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. 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 decision–making may be biased either in favor or against the team's initially preferred alternative.

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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. Nevertheless, 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 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 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, 1982). Similar behavior has been documented using firm (Perlow, 2003) and laboratory studies (Stasser and Titus, 1985, Gigone and Hastie, 1993).

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.[2] 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.[3]

To examine the above trade–off formally, Section 2 presents a model of team production in which two identical individuals select and work on one out of two feasible projects. A project's likelihood of success depends positively on the team members' unobservable efforts and the project's state–contingent "quality". Individual efforts are independent inputs of team production. Project choice and efforts are complementary, as returns to effort are increasing in the project's quality. Each team member privately obtains (with some probability) verifiable evidence about the state of the world. Ex ante project A is expected to be better than project B, but information is valuable since project B is better when the state is B. In the first–best benchmark, team members select the best project, conditional on their aggregate information, and exert efficient levels of effort.

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

[2]Interview with Martha Raddat, ABC News on April 11, 2008, transcript available at http://abcnews.go.com/Politics/story?id=4634219&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=13047099.

colleague. We find that the mechanism implementing the benchmark in the widest range of parameters rewards the (unilateral) disclosure of information that is *unpopular* i.e. 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), our results suggest that dissenting voices should be actively rewarded.

Although the presence of private information often represents a challenge to the implementability of the first best, we find that, in some occasions, the asymmetry of information turns out to be beneficial. In particular, the first best turns out to be implementable in an area of the parameter space for which efficiency could not be obtained if evidence was observed publicly rather than privately. As in Hermalin's (1998) model of leadership, the presence of asymmetric information alleviates the team's free–riding problem. In our setting this holds even though agents are ex ante identical and have no access to a signaling technology.

In Section 4 we consider how the implementability of the first best depends on the size of the team. Contrary to a standard free-riding argument, we show that an increase in team size may *improve* efficiency by making the first best become implementable. This is because, although potentially detrimental for the incentive to exert effort, an increase in team size can improve the members' willingness to share information. Critical to this result is the fact that the optimal mechanism rewards the disclosure of unpopular information. If instead, revenue is allocated independently of the disclosed evidence, then an increase in team size not only exacerbates free–riding but also worsens information–sharing. This underlines the importance of rewarding dissent in a team setting.

We also introduce heterogeneity into our framework and find that members who are less productive or more likely to be informed have a stronger incentive to conceal their information. The optimal mechanism accounts for this asymmetry by giving these members a smaller stake in the initially preferred project. The fact that, in practice, higher stakes are usually associated with better information, might therefore explain some of the decision–making failures mentioned above.

In Section 5 we return to our baseline model and determine the optimal mechanism for the case where the first best fails to be implementable. We first characterize the conditions under which the first–best project choice can be implemented, at the expense of inefficient effort levels. The corresponding mechanism induces one member to exert inefficiently low effort in the absence of evidence by assigning a disproportionately large share of revenue to the other member. While for the disadvantaged member concealment is deterred by the threat of receiving a low share of revenue, for the advantaged member concealment ceases to have a positive effect on the colleague's effort. The shortcoming of this arrangement is that it may fail to be collusion–proof. This is the case when the value of motivation is high, since then team members will overcome the induced effort distortion by use of a side–contract. We therefore conclude that the first–best project choice cannot be implemented for high values of motivation, even when effort levels are allowed to differ from the first best.

If not only effort but also project choices are allowed to be inefficient, there exist exactly two alternative ways to strengthen the team members' incentive to disclose unpopular information. The first is to inefficiently choose project B over project A in the absence of evidence, thereby introducing a *negative* bias to the team's decision making. This gives team members an incentive to disclose evidence in favor of B, since its concealment no longer increases the colleague's motivation. Therefore, a decision rule which makes "unpopular" choices when no evidence is produced by the team members can induce the revelation of information in conflict with prior expectations.

The second possibility is to bias the team's project choice *positively* i.e. in the direction of its initially preferred alternative. The corresponding mechanism selects project A even when evidence in favor of B has been observed by (exactly) one member. Importantly, the evidence communicated to the designer by the informed member fails to be shared with the other. As a result, the uninformed member can be induced to exert inefficiently high effort on project A giving the informed member the incentive to disclose B. This mechanism resonates with the examples above, where information in conflict with prior expectations fails to be shared in order to maintain morale and at the cost of a failure to adapt.

The relative size of the values of motivation and adaptation determines which of the three arrangements above constitutes the second–best mechanism. As the value of motivation increases, the second–best project allocation switches from being unbiased, to having a negative bias, to having a positive bias. One way to interpret the decision–rule's bias is as the inherent conservatism of the organisation (Li 2001). Our findings therefore suggest that a team's optimal degree of conservatism is non–monotonic in the relative value of motivation.

We conclude our analysis in Section 6 by considering the robustness of our results. We show that the first best fails to be implementable even when the team members observe non–verifiable signals about the state of the world, and when team production exhibits complementarities. We find that increasing the signals' precision or the strength of complementarities enlarges the set of parameters for which the first best can be implemented.

Related literature

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 the quality of the project and the team's morale at the execution stage. This emphasis is novel to the literature on group decision–making and hence complementary to existing work.[4] 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 execute 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 execution lie at different levels of the organizational hierarchy (Zabojnik, 2002; Blanes i Vidal and Möller, 2007; Landier et al., 2009).[5] An exception in this respect is Banal–Estañol and Seldeslachts (2009), who

[4]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.

[5]A related literature studies organizations where different divisions need to be encouraged to exert effort and to take decisions that are both coordinated and adapted to local circumstances (Dessein et al., 2009; Rantakari, 2009). We assume a common project choice, and so coordination is not an issue.

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

Our result that commitment to an ex post inefficient decision can improve the communication of information in teams is related to Gerardi and Yariv (2007) who show that such commitment can induce the acquisition of costly information (see also Li 2001 and Szalay 2005). In our application this commitment might be achieved by delegating decision–making to an outsider (i.e. a manager), 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".

In our model, the mechanism designer chooses implicitly whether to communicate to one team member the information reported by the other. This role of the designer as intermediary between two parties links our paper to the literature on optimal information disclosure. In Rayo and Segal (2010), for instance, the principal's role is to transform a report sent by an advertiser into a signal observed by a consumer. Coarsening the information revealed by the parties in a potential conflict is also the function of the mediator in Hörner et al. (2011). Similar roles are played by the intermediaries in the two–sided market models of Ostrovsky and Schwarz (2010) and Hagiu and Jullien (2011). One major difference relative to these papers is that in our model, the mechanism designer not only influences communication but also selects the team's project.

The assumption of limited liability is important for our results. In its absence the first best can be easily implemented by punishing (sufficiently) a team member who fails to report evidence when his colleague happens to do so. Our paper is therefore related to the literature examining how limited liability constraints hinder the implementability of first–best outcomes in mechanism–design settings (Robert 1991, Demougin and Garvie 1991, Demski, Sappington and Spiller 1987, Gary–Bobo and Spiegel 2006).[6]

[6] Limited liability is a reasonable assumption in many settings. In managerial accounting, for instance, the assumption has been used to explain issues such as earnings management and capital budgeting (Arya, Glover and Sunder 1998, Demski and Dye 1999 and Lambert 2001).

2 The model

We consider a team with two identical members $i = 1, 2$.[7] 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 $R = 1$, otherwise its revenue is $R = 0$. Project x's likelihood of success is increasing in the team members' efforts e_i and depends on 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 say that one project is better than the other if it has a higher quality. According to (1), project choice 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).

We assume that information about the state 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. 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.[8]

[7] The issues of team size and heterogeneity are the subject of Section 4.

[8] 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.

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 $0 < f_0 < f_1 < f_2$. To simplify the analysis, we assume that efforts are independent, i.e. $f_2 - f_1 = f_1 - f_0 \equiv \Delta f$.[9]

We show below 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' efforts. As we show below, a trade–off between adaptation and motivation exists when effort can be induced for one project but not for the other. Our main analysis focuses on the case where

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

The first inequality guarantees that, in the absence of any evidence, both team members can be induced to exert effort on the ex ante preferred 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 has observed evidence in favor or B and receives its entire revenue. A discussion of the case where $\Delta f \leq \frac{2c}{\bar{p}_A}$ is postponed until the end of Section 3.

Finally, in order to simplify the exposition, we normalize by setting $p_{AA} = 1$ and $p_{BA} = 0$. Our results remain qualitatively unchanged if we allow these values to be general. We will discuss the problem in a two–dimensional parameter space. The x–axis will measure the value of motivation Δf corresponding to an increase in the colleague's effort. 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

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

of the parameter space. To guarantee that T is non–empty and that $Pr(R = 1) \leq 1$ for

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

all $(\Delta f, \frac{p_{BB}}{p_{AB}}) \in T$ the following parametric restrictions are necessary and sufficient:[10]

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

A mechanism design approach

Following Myerson (1982), we use a mechanism design approach to determine the team's optimal institution. In a mechanism, each team member sends a message conditional on his private information. Depending on these messages, the mechanism selects a project, specifies the team members' outcome–contingent compensation, and recommends effort levels.

