Decision Making and Implementation in Teams

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Abstract

This paper examines joint decision–making in a team where members have a common goal and exert individual efforts to implement the agreed decision. There is uncertainty about the productivities of alternative projects. Since members are concerned about each others' motivation to exert effort, private information in conflict with the initially preferred project fails to be communicated. As a consequence, the team may select the initially preferred project even when all members know (privately) that another project is more productive. We show that: (1) The concealment of information can be welfare improving but the team's incentive to conceal is stronger than socially optimal; (2) Delegating authority to an external agent restores full information sharing but does so at the cost of ex post sub–optimal decisions. (3) Using transfers to reward the disclosure of information improves information sharing only partially. (4) To optimize decision making members with higher costs of effort should receive larger shares of revenue and the team's size should be restricted.

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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 implement the 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). Closer to home, co–authors in academia decide what idea to pursue and then strive to prove the theorems or to obtain the data.

In the above examples implementation 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 most productive project, one might think that they should be able to share information efficiently and reach the best possible decision. And yet, teams with largely aligned incentives often fail to communicate valuable information and end up with sub–optimal decisions. 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).

Our starting point is the observation that the team's desire to keep "morale" or "motivation" high at the implementation stage may hinder information–sharing and lead to sub–optimal choices at the decision making stage. This tradeoff has long been recognized by scholars of group decision–making as critical to the understanding of why information questioning the prevailing consensus often remains unshared. Perlow and Williams (2003), for instance, describe a meeting of top–managers at a web–based company where dissenting voices failed to emerge. While this apparent consensus left some managers "excited–passionate–committed to the future", others recognized the implicit cost of this boost in morale by privately admitting that they had been "silencing themselves and one another" and that as a consequence "the company continued with no clear direction".

The conflict between decision making and motivation is often most dramatic in military settings. For instance, President George W. Bush admitted recently that, while privately aware throughout 2006 of the increasing likelihood of failure in Iraq, he continued to produce upbeat public assessments, thereby easing public pressure to correct his existing strategy, in order to avoid hurting troops morale.[1]

To examine the above trade–off formally, we propose a model of team production in which members (jointly) choose to work on one out of two feasible projects. Team members receive private information about the projects' productivities and we study their incentive to share this information with other members of the team. To fix ideas consider two academic co-authors choosing between two alternative scientific projects. In our model the project's productivity and the team members' implementation efforts are complementary. For instance, collecting data for an empirical project is more rewarding the more revolutionary the underlying idea. A team member's implementation effort is thus increasing in his motivation, i.e. his expectation of the project's productivity. Suppose that ex ante both co–authors expect idea A to be the most revolutionary. Further suppose that one author receives information, e.g. feedback in a seminar, indicating that idea B is more revolutionary than A but less revolutionary than idea A was expected to be ex ante. In this situation the author faces a tradeoff. 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 author can induce the team to work on the more productive idea B. The finding that an initially preferred alternative represents a threat to the frank exchange of information resonates with lessons from social psychology (Stasser, 1999) and political science ('T Hart, 1990) as well as with views expressed by practitioners.[2]

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

[2] Alfred P. Sloan once terminated a GM senior executive meeting with the following statement: "Gentlemen, I take it we are all in complete agreement on the decision here. Then I propose we postpone further discussion on this matter until our next meeting to give ourselves time to develop

We show that the team's ability to share information depends on two dimensions of the underlying choice problem; it is increasing in the *value of adaptation* and decreasing in the *value of motivation*. The value of adaptation measures the benefits from making a decision in accordance with the characteristics of the situation. It is higher the stronger the dependence of the projects' outcomes on the state of the world, i.e. the greater the projects' uncertainty. In contrast, the value of motivation measures the potential benefits from inducing efforts in accordance with (incorrectly) high prior expectations. It is increasing in the size of the projects' ex ante heterogeneity.

While the main focus of this paper is on whether information sharing is achievable, we also consider whether it is desirable. We find that the concealment of private information may be welfare improving since it alleviates the team's free–riding problem. This occurs as long as the *social* value of motivation is positive and the value of adaptation is sufficiently small. Nevertheless, we show that the team's incentive to conceal information is stronger than socially optimal.

This raises the question of whether it is possible to encourage information–sharing by altering the team's institutional or contractual environment. We first show that the team can achieve full information sharing by delegating decision–making rights to an outsider, i.e. a principal. The principal enables the team to take decisions that are sub–optimal ex post. While in Holmstrom (1982) the principal provides optimal incentives to exert effort by allowing the team to *break the budget*, in our model the principal provides optimal incentives to share information by allowing the team to *take unpopular decisions*. Since delegation comes at the cost of sub–optimal decisions, some authority should reside within the team. We show that the team's optimal level of autarky is increasing in the value of adaption and decreasing in the value of motivation.

A second possibility to improve the team's information sharing is to offer rewards for the disclