L_\alpha(\alpha)$ is increasing in α since

$$\frac{\partial}{\partial \alpha}\left[\frac{1+2\alpha+p_{Ab}\alpha^2}{(1+p_{Ab}\alpha)^2}\right] = \frac{2[1-p_{Ab}(1-\alpha)]}{(1+p_{Ab}\alpha)^3} > 0. \tag{30}$$

Hence $\alpha^{**} > 0$ if and only if $L_\alpha(0) < L_\beta$ or

$$\frac{p_{Bb}}{p_{Ab}} < t^+(\Delta f) \equiv \frac{1}{f_0}\frac{q(p_{Ab}f_1 - c) + 2(1-q)[\bar{p}(A) - \frac{c}{\Delta f}][f_1 - c(1+\frac{f_0}{(1-q)\Delta f})]}{qp_{Ab} + 2(1-q)[\bar{p}(A) - \frac{c}{\Delta f}]}. \tag{31}$$

It is easy to see that L_α is increasing in p_{Bb} and decreasing in Δf. Moreover L_β is increasing in Δf and independent of p_{Bb}. It follows that $t^+(\Delta f)$ must be increasing in Δf. Finally, $T^+ \neq \emptyset$ since $L_\beta > 0$ and

$$\lim_{\Delta f \to \Delta f^{max}} \lim_{p_{Bb} \to p_{Ab}} L_\alpha(\alpha) = 0. \tag{32}$$

This completes the proof of Proposition 3. ■

Proof of Proposition 4

Since t_N^* is increasing in Δf, $T_N^{**} \neq \emptyset$ if and only if $t_N^*(\Delta f) > 1$ for $\Delta f \to \max_{T_N} \Delta f = \frac{c}{p_{Ab}}$. This is equivalent to

$$p_{Ab} < \frac{c}{f_0}\frac{(N-1)q(1-q)^{N-1}}{1-(1-q)^{N-1}} = \frac{c}{f_0}(1-q)P(q,N). \tag{33}$$

Here we have defined $P(q, N)$ as 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 (33) holds if and only if

$$p_{Ab} < \frac{c}{f_0} \quad \text{and} \quad q < q_N^* \tag{34}$$

for some $q_N^* \in (0, 1)$ and q_N^* is decreasing in N. The fact that $P(q, N)$ is decreasing in N also implies that t_N^* is decreasing in N. ■

Proof of Corollary 1

From $p_{Ab} < \frac{1}{2N+1}$ it follows that $\Delta f_{N+1}^{min} < \frac{c}{p_{Ab}} = \lim_{p_{Bb}\to p_{Ab}} \Delta f^{max}$. Together with $q \geq q_{N+1}^*$ this implies that the first best is implementable in a team of size $N+1$ for all $(\frac{p_{Bb}}{p_{Ab}}, \Delta f) \in T_N$ such that $\Delta f \geq \Delta f_{N+1}^{min}$. Finally, since $p_{Ab} < \frac{c}{f_0}$, and $q < q_N^*$, there exist $(\frac{p_{Bb}}{p_{Ab}}, \Delta f) \in T_N$ such that $\Delta f \geq \Delta f_{N+1}^{min}$ and $\frac{p_{Bb}}{p_{Ab}} < t_N^*(\Delta f)$. For all those parameter values, the first best is implementable in a team of size $N+1$ but fails to be implementable in a team of size N. ■

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