Formally, 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. The set of possible type profiles $s = (s_1, s_2)$ is given by

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

Member i sends *message*, $m_i(s_i)$, to the mechanism designer, conditional on his type. 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 $m_i \in M_i(\emptyset) = \{\emptyset\}$.[11]

A *mechanism* $(\hat{x}, \hat{e}_1^r, \hat{e}_2^r, w_1, w_2)$ consists of a *project allocation* $\hat{x} : S \to X$, recommended *effort allocations* $\hat{e}_i^r : S \to \{0, 1\}$, and outcome–contingent *compensation schemes* $w_i : S \times \{0, 1\} \to [0, 1]$. It induces a (Bayesian) game defined by the following sequence of events: (1) Members observe (private) information $s \in S$. (2) Members send messages $m_i(s_i) \in M_i(s_i)$ to the mechanism designer simultaneously and confidentially. (3) The designer selects project $\hat{x}(m_1, m_2)$, makes effort recommendations $\hat{e}_i^r(m_1, m_2)$ and

[10] $T \neq \emptyset$ 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 $c < \frac{1-f_0}{6}$.

[11] 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 (2007) 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 viceversa.

announces compensation schemes $w_i(m_1, m_2, .)$. (4) Members choose unobservable efforts $e_i \in \{0, 1\}$. (5) Revenue $R \in \{0, 1\}$ is realized and member i receives compensation $w_i(m_1, m_2, R) \in [0, 1]$.

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. $w_1 + w_2 = R$.[12] Following Levitt and Snyder (1997), we further 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. Finally, we 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.[13]

We say that the mechanism $(\hat{x}, \hat{e}_1^r, \hat{e}_2^r, w_1, w_2)$ *implements* the *allocation* $(\hat{x}, \hat{e}_1, \hat{e}_2)$ if it is an equilibrium for team members to report their types truthfully $(m_i = s_i)$ and to follow their effort recommendations obediently $(e_i = \hat{e}_i^r(s))$ for all $s \in S$. An allocation $(\hat{x}, \hat{e}_1, \hat{e}_2)$ is said to be *implementable* when there exists a mechanism that implements it. According to the *revelation principle*, the restriction to mechanisms and equilibria of the above form comes at no loss to generality with respect to the set of implementable allocations.[14] Note however that we restrict attention to *deterministic* mechanisms. As we will see, this restriction has no influence on the implementability of the first–best allocation. Allowing for random mechanisms only affects the characterization of the second best. For details see our discussion at the end of Section 5.

[12] 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. A detailed discussion can be found at the end of Section 3.

[13] Collusion–proofness affects the second–best mechanism but has no influence on the implementability of the first best. See Section 5 for details.

[14] 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.

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 $(\hat{x}^*, \hat{e}_1^*, \hat{e}_2^*)$ 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 $\hat{x}^*(s) = A$ for all $s \in S^A$. Similarly $p_{BB} > p_{AB}$ implies that $\hat{x}^*(s) = B$ for all $s \in S^B$. 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 $\hat{x}^*(\emptyset, \emptyset) = A$. 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 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 in favor of project B. Formally, $\hat{e}_i^*(s) = 0$ for all $s \in S^B$ and $\hat{e}_i^*(s) = 1$ for all $s \in S^A \cup \{(\emptyset, \emptyset)\}$.

Since Holmstrom (1982), it is well established that team production may suffer from an under–provision of effort. To see this, note that for $\frac{c}{\bar{p}_A} < \Delta f < \frac{2c}{\bar{p}_A}$, efficiency would require both team members to exert effort on project A, but only one team member could be induced to do so by receiving a sufficiently high share of revenue.[15] 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 about the projects' qualities.

[15] Limited liability obstructs *approximate* efficiency to be implementable with the help of mediated contracts in the spirit of Rahman and Obara (2010).

3 Implementability of the first best

In order to implement the first best we need to find compensation schemes w_1, w_2, such that the efficient allocation $(\hat{x}^*, \hat{e}_1^*, \hat{e}_2^*)$ is implemented by the mechanism $(\hat{x}^*, \hat{e}_1^*, \hat{e}_2^*, w_1, w_2)$. Since budget balance and limited liability imply that $w_i(m_1, m_2, 0) = 0$ we can simplify notation by defining $w_i(m_1, m_2) \equiv w_i(m_1, m_2, 1)$.

The compensation schemes have to induce the truthful revelation of information and provide the team members with incentives to choose efficient effort levels. Since the first–best allocation is the same for all $s \in S^A \cup \{(\emptyset, \emptyset)\}$, a team member's decision whether to disclose evidence for A has an effect neither on the selection of the project nor on the other member's effort. The disclosure of A can therefore be guaranteed by making the compensation under project A independent of the members' messages, i.e. by setting $w_i(A, A) = w_i(A, \emptyset) = w_i(\emptyset, A) = w_i(\emptyset, \emptyset)$. In contrast, the disclosure of evidence for B is optimal for member 1 if and only if

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

and an analog condition needs to be satisfied by w_2. Condition (8) can be relaxed by increasing $w_1(B, B)$ or by decreasing $w_1(\emptyset, \emptyset)$. 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 $w_1(B, B) = w_1(\emptyset, \emptyset) = \frac{1}{2}$. For the same reason $w_1(B, \emptyset) = w_2(\emptyset, B)$ and $w_1(\emptyset, B) = w_2(B, \emptyset)$. The conditions that guarantee the disclosure of evidence in favor of B thus become:

$$w_1(B, \emptyset) = w_2(\emptyset, B) \geq \frac{1}{2}[q + (1-q)\frac{p_{AB}}{p_{BB}}\frac{f_1}{f_0}]. \quad (9)$$

Note that the lower bound in (9) 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 in favor of B. Since rewards cannot exceed the team's revenue, the disclosure of B can be induced if and only if

$$1 \geq \frac{1}{2}[q + (1-q)\frac{p_{AB}}{p_{BB}}\frac{f_1}{f_0}] \quad \Leftrightarrow \quad \frac{p_{BB}}{p_{AB}} \geq \frac{1-q}{2-q}(1 + \frac{\Delta f}{f_0}) \equiv t^*(\Delta f). \quad (10)$$

The benchmark allocation also requires both team members to exert effort on project A. As a consequence w_i has to satisfy the following incentive constraints:

$$\tilde{p}_A \Delta f w_i(\emptyset, m_j) > c \quad \text{and} \quad p_{AA} \Delta f w_i(A, m_j) > c \quad \text{for all} \quad m_j \in \{A, \emptyset\}. \tag{11}$$

Here $\tilde{p}_A$ denotes member i's (updated) expectation of project A's quality after observing $s_i = \emptyset$, $x = A$, and $w_i(\emptyset, A) = w_i(\emptyset, \emptyset)$. Since member i is able to infer that $s_j \neq B$ from the choice of project A, his expectation is revised upwards. Using Bayes' rule it can be determined as:

$$\tilde{p}_A = \frac{1 + (1-q)p_{AB}}{2-q} \in (\bar{p}_A, p_{AA}). \tag{12}$$

Since $\Delta f > \frac{2c}{\bar{p}_A} > \frac{2c}{\tilde{p}_A}$, the incentive constraints in (11) are satisfied by setting $w_i(A, A) = w_i(A, \emptyset) = w_i(\emptyset, A) = w_i(\emptyset, \emptyset) = \frac{1}{2}$. In the Appendix we prove the following:

Proposition 1 *The set of parameters for which the first–best allocation fails to be implementable is given by* $T^{**}(p_{AB}, c) = \{(\Delta f, \frac{p_{BB}}{p_{AB}}) \in T | \frac{p_{BB}}{p_{AB}} < t^*(\Delta f)\}$. $T^{**} \neq \emptyset$ *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* $(\Delta f, \frac{p_{BB}}{p_{AB}}) \in T^* \equiv T \backslash T^{**}$ *the first best is implementable by a mechanism which shares revenue equally except for including a reward for the unilateral disclosure of evidence for* B *when* $p_{AB} f_1 > p_{BB} f_0$.

Figure 1 depicts the case where the conditions of Proposition 1 are satisfied.[16] The parameter space T, where a trade–off between adaptation and motivation exists, is the area below the solid line. The first 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 the reward in (9) 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 rewards exceed the upper limit, 1, implied by the conditions of budget balance and limited liability. As a result, the first best is no longer implementable.

[16]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 $\frac{2c}{1-f_0} < \frac{c}{f_0} \Leftrightarrow f_0 < \frac{1}{3}$.

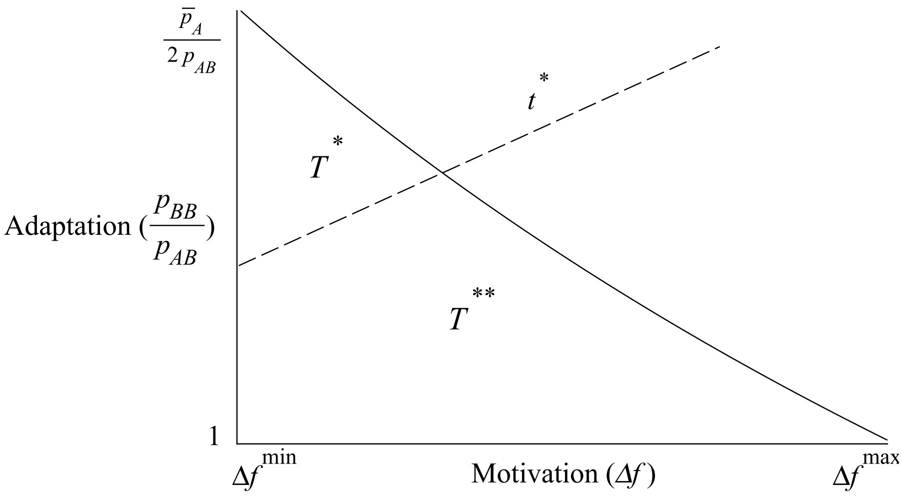

Figure 1: Implementability of the first best: The first best is implementable in T^* but fails to be implementable in T^{**}. $\Delta f^{min} = \frac{2c}{\bar{p}_A}$, $\Delta f^{max} = \frac{c}{p_{AB}}$. Solid line: $\frac{p_{BB}}{p_{AB}} = \frac{c}{p_{AB}\Delta f}$.

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 $p_{AB} < \frac{c}{f_0}$.

We now briefly comment on the range of parameters which has so far been neglected from our analysis. For $\Delta f < \frac{2c}{\bar{p}_A}$, the first best fails to be implementable under symmetric information. This is because, when $s_1 = s_2 = \emptyset$, both team members would require strictly more than half of the project's revenue to exert effort on project A. In contrast, our analysis above shows that, under asymmetric information, both team members can be induced to exert effort on project A as long as $\Delta f > \frac{2c}{\tilde{p}_A}$. Under the mechanism outlined above, the selection of project A serves as a favorable signal about the project's quality. As a consequence, both team members update favourably their expectation of project A's quality ($\tilde{p}_A > \bar{p}_A$) and can be induced to exert effort by receiving half of its revenue. We summarize this finding as:

Remark 1 *If $\frac{2c}{\tilde{p}_A} \leq \Delta f < \frac{2c}{\bar{p}_A}$ and $\frac{p_{BB}}{p_{AB}} \geq t^*(\Delta f)$ then the first best is implementable when team members have private information about the projects' qualities but fails to be* *implementable when such information is publicly available.*

This finding is reminiscent of Hermalin's (1998) result that the efficiency of team production can be improved when the access to information about the project's quality is restricted to one member, i.e. the leader. However, in Hermalin (1998) the improvement derives from the leader's ability to signal his private information via his choice of effort. In contrast, in our model it is due to the mechanism's ability to pool information in a way which optimally manipulates the team members' expectations.

We have so far characterized the conditions under which the first best is implementable for a team with two identical members. In the next section we consider how these conditions vary with the size of the team and study the effect of introducing heterogeneity into our setup. However, before doing so, we discuss the influence of budget balance and limited liability on the implementability of the first best.

The role of budget balance

Suppose we relax the requirement that the team has a balanced budget 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 first best 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 selected. However, in this case, w_i cannot be reduced below $\frac{c}{\tilde{p}_A \Delta f}$ in order to guarantee the provision of effort. We can therefore substitute $w_1^A(\emptyset, \emptyset) = \frac{c}{\tilde{p}_A \Delta f}$ in (8) to obtain the minimum value of $\frac{p_{BB}}{p_{AB}}$ compatible with the implementability of the first best. Without budget balance the first best is implementable if and only if

$$\frac{p_{BB}}{p_{AB}} \geq \frac{1-q}{2-q} \left(\frac{1}{\Delta f} + \frac{1}{f_0} \right) \frac{2c}{\tilde{p}_A} \equiv t_{BB}^*(\Delta f). \tag{13}$$

Note that in contrast to the case of budget balance, the threshold t_{BB}^* is decreasing in Δf. In the absence of budget balance, an increase in the value of motivation Δf has the additional effect of raising the amount of money that can be burned without harming the incentives to exert effort. As a consequence, the first best becomes easier to implement for higher values of motivation. The benchmark fails to be implementable in a non–empty subset of T if and only if $t^*_{BB}(\Delta f^{min}) > 1$ which is equivalent to

$$\frac{\bar{p}_A}{2} < \frac{c}{f_0} \quad \text{and} \quad q < 1 - \frac{f_0}{2c + f_0(1 - \bar{p}_A)} \in (0, 1). \tag{14}$$

Since $\bar{p}_A > 2p_{AB}$ these conditions are stronger than the corresponding conditions under budget balance specified in Proposition 1.[17] Relaxing budget balance therefore enlarges the parameter set for which the first best is implementable. However, even after relaxing budget balance, the first best fails to be implementable in a non–empty subset of the parameter space.

The role of limited liability

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

$$\frac{p_{BB}}{p_{AB}} \geq \frac{1-q}{2-q}(1 + \frac{\Delta f}{f_0}) - \frac{2L}{(2-q)p_{AB} f_0} \equiv t^*_{LL}(\Delta f). \tag{15}$$

An increase in L leads to a (parallel) downward shift of the implementability threshold $t^*_{LL}(\Delta f)$. 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 are no longer 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 the first best is implementable in the entire parameter space.

[17] 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 Team size and heterogeneity

In this section we consider how the implementability of the first-best benchmark depends on the team's size and the heterogeneity of its members. In the first part we allow for a general number N of identical team members. We obtain the surprising result, that, although potentially detrimental to 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 heterogeneity, 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. The objective is to generalize Proposition 1 and to understand how an increase in N affects the implementability of the first–best allocation in the set T of parameters for which a trade–off between motivation and adaptation exists.[18]

Following our arguments in Section 3, consider a mechanism which distributes the revenue of project A equally amongst all members and selects project B if and only if evidence for B has been disclosed. Member i will exert effort on project A after observing $s_i = \emptyset$ if and only if $\Delta f \geq \frac{Nc}{\tilde{p}_A(N)} \equiv \Delta f_N^F$. As before, $\tilde{p}_A(N)$ denotes member i's updated belief about project A's quality once project A has become selected. It is given by

$$\tilde{p}_A(N) = \frac{1 + (1-q)^{N-1} p_{AB}}{1 + (1-q)^{N-1}} \tag{16}$$

and is increasing in N. In a team of size N the fact that project A has become selected means that $N-1$ members must have failed to observe evidence for B. Hence in a larger team the selection of project A represents a more favorable signal regarding the quality of the project. Note however, that this effect is more than compensated by the fact that

[18] $Pr(R = 1) \leq 1$ 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 $p_{AB} \in [\frac{Nc}{1-f_0}, \frac{1}{3})$.

in a larger team, revenue has to be divided amongst a higher number of members. In particular, the term $\frac{\tilde{p}_A(N)}{N}$ is decreasing in N which means that in a larger team free–riding represents a greater obstacle to the implementation of the first–best effort levels.

While the negative effect of team size on effort incentives is standard in models of team production[19], in our setup team size also affects the members' ability to share information. In a bigger team, the concealment of evidence is potentially more rewarding since it can boost the motivation of a higher number of colleagues. A countervailing effect arises since the concealment of evidence is less likely to succeed in a bigger team. In other words, if member i conceals evidence in favor of B, then $N-1$ team members can be motivated to exert effort on project A. However, this only happens when all $N-1$ members have failed to observe evidence, i.e. with probability $(1-q)^{N-1}$. It is therefore not clear whether the incentive to disclose evidence is increasing or decreasing in N.

A more subtle effect is that, in a larger team, there exists a wider range of possibilities to reward the disclosure of information. In particular, evidence in favor of B can not only be rewarded when it is disclosed unilaterally but whenever *at least one other* member failed to disclose it. The incentive to disclose B is then maximized by sharing project B's revenue (equally) amongst all members who disclosed 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

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

$$\Leftrightarrow \frac{p_{BB}}{p_{AB}} \geq \frac{q(1-q)^{N-1}}{1-(1-q)^N}\left(1 + (N-1)\frac{\Delta f}{f_0}\right) \equiv t_N^*(\Delta f). \qquad (17)$$

In the Appendix we prove the following:

Proposition 2 *For a team with $N > 2$ members, the first best is implementable in $T_N^* = \{(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T | \Delta f \geq \Delta f_N^F, \frac{p_{BB}}{p_{AB}} \geq t_N^*(\Delta f)\}$. The first best fails to be implementable due to free–riding in $T_N^F = \{(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T | \Delta f < \Delta f_N^F\}$, and due to a lack of information disclosure in $T_N^I = \{(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T | \frac{p_{BB}}{p_{AB}} < t_N^*(\Delta f)\}$. $T_N^I \neq \emptyset$, 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.*

[19] An exception is Adams (2006) who shows that the effect can be positive when team production exhibits sufficiently strong complementarities.

Proposition 2 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 first best fails to be implementable due to the team's inability to disclose information. There now also exists a subset of T, denoted as T_N^F, for which free–riding hinders the implementability of the first–best allocation. 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 q_N^* and t_N^* are decreasing in N, information sharing becomes less of

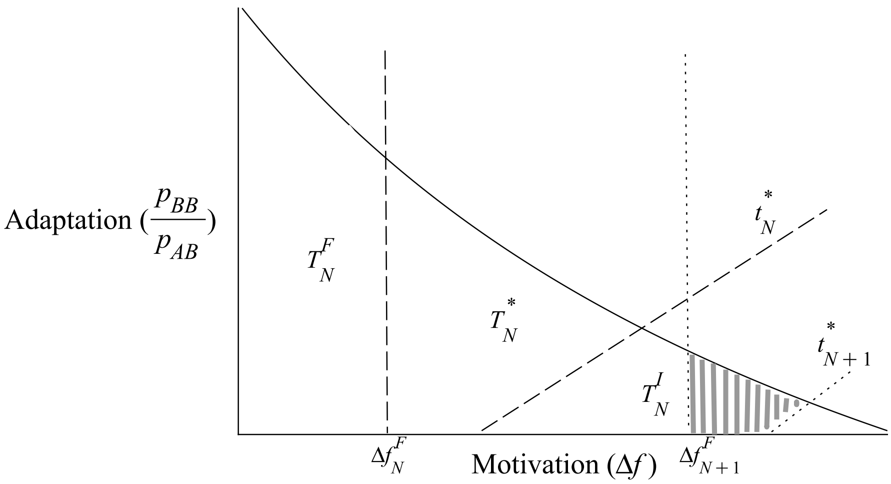

Figure 2: Team size N: The first best is implementable in T_N^*. It fails to be implementable due to free–riding in T_N^F and due to a lack of information sharing in T_N^I. Increasing team size to $N + 1$ makes the first best become implementable in the area between the dotted lines.

a problem as the team size increases. Hence there may exist a subset of the parameter space T for which an increase in team size actually improves the implementability of the first best. This is confirmed by the following:

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 subset* $\{(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T | \Delta f > \Delta f_{N+1}^F, \frac{p_{BB}}{p_{AB}} < t_N^*(\Delta f)\} \neq \emptyset$ *of the parameter space 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 sufficient conditions under which an increase in team size *increases* *efficiency* by making the first best become implementable.[20] This contrasts with the common view, based on free–riding alone, that efficiency is harder to achieve in larger teams.

Note that for Corollary 1 to hold, it is crucial that the team rewards the disclosure of evidence in favor of B. If instead, members received a fixed share $\frac{1}{N}$ of the team's revenue, independently of the messages sent to the designer, then condition (17) would become

$$\frac{p_{BB}}{p_{AB}} \geq 1 + (N-1)\frac{\Delta f}{f_0}. \tag{18}$$

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 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*.

Note also that an increase in team size improves the information potentially available to the team, due to the evidence observed by the added member. Corollary 1 shows that the team can benefit from this added source of information not only marginally, but also through its positive effect on the existing members' disclosure incentives.

Heterogeneity

We now introduce heterogeneity into 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 in favor of B it is still optimal to offer maximum rewards for the (unilateral)

[20] 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 $\frac{(N+1)c}{1-f_0} < \min(\frac{1}{2N+1}, \frac{c}{f_0}) \Leftrightarrow f_0 < \frac{1}{N+2}$.

disclosure of B. From (8) it therefore follows that both team members disclose evidence in favor of B if and only if $\max(g_1, g_2) \leq p_{BB} f_0$ where

$$g_i = p_{AB}(f_0 + \Delta f_j) w_i(\emptyset, \emptyset) - \frac{q_j}{1 - q_j} p_{BB} f_0 w_i(B, B) \tag{19}$$

can be interpreted as member i's incentive to conceal B.

Note that for $w_i(\emptyset, \emptyset) = w_i(B, B) = \frac{1}{2}$, it holds that $g_1 > g_2$, i.e. member 1 has a stronger incentive to conceal evidence. This is because, for member 1, concealment is either more likely to motivate his 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, $w_i(\emptyset, \emptyset) = w_i(B, B) = \frac{1}{2}$ cannot be optimal. Instead $w_i(\emptyset, \emptyset)$ and $w_i(B, B)$ should be optimally chosen to give both members an equal incentive for disclosure. This can be achieved either by decreasing $w_1(\emptyset, \emptyset)$ or by increasing $w_1(B, B)$. Lowering member 1's incentive to conceal by decreasing $w_1(\emptyset, \emptyset)$ comes at a lower cost, i.e. a smaller increase in member 2's incentive to conceal.[21] In order to implement the benchmark for the largest range of parameters it is therefore necessary to set $w_1(\emptyset, \emptyset) < \frac{1}{2}$. However, this decrease in $w_1(\emptyset, \emptyset)$ could potentially alter the incentives to disclose evidence for A. One way to guarantee that A is disclosed is to keep the allocation of project A's revenue independent of messages by setting $w_1(A, A)$, $w_1(A, \emptyset)$ and $w_1(A, \emptyset)$ equal to $w_1(\emptyset, \emptyset)$. We summarize these findings as follows:

Proposition 3 *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 optimal mechanism accounts for this by assigning a smaller share of project A's revenue to member* 1.

The optimal compensation scheme is characterized in more detail in the proof of Proposition 3. Proposition 3 contrasts with the results of more standard models of team production. To see this note that, in the absence of informational asymmetries, it could be necessary to give a *larger* share of revenue to the member with the lower productivity if

[21] For $\Delta f_1 < \Delta f_2$, $q_1 = q_2$, decreasing g_1 by one unit can be achieved by decreasing $w_1(\emptyset, \emptyset)$ by $[p_{AB}(f_0 + \Delta f_2)]^{-1}$ units or by increasing $w_1(B, B)$ 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 $q_1 > q_2$, $\Delta f_1 = \Delta f_1$.

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 $w_1(\emptyset, \emptyset) \geq \frac{c}{\bar{p}_A \Delta f_1} > \frac{c}{\bar{p}_A \Delta f^{min}} = \frac{1}{2}$.

If we interpret project A as the status quo and project B as the adoption of changes, our results suggest that teams more effectively adapt to a changing environment when better informed members own smaller shares in the status quo and opinions in conflict with the status quo are rewarded. In practice, better information often goes hand in hand with higher stakes and dissenting voices are punished rather than rewarded. This may help to explain why teams are less effective in the adoption of changes than would be desirable.

5 Second best

We now return to our baseline model with two homogeneous team members in order to characterize the optimal mechanism for the case where the benchmark fails to be implementable. Hence in the following we assume that the conditions of Proposition 1 are satisfied so that $T^{**} \neq \emptyset$. The revelation principle allows us to restrict attention to mechanisms in which team members reveal their private information to the designer. Any revelation mechanism must, by definition, provide team members with incentives to disclose evidence for B. In Section 3 we have seen that this may require a reward for the unilateral disclosure of B. Furthermore, in T^{**} even the maximum feasible reward is not sufficient to induce truth–telling, since the expected payoff from disclosure is smaller than the expected payoff from concealment, i.e.

$$q p_{BB} f_0 \frac{1}{2} + (1-q) p_{BB} f_0 < \frac{1}{2}(1-q) p_{AB} f_1. \tag{20}$$

In this section we show that this relation can be reversed by allowing project or effort choices to differ from the first best. We argue that there exist exactly three possibilities to achieve this. The corresponding mechanisms differ with respect to the distortion that they induce to the team's project choice. We define the team's project choice as exhibiting a positive (negative) bias when the initially preferred alternative is selected more (less) frequently than in the first best. The main insight of this section is that the second–best mechanism may entail either a positive or a negative bias, or alternatively, induce first–best decision–making at the expense of inefficient effort choices.

Unbiased project choice

In order to strengthen the team members' incentive to disclose B one may either increase their payoff from disclosure or decrease their payoff from concealment. If the mechanism is to implement the first–best project allocation, the former is not feasible and there exists exactly one way in which the latter can be achieved. To see this, consider a mechanism which differs from the one implementing the first best (with maximum rewards) only in that, when no evidence is disclosed, it assigns the entire revenue to one member, say member 1, i.e. $w_1(\emptyset, \emptyset) = 1$, and requests zero effort from the other, i.e. $\hat{e}_2^r(\emptyset, \emptyset) = 0$. Under this mechanism the disclosure of B is optimal for member 1 since

$$qp_{BB}f_0\frac{1}{2} + (1-q)f_0p_{BB} \geq (1-q)f_0p_{AB}. \tag{21}$$

Disclosure is optimal because, conditional on member 2 observing $\emptyset$, 1's compensation and 2's effort are independent of 1's message, but the quality of the project chosen is strictly higher following disclosure. Clearly, the disclosure of B is also optimal for member 2 since he expects a zero payoff from concealment. Hence, assigning the project to *one* member in the absence of evidence provides *both* members with incentives to disclose B.

Note however, that the above mechanism faces two problems. Firstly, since member 1 may obtain the project's entire revenue not only by concealing B but also by concealing A, we need to be concerned with his incentive to disclose A. Member 1's incentive to disclose A can be maximized without harm to member 2's incentive to exert effort by setting $w_1^A(A, A) = w_1^A(A, \emptyset) = \left(1 - \frac{c}{\Delta f}\right)$ and $w_1^A(\emptyset, A) = \frac{c}{\Delta f}$. Given these choices, the disclosure of A is optimal if and only if

$$f_2\left(1 - \frac{c}{\Delta f}\right) \geq qf_2\left(1 - \frac{c}{\Delta f}\right) + (1-q)f_1w_1(\emptyset, \emptyset). \tag{22}$$

Secondly, note that in the absence of evidence, member 1 may want to induce member 2 to exert effort by offering a side–contract. If this side–contract assigns a share $\frac{c}{\bar{p}_A\Delta f}$ of revenue to member 2 then member 2 will exert effort. Member 1 will offer such a 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 member 2. In particular, for the mechanism to be collusion–proof it has to hold that

$$\bar{p}_A f_1 w_1(\emptyset,\emptyset) \geq \bar{p}_A f_2(1-\frac{c}{\bar{p}_A \Delta f}). \tag{23}$$

Since $w_1(\emptyset,\emptyset) \leq 1$, this implies that the first–best project choice cannot be implemented if

$$f_1 < f_2(1-\frac{c}{\bar{p}_A \Delta f}) \quad \Leftrightarrow \quad \Delta f > \frac{c}{\bar{p}_A}\left(1+\sqrt{1+\frac{\bar{p}_A f_0}{c}}\right) \equiv \Delta f^{cp}. \tag{24}$$

In the Appendix we show that if (22) is violated for $w_1(\emptyset,\emptyset)=1$ then setting $w_1(\emptyset,\emptyset)$ equal to the lower bound implied by (23) and $w_1(B,B)=0$ is sufficient to give *both* members an incentive to disclose B. Hence we have the following:

Proposition 4 *In T^{**} the first-best project allocation is implementable if and only if $\Delta f \leq \Delta f^{cp}$. The corresponding mechanism induces one member to exert inefficiently low effort in the absence of evidence. $\Delta f^{cp} > \Delta f^{min}$ is increasing in f_0 with $\lim_{f_0 \to 0} \Delta f^{cp} = \Delta f^{min}$.*

Under the above mechanism, the loss of welfare relative to the first best is given by

$$\Delta W^0 = (1-q)^2(\bar{p}_A \Delta f - c). \tag{25}$$

Here we use the superindex "0" to highlight the fact that the team's decision–making is subject to a *zero* bias. The welfare loss is entirely due to the induced distortion of effort.

Negatively biased project choice

If we allow project choices to differ from the first best then there exists exactly one alternative way in which the team members' payoff from concealment can be decreased. It consists of distorting the first–best project–selection rule by choosing project B rather than project A when no evidence is disclosed. Combining this rule with maximum rewards for the unilateral disclosure of B and equal revenue sharing in all other cases, the disclosure condition is satisfied since

$$q p_{BB} f_0 \frac{1}{2} + (1-q) p_{BB} f_0 > \frac{1}{2}(1-q) p_{BB} f_0. \tag{26}$$

The mechanism biases the team's decision–making negatively, i.e. against the direction of the initially preferred alternative. In particular, when $s = (\emptyset, \emptyset)$, project B is selected even though efficiency requires the choice of project A. Although, conditional on project choice, the mechanism induces efficient effort levels, from an ex ante perspective effort is inefficiently low. The loss of welfare relative to the first best can be written as

$$\Delta W^{-} = (1-q)^2 \left[(\bar{p}_A - \bar{p}_B) f_0 + 2 (\bar{p}_A \Delta f - c) \right] \tag{27}$$

where the superindex is chosen to account for the direction of the decision–making bias. The revelation of information in conflict with prior expectations is now guaranteed by the team's commitment to take "unorthodox" decisions even in the absence of evidence in their favor.

Positively biased project choice

The final way to strengthen the team members' incentive to disclose B is to increase their payoffs from disclosure. As can be seen from (20), the only way to achieve this is to induce one of the agents to exert effort. When $s = (B, B)$ this is not feasible since both members are unwilling to exert effort independently of project choice and compensation. In this case one member's payoff from disclosure cannot be increased beyond $p_{BB} f_0 \frac{1}{2}$ without decreasing the other member's payoff. However, when $s = (B, \emptyset)$, the mechanism could select project A, offer both members equal shares of revenue, and request effort from the uninformed member. If the mechanism makes first–best project choices and offers equal shares for any other pair of types $s \notin \{(B, \emptyset), (B, \emptyset)\}$, then the uninformed member will retain his prior expectations regarding the quality of project A. He will therefore be willing to exert effort on project A. The disclosure condition is then trivially satisfied since

$$q p_{BB} f_0 \frac{1}{2} + (1-q) p_{AB} f_1 \frac{1}{2} > \frac{1}{2} (1-q) p_{AB} f_1. \tag{28}$$

This mechanism does not reward the unilateral disclosure of B by promising a higher share of revenue but instead by maintaining equal shares and inducing effort from the uninformed team member. This clearly comes at the cost that the team's decision making becomes positively biased, i.e. in the direction of the initially preferred alternative. In other words, A becomes selected even when efficiency requires the choice of project B, i.e. when $s \in \{(B, \emptyset), (B, \emptyset)\}$. Surplus is further reduced by the fact that one team member is induced to exert an inefficiently high level of effort. The loss of welfare relative to the first best can be written as

$$\Delta W^{+} = q(1-q)\left[(p_{BB} - p_{AB})\, f_0 + c - p_{AB}\Delta f\right]. \tag{29}$$

Note that for the above mechanism to succeed two requirements are essential. Firstly, messages to the mechanism designer must be confidential. Secondly, the uninformed team member must not be able to deduce the informed member's message from the outcome of the mechanism. This requires that, when member i observes $s_i = \emptyset$, project choice and compensation should be independent of member j's message. Hence although the mechanism is revealing in the sense of the revelation principle, information fails to be transmitted across team members. In the spirit of the examples mentioned in the Introduction, in order to maintain morale unpopular opinions fail to be shared at the cost of suboptimal decisions. The mechanism is diametrically opposed to the one with a zero bias. While the unbiased mechanism sacrifices motivation in order to ensure optimal adaptation the positively biased mechanism permits sub–optimal project choices in exchange for a boost in morale.

Comparison

The three mechanisms above constitute the only means by which the incentives to disclose B can be strengthened. In order to derive the second–best mechanism it therefore remains to compare the welfare losses of these three mechanisms. For this purpose, note that the unbiased mechanism dominates the negatively biased mechanism, since it induces a smaller welfare loss $\Delta W^0 < \Delta W^-$. However, for $\Delta f > \Delta f^{cp}$, the unbiased mechanism fails to be collusion–proof. It therefore remains to compare ΔW^+ with ΔW^0 for $\Delta f \leq \Delta f^{cp}$ and ΔW^+ with ΔW^- for $\Delta f > \Delta f^{cp}$. These comparisons are straightforward: $\Delta W^+ > \Delta W^0$ if and only if

$$\frac{p_{BB}}{p_{AB}} > 1 - \frac{c}{q p_{AB} f_0} + (1 + \frac{1-q}{q}\frac{\bar{p}_A}{p_{AB}})\frac{\Delta f}{f_0} \equiv t^{+0}(\Delta f) \tag{30}$$

whereas $\Delta W^+ > \Delta W^-$ if and only if

$$\frac{p_{BB}}{p_{AB}} > 1 + \frac{1 - q - 2(2-q)\frac{c}{f_0}}{(1+q)p_{AB}} + \frac{2(1-q+p_{AB})}{(1+q)p_{AB}}\frac{\Delta f}{f_0} \equiv t^{+-}(\Delta f). \tag{31}$$

Using these thresholds we can characterize the subsets of parameters for which each of the three mechanisms constitutes the second best:

$$\begin{aligned} T^0 &= \{(\Delta f, \frac{p_{BB}}{p_{AB}}) \in T^{**} | \Delta f \leq \Delta f^{cp}, \frac{p_{BB}}{p_{AB}} \geq t^{+0}(\Delta f)\} \\ T^- &= \{(\Delta f, \frac{p_{BB}}{p_{AB}}) \in T^{**} | \Delta f \geq \Delta f^{cp}, \frac{p_{BB}}{p_{AB}} \geq t^{+-}(\Delta f)\} \\ T^+ &= T^{**} \backslash (T^0 \cup T^-). \end{aligned} \tag{32}$$

Proposition 5 *In T^+ or T^- the second–best mechanism imposes a positive or negative bias to the team's project choice. In T^0 the team's project choice is unbiased but effort is inefficiently low. $T^+ \neq \emptyset$ since $\Delta W^+ \to 0$ for $(\Delta f, \frac{p_{BB}}{p_{AB}}) \to (\Delta f^{max}, 1)$. Finally, for any (c, p_{AB}, q) such that $c < \frac{1}{6}$, $p_{AB} \in (2c, \frac{1}{3})$ and $q \in (1 - \frac{\bar{p}_A - 2p_{AB}}{2 - \bar{p}_A}, 1)$, there exists a $f_0^{max} \in (0, \frac{1}{3})$ such that $T^- \neq \emptyset$ and $T^0 \neq \emptyset$ for all $f_0 < f_0^{max}$.*

Proposition 5 characterizes the second–best allocation and provides conditions under which each of the three corresponding mechanisms are optimal in a non–empty subset of T^{**}. Figure 3 depicts the case where these conditions are satisfied. As can be seen from the Figure, an unbiased project–choice rule is part of the second–best mechanism only when the value of motivation is relatively low. In this case, the trade–off between adaptation and motivation is resolved by ensuring first–best decision–making at the expense of depressing morale. Instead, when the value of motivation is relatively high, the team's decision–making exhibits a bias and adaptation fails to be first best. The bias may be in favor or against the team's initially preferred alternative. A positive bias induces efforts which are inefficiently high while a negative bias leads to efforts which are inefficiently low. It follows that a positive bias is preferable when the value of motivation is high.

To conclude, the likelihood of adopting the initially preferred alternative is non–monotonic in the relative value of motivation. Similarly, the overall level of effort initially decreases as the value of motivation increases and the optimal mechanism switches from

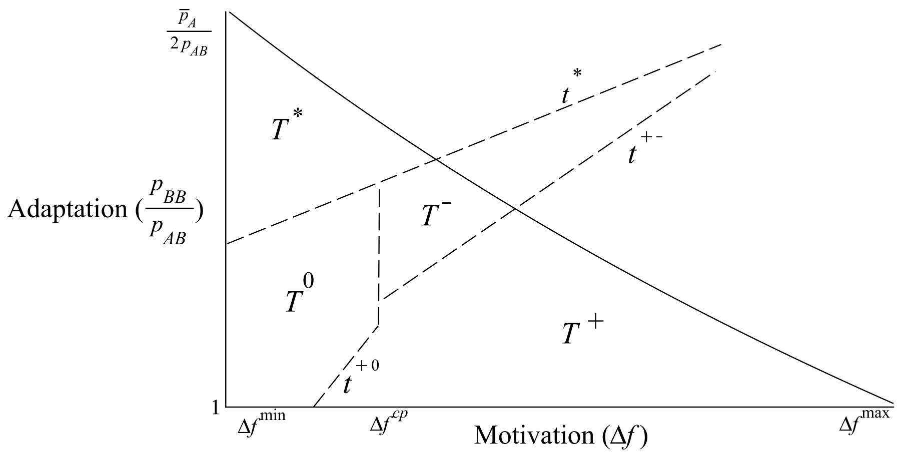

Figure 3: Second best. The set T^{**} where the first best fails to be implementable is divided into three areas T^+, T^-, and T^0 where project choice exhibits a positive, negative, or zero bias respectively.

being unbiased to being negatively biased. Effort then increases as the value of motivation increases further and a morale–boosting positively–biased project choice becomes part of the optimal mechanism.

Random Mechanisms

We close this section with a discussion of *random* mechanisms. Due to the applied focus of our model, we have restricted attention to deterministic mechanisms. Allowing for stochastic mechanisms does not improve the implementability of the first best but can increase the level of surplus that is achieved with second–best alternatives. To see this, consider the following randomization of the negative–bias mechanism. Suppose that, in the absence of evidence, the mechanism selects project A with probability α and project B with probability $1-\alpha$. Our analysis above has shown that for $\alpha = 0$ team members strictly prefer disclosure over concealment. Since surplus is increasing in α, welfare can therefore be increased by selecting the maximum α for which the disclosure of evidence is still guaranteed. This value is readily determined and given by

$$\alpha^* = \frac{p_{BB} f_0}{(1-q)(p_{AB} f_1 - p_{BB} f_0)}. \tag{33}$$

α^* is increasing in the value of adaptation and decreasing in the value of motivation and converges to 1 as $\frac{p_{BB}}{p_{AB}} \to t^*(\Delta f)$. This implies that, in the proximity of the implementability threshold t^*, the first best can be approximated by a random mechanism. Similar randomized versions exist for the mechanisms with a positive or zero bias.

It can easily be shown that the implementability of an unbiased project choice remains limited by the requirement of collusion–proofness and that, for $\frac{p_{BB}}{p_{AB}} \to 1$ and $\Delta f \to \Delta f^{max}$, only a positive bias mechanism is capable of approximating the first best. Moreover, it is easy to show that the optimal mechanism should be one of the three (randomized) mechanisms discussed above rather than any combination of them. We therefore expect the characterization of the second best to be qualitatively similar to Figure 3 with each deterministic mechanism substituted by its randomized equivalent.

6 Robustness

Our model assumes that information is verifiable and that individual efforts are independent inputs of production. 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 in this section is that an increase in the signals' precision or in the strength of complementarities makes the set of parameters for which the first best fails to be implementable become smaller, without reducing it to $\emptyset$.

Non–verifiable information

So far, our analysis has focused 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 necessary 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 the two 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 the signals differ from each other. These assumptions require that

$$1 > p_{BB} > \frac{(1-\tilde{q})^2}{\tilde{q}^2}. \tag{34}$$

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. These assumptions require that

$$4c < \Delta f < \frac{\tilde{q}^2 + (1-\tilde{q})^2}{\tilde{q}^2} \frac{c}{p_{BB}}. \tag{35}$$

In summary, the set

$$\tilde{T}(c, \tilde{q}) = \{(\Delta f, p_{BB}) | 4c < \Delta f < \frac{\tilde{q}^2 + (1-\tilde{q})^2}{\tilde{q}^2} \frac{c}{p_{BB}}, 1 > p_{BB} > \frac{(1-\tilde{q})^2}{\tilde{q}^2}\} \tag{36}$$

represents the analog to the set T in our baseline model.[22] This benchmark allocation is similar to the one in our baseline model. In particular, project B should be selected if and only if $s_1 = s_2 = B$, and $\hat{e}_i^*(s_1, s_2) = 1$ unless $s_1 = s_2 = B$.

We now proceed to examine whether this benchmark allocation can be implemented. Following the reasoning in Section 3, symmetry implies that truth–telling incentives are maximized by setting $w_i(B, B) = w_i(A, A) = \frac{1}{2}$. It remains to consider $w_1(B, A)$.

[22]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 sufficient: $f_0 < 1$, $\tilde{q} > \frac{3}{2} - \frac{1}{2}\sqrt{3}$, and $c < \frac{1}{2}(1 - f_0)\frac{(1-\tilde{q})^2}{\tilde{q}^2+(1-\tilde{q})^2}$.

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

$$I_1(B,B) = \tilde{q}^2 p_{BB} f_0 \frac{1}{2} - (1-\tilde{q})^2 f_1[1 - w_1(B,A)] + \tilde{q}(1-\tilde{q}) f_2[w_1(B,A) - \frac{1}{2}]. \tag{37}$$

If $p_{BB} \geq \frac{(1-\tilde{q})^2}{\tilde{q}^2}(1 + \frac{\Delta f}{f_0})$, setting $w_1(B,A) = \frac{1}{2}$ is sufficient to induce truth-telling, i.e. the benchmark is implementable by an equal share contract, $w_i(m_1, m_2) = \frac{1}{2}$ for all (m_1, m_2). In the remainder we can therefore restrict attention to the case where $p_{BB} < \frac{(1-\tilde{q})^2}{\tilde{q}^2}(1+\frac{\Delta f}{f_0})$.

For $p_{BB} < \frac{(1-\tilde{q})^2}{\tilde{q}^2}(1 + \frac{\Delta f}{f_0})$ a reward $w_1(B,A) > \frac{1}{2}$ is necessary to induce truth-telling of B. As a consequence we also have to be concerned 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

$$I_1(B,A) = 2\tilde{q}(1-\tilde{q}) \left[\frac{1}{4} p_{BB} f_0 - \frac{1}{2} f_2[1 - w_1(B,A)] + c\right] + \tilde{q}^2 f_2[w_1(B,A) - \frac{1}{2}]. \tag{38}$$

To induce truth–telling the mechanism has to choose a $w_1(B,A)$ such that $I_1(B,B) \geq 0$ and $I_1(B,A) < 0$. In the Appendix we show that if $w_1(B,A)$ makes the B–type indifferent between truth–telling and lying, then the A-type will tell the truth. Hence truth–telling can be guaranteed by choosing the $w_1(B,A)$ which solves $I_1(B,B) = 0$, i.e.

$$w_1(B,A) = 1 - \frac{\tilde{q}^2 p_{BB} f_0 + \tilde{q}(1-\tilde{q}) f_2}{2(1-\tilde{q})\left[\tilde{q} f_2 + (1-\tilde{q}) f_1\right]} \equiv \bar{w}_1(B,A) \in (\frac{1}{2}, 1). \tag{39}$$

It remains to consider the members' incentive to exert effort on project A. Note that after observing $s_1 = B$ and reporting $m_1 = B$, member 1 can infer $s_2 = A$ from the selection of project A. Similarly, after observing $s_2 = A$ and reporting $m_2 = A$, member 2 can infer $s_1 = B$ from observing $w_2(B,A) > \frac{1}{2} = w_2(A,A)$. Hence both members will expect project A's quality to be equal to its prior value of $\frac{1}{2}$. In order to induce efficient effort levels for project A, $w_1(B,A)$ therefore has to satisfy the following incentive constraints:

$$\frac{2c}{\Delta f} \leq w_1(B,A) \leq 1 - \frac{2c}{\Delta f}. \tag{40}$$

As in the baseline model without budget balance, the reward for member 1 is restricted by the incentive constraint of member 2. The benchmark is implementable if and only $\bar{w}(B,A) \leq 1 - \frac{2c}{\Delta f}$ which is equivalent to

$$p_{BB} \geq \frac{1-\tilde{q}}{\tilde{q}} \left[\frac{4c}{\tilde{q} f_0}(1 + \tilde{q} + \frac{f_0}{\Delta f}) - 1 - 2\frac{\Delta f}{f_0} \right] \equiv \tilde{t}^*(\Delta f). \tag{41}$$

Note that the threshold $\tilde{t}^*(\Delta f)$ is decreasing in $\tilde{q}$. Moreover, in the Appendix we show that no further restrictions on the parameters f_0, c, and $\tilde{q}$ are required to ensure that the benchmark fails to be implementable in a non–empty subset of $\tilde{T}$. We can therefore summarize our findings as follows:

Remark 2 *When team members receive unverifiable signals with precision $\tilde{q} \in (\frac{1}{2}, 1)$, the first best fails to be implementable in $\tilde{T}^{**}(\tilde{q}) = \{(\Delta f, p_{BB}) \in \tilde{T} | p_{BB} < \tilde{t}^*(\Delta f)\} \neq \emptyset$. If the signals' precision increases from $\tilde{q}$ to $\tilde{q}'$ then $\tilde{T}^{**}(\tilde{q}') \subset \tilde{T}^{**}(\tilde{q})$.*

As in the baseline model, the benchmark becomes implementable in a larger subset of the parameter space when team members are better informed about the projects' qualities. The reason is that the misrepresentation of information is in that case less likely to result in an increase in motivation.

In comparison to the baseline model, the model with unverifiable signals has an additional feature encouraging truth-telling which is similar to the subordinate's incentive to conform with the views of his superior in Prendergast (1993), or to the leader's propensity to pander to his follower's opinion in Blanes i Vidal and Möller (2007). In particular, each team member has an interest 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 therefore have an additional incentive to tell the truth. We find it reassuring that our main result remains qualitatively 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. $\frac{1}{2}\bar{p}_A \Delta f > c$.[23] In the presence of complementarities assumption (3) therefore becomes

$$\frac{2c}{(2+\gamma)p_{BB}} > \Delta f > \frac{2c}{\bar{p}_A}. \tag{42}$$

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

$$f_0 < 1, \quad c < \frac{1-f_0}{6+4\gamma}, \quad p_{AB} \in [\frac{2c}{1-f_0}, \frac{1}{3+\gamma}). \tag{43}$$

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 is satisfied if and only if

$$p_{AB} < \frac{2c}{(2+\gamma)f_0} \quad \text{and} \quad q < 1 - \frac{(2+\gamma)p_{AB}f_0}{2c}. \tag{44}$$

The upper bound on p_{AB} in (44) is larger than the lower bound in (43) if and only if $f_0 < \frac{1}{3+\gamma}$. The fact that all upper bounds are positive and decreasing in γ implies the following:

Remark 3 *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.*

[23]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.

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 conflict with an initially preferred alternative in situations where maximizing the colleagues' motivation is more important than the adoption of the best project. To overcome this, the optimal mechanism includes a reward for the disclosure of unpopular information. Counterintuitively, we show that an increase in team size can make the first best become implementable, and hence lead to an improvement in efficiency.

If the first best is not implementable, three candidates for the second–best mechanism emerge. While the implementation of the first–best project choice requires a downward distortion of effort and is optimal for low values of motivation, for intermediate and high values of motivation project choice will be biased against or in favor of the team's initially preferred alternative respectively.

What specific institutional form could these mechanisms take? One possibility for the team to commit to a biased project choice is the delegation of decision–making rights to an outsider, e.g. a manager. Consider for instance a manager who neither obtains any private information nor exerts any implementation effort himself. To give project choice a negative bias, the manager could select the team's preferred project in the presence of evidence, but project B rather than A in its absence.[24] This mechanism could then be interpreted as Garicano's (2000) principle of "management by exception". The interpretation of biased project choices as delegation also resonates well with Holmstrom (1982). In his paper the principal provides optimal incentives to exert effort by allowing the team to *break the budget*. By contrast in our model the manager provides optimal incentives to share information by enabling the team to *take unpopular decisions*.

[24] This may be motivated in two ways. First, as in Landier et al. (2009), the manager's preferences may differ from the team's. For example, when A represents the status quo and B represents 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".

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.

$$\frac{1-q}{2-q}(1+\frac{\Delta f^{max}}{f_0}) > \frac{c}{p_{AB}\Delta f^{max}} = 1 \quad \Leftrightarrow \quad p_{AB} < \frac{c(1-q)}{f_0}. \tag{45}$$

This holds if and only if

$$p_{AB} f_0 < c \quad \text{and} \quad q < 1 - \frac{p_{AB} f_0}{c}. \quad \blacksquare \tag{46}$$

Proof of Proposition 2

It remains to determine the conditions under which $T_N^I \neq \emptyset$. Since t_N^* is increasing in Δf, $T_N^I \neq \emptyset$ if and only if $t_N^*(\Delta f^{max}) > 1$. Given $\Delta f^{max} = \frac{c}{p_{AB}}$, this is equivalent to

$$p_{AB} < \frac{c}{f_0} \frac{(N-1)q(1-q)^{N-1}}{1-(1-q)^{N-1}} = \frac{c}{f_0}(1-q)P(q,N). \tag{47}$$

Here $P(q,N)$ 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 (47) holds if and only if

$$p_{AB} < \frac{c}{f_0} \quad \text{and} \quad q < q_N^* \tag{48}$$

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. $\blacksquare$

Proof of Corollary 1

$q \geq q_{N+1}^*$ implies that $T_{N+1}^I = \emptyset$. Moreover, from $p_{AB} < \frac{1}{2N+1}$ it follows that $\frac{(N+1)c}{\tilde{p_A}(N+1)} < \Delta f^{max}$. Taken together this implies that $(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T_{N+1}^*$ if $\Delta f \geq \frac{(N+1)c}{\tilde{p_A}(N+1)}$. Finally, since $p_{AB} < \frac{c}{f_0}$, and $q < q_N^*$, there exist $(\frac{p_{BB}}{p_{AB}}, \Delta f) \in T$ such that $\Delta f \geq \frac{(N+1)c}{\tilde{p_A}(N+1)}$ and $\frac{p_{BB}}{p_{AB}} < t_N^*(\Delta f)$. For all those parameter values, the first best is implementable in a team with $N+1$ members but fails to be implementable in a team with N members. $\blacksquare$

Proof of Proposition 3

Setting $w_1(A,A) = w_1(A,\emptyset) = w_1(\emptyset,A) = w_1(\emptyset,\emptyset)$ the disclosure of A is guaranteed. Setting $w_1(B,\emptyset) = 1$ and $w_1(\emptyset,B) = 0$, member i's incentive to conceal is $g_i(w_i(\emptyset,\emptyset), w_i(B,B))$ as defined in (10). In the following we characterize the compensations $w_1(\emptyset,\emptyset)$ and $w_1(B,B)$ 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 $w_1(\emptyset,\emptyset) = w_1(B,B) = \frac{1}{2}$, $w_1(\emptyset,\emptyset)$ should be reduced as long as $g_1(w_1(\emptyset,\emptyset), \frac{1}{2}) > g_2(1 - w_1(\emptyset,\emptyset), \frac{1}{2})$. However, for member 1 to provide effort on project A we require that $w_1(\emptyset,\emptyset) \geq \frac{c}{\tilde{p}_A \Delta f_1}$. If the degree of heterogeneity $\Delta f_2 - \Delta f_1$ is larger than some threshold h (to be determined below), then for $w_1(\emptyset,\emptyset) = \frac{c}{\tilde{p}_A \Delta f_1}$ it will still hold that $g_1(w_1(\emptyset,\emptyset), \frac{1}{2}) > g_2(1 - w_1(\emptyset,\emptyset), \frac{1}{2})$. In this case $w_1(B,B)$ should be increased as long as $g_1(\frac{c}{\tilde{p}_A \Delta f_1}, w_1(B,B)) > g_2(1 - \frac{c}{\tilde{p}_A \Delta f_1}, 1 - w_1(B,B))$. In contrast, when the degree of heterogeneity is small, i.e. $\Delta f_2 - \Delta f_1 \leq h$, then there exists some $w_1(\emptyset,\emptyset) \in (\frac{c}{\tilde{p}_A \Delta f_1}, \frac{1}{2})$ such that $g_1(w_1(\emptyset,\emptyset), \frac{1}{2}) = g_2(1 - w_1(\emptyset,\emptyset), \frac{1}{2}) = G$. In this case, G can be reduced further by simultaneously decreasing $w_1(\emptyset,\emptyset)$ and $w_1(B,B)$. To see this, note that a reduction in $w_1(\emptyset,\emptyset)$ decreases g_1 by more than it increases g_2. A reduction in $w_1(B,B)$ 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 $w_1(\emptyset,\emptyset)$ and $w_1(B,B)$ are therefore reduced until one of the two reaches its lower bound given by $\frac{c}{\tilde{p}_A \Delta f_1}$ and 0 respectively. The threshold h can be determined from $g_1(\frac{c}{\tilde{p}_A \Delta f_1}, \frac{1}{2}) = g_2(1 - \frac{c}{\tilde{p}_A \Delta f_1}, \frac{1}{2})$ and is given by

$$h = 2(f_0 + \Delta f_1)(\frac{\tilde{p}_A \Delta f_1}{2c} - 1) > 0. \tag{49}$$

In summary, we have shown that the optimal compensation scheme can be characterized as follows: if $\Delta f_2 > \Delta f_1 + h$, then $w_1(\emptyset,\emptyset) = \frac{c}{\tilde{p}_A \Delta f_1} < \frac{1}{2}$ and $w_1(B,B) > \frac{1}{2}$. If $\Delta f_2 < \Delta f_1 + h$, then either $w_1(\emptyset,\emptyset) = \frac{c}{\tilde{p}_A \Delta f_1} < \frac{1}{2}$ and $w_1(B,B) \in (0, \frac{1}{2})$ or $w_1(\emptyset,\emptyset) \in (\frac{c}{\tilde{p}_A \Delta f_1}, \frac{1}{2})$ and $w_1(B,B) = 0$.■

Proof of Proposition 4

Consider the members' incentives to exert effort on project A. If member 2 observes $s_2 = \emptyset$, $\hat{x} = A$, and $\hat{e}_2^r = 0$ then he knows that member 1 must have observed $s_1 = \emptyset$. If instead he observes $s_2 = \emptyset$, $\hat{x} = A$, and $\hat{e}_2^r = 1$ then he learns $s_1 = A$. His incentive constraints therefore read as follows;

$$w_2(A,A), w_2(A,\emptyset), w_2(\emptyset,A) \geq \frac{c}{\Delta f} \quad \text{and} \quad w_2(\emptyset,\emptyset) < \frac{c}{\bar{p}_A \Delta f}. \tag{50}$$

Now consider member 1. After observing $s_1 = \emptyset$, $\hat{x} = A$, and $\hat{e}_1^r = 1$ he knows that $s_2 \in \{A, \emptyset\}$. If $w_1(\emptyset,\emptyset) \neq w_1(\emptyset,A)$ he also learns from the observation of the share assigned to him whether $s_2 = \emptyset$ or $s_2 = A$. In the following we assume that $w_1(\emptyset,\emptyset) \neq w_1(\emptyset,A)$ is satisfied. At the end we confirm that this assumption is indeed satisfied by the proposed mechanism. Hence member 1's incentive constraints read as follows;

$$w_1(A,A), w_1(A,\emptyset), w_1(\emptyset,A) \geq \frac{c}{\Delta f} \quad \text{and} \quad w_1(\emptyset,\emptyset) \geq \frac{c}{\bar{p}_A \Delta f}. \tag{51}$$

Member 1 has an incentive to disclose A if and only if

$$qf_2 w_1(A,A) + (1-q)f_2 w_1(A,\emptyset) \geq qf_2 w_1(\emptyset,A) + (1-q)f_1 w_1(\emptyset,\emptyset) \tag{52}$$

Without violating (50) or (51) we can set $w_1(A,A) = w_1(A,\emptyset) = \left(1 - \frac{c}{\Delta f}\right)$ and $w_1(\emptyset,A) = \frac{c}{\Delta f}$ to maximize member 1's incentive to disclose A. Given these choices, (52) becomes

$$w_1(\emptyset,\emptyset) \leq \frac{f_2\left[1-(1+q)\frac{c}{\Delta f}\right]}{f_1(1-q)}, \tag{53}$$

and member 2 is guaranteed to disclose A since $w_2(A,A) = w_2(A,\emptyset)$ and $w_2(\emptyset,A) = 1 - \frac{c}{\Delta f} > \frac{1}{2} > \frac{c}{\bar{p}_A \Delta f} > w_2(\emptyset,\emptyset)$ from (50). For the mechanism to be collusion proof we also require that

$$w_1(\emptyset,\emptyset) \geq (1 - \frac{c}{\bar{p}_A \Delta f})\frac{f_2}{f_1} \tag{54}$$

The RHS is larger than 1 if and only if $\Delta f > \Delta f^{cp}$. Hence for $\Delta f > \Delta f^{cp}$ the first-best project allocation is not implementable and in the remainder we can restrict attention to the case where $\Delta f \leq \Delta f^{cp}$.

Using $\Delta f > \Delta f^{min} = \frac{2c}{\bar{p}_A}$ it is immediate that collusion–proofness implies the remaining incentive constraints $w_1(\emptyset,\emptyset) \geq \frac{c}{\bar{p}_A \Delta f}$ and $w_2(\emptyset,\emptyset) < \frac{c}{\bar{p}_A \Delta f}$. Hence the disclosure of A is guaranteed, appropriate effort incentives are provided and the mechanism is collusion–proof if and only if

$$(1 - \frac{c}{\bar{p}_A \Delta f})\frac{f_2}{f_1} \leq w_1(\emptyset,\emptyset) < \frac{f_2}{f_1}\frac{1-(1+q)\frac{c}{\Delta f}}{1-q}. \tag{55}$$

The lower bound is smaller than the upper bound since $(1-q)(1-\frac{c}{\bar{p}_A \Delta f}) < 1-(1+q)\frac{c}{\Delta f}$ holds for $q=0$ and $q=1$ and hence for all $q \in (0,1)$. It remains to consider the team members' incentive to disclose B. Member 1 will disclose B if and only if

$$qp_{BB} f_0 w_1(B,B) + (1-q)p_{BB} f_0 \geq (1-q)p_{AB} f_0 w_1(\emptyset,\emptyset) \tag{56}$$

while for member 2 the corresponding condition reads

$$qp_{BB} f_0 w_2(B,B) + (1-q)p_{BB} f_0 \geq (1-q)p_{AB} f_1 w_2(\emptyset,\emptyset). \tag{57}$$

Since $p_{BB} > p_{AB}$, (56) is satisfied for any choice of $w_1(B,B)$ and $w_1(\emptyset,\emptyset)$. Hence we can set $w_2(B,B) = 1$ and choose the lowest $w_2(\emptyset,\emptyset)$ consistent with (55) in order to maximize member 2's incentive to disclose B. (57) then becomes

$$\frac{p_{BB}}{p_{AB}} \geq 1 - (1+q)\left[1 - \frac{c}{\Delta f} + \frac{\Delta f}{f_0}(1 - \frac{2c}{\Delta f})\right]. \tag{58}$$

This condition holds in T since $p_{BB} > p_{AB}$ and the RHS is strictly smaller than 1. Finally, it is straightforward to show that $\frac{f_2}{f_1}\frac{1-(1+q)\frac{c}{\Delta f}}{1-q} = w_1(\emptyset,\emptyset) > \frac{c}{\Delta f} = w_1(\emptyset, A)$ as assumed. This shows that the first-best project choice is implementable for all $\Delta f \leq \Delta f^{cp}$. ■

Proof of Proposition 5

It is straight forward to see that $\Delta W^+ \to 0$ for $(\Delta f, \frac{p_{BB}}{p_{AB}}) \to (\Delta f^{max}, 1)$ and thus $T^+ \neq \emptyset$. It remains to show that $T^- \neq \emptyset$ and $T^0 \neq \emptyset$ under the conditions stated in the proposition. The proof proceeds in four steps. Step 1: Since $c < \frac{1}{6}$ and $p_{AB} > 2c$ there exists a $f_0^1 \in (0,1)$ such that $c < \frac{1-f_0}{6}$ and $p_{AB} > \frac{2c}{1-f_0}$ and hence $T \neq \emptyset$ for all $f_0 < f_0^1$. Step 2: Since Δf^{cp} is increasing in f_0 and $\lim_{f_0 \to 0} \Delta f^{cp} = \Delta f^{min}$, there exists a $f_0^2 > 0$ such that $\Delta f^{cp} < \Delta f^{max}$ for all $f_0 < f_0^2$. Step 3: Since $t^*(\Delta f^{min}) = \frac{1-q}{2-q}(1 + \frac{2c}{\bar{p}_A f_0})$ is strictly decreasing in f_0 and tends to infinity for $f_0 \to 0$, there exists a $f_0^3 > 0$ such that $t^*(\Delta f^{min}) > \frac{\bar{p}_A}{2p_{AB}}$ for all $f_0 < f_0^3$. Note that $t^*(\Delta f^{min}) > \frac{\bar{p}_A}{2p_{AB}}$ is equivalent to $T^{**} = T$. It follows from Proposition 1 that $f_0^3 < \frac{1}{3}$. Step 4: Note that $t^{+-}(\Delta f^{cp}) < 1$ if and only if

$$(1-q)f_0 - 2(2-q)c + 2(1 - q + p_{AB})\Delta f^{cp} < 0. \tag{59}$$

Since Δf^{cp} is increasing in f_0, the LHS is increasing in f_0. Since Δf^{cp} is independent of f_0 and $2(c - \Delta f^{cp}) - f_0 < 0$, the LHS is decreasing in q. The inequality therefore holds if and only if

$$q > q^{min} \equiv 1 - \frac{2c - 2p_{AB}\Delta f^{cp}}{f_0 - 2(c - \Delta f^{cp})} \tag{60}$$

and q^{min} is increasing in f_0. Moreover $\lim_{f_0 \to 0} q^{min} = 1 - \frac{\bar{p}_A - 2p_{AB}}{2 - \bar{p}_A} < 1 = \lim_{f_0 \to 0} q^*$. Hence there exist a $f_0^4 > 0$ such that $t^{+-}(\Delta f^{cp}) < 1$ for all $f_0 < f_0^4$. We have therefore shown that for all $f_0 < f_0^{max} = \min(f_0^1, f_0^2, f_0^3, f_0^4) \in (0, \frac{1}{3})$ it holds that $T^{**} = T \neq \emptyset$, $\Delta f^{cp} < \Delta f^{max}$, and $t^{+-}(\Delta f^{cp}) < 1$. These conditions imply $T^- \neq \emptyset$ and $T^0 \neq \emptyset$. ■

Proof of Remark 2

To abbreviate notation, let $w_1(B, A) = w$. We first show 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

$$I_1(B,A) = \tilde{q}(1-\tilde{q})[p_{BB} f_0 \frac{1}{2} - f_1(1-w)] + \tilde{q}^2 f_2(w - \frac{1}{2}). \tag{61}$$

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

$$f_2(w - \frac{1}{2}) = \frac{1-\tilde{q}}{\tilde{q}} f_1(1-w) - \frac{\tilde{q}}{1-\tilde{q}} f_0 p_{BB} \frac{1}{2} \tag{62}$$

can be substituted into (61) to get

$$I_1(B, A) = f_0 p_{BB} \frac{1}{2} \tilde{q}(1-\tilde{q}) \left(1 - \frac{\tilde{q}^2}{(1-\tilde{q})^2}\right) < 0. \tag{63}$$

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

$$\frac{\partial \Delta I_1}{\partial w} = (1-\tilde{q})^2 f_1 - \tilde{q}^2 f_2 < 0. \tag{64}$$

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

$$\frac{\partial \Delta I_1}{\partial p_{BB}} = f_0 \tilde{q}(\tilde{q} - \frac{1}{2}) > 0. \tag{65}$$

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.

It remains to show that $\tilde{T}^{**} \neq \emptyset$. To see this note that $\tilde{t}^*(\Delta f)$ is decreasing in Δf. Hence $\tilde{T}^{**} \neq \emptyset$ 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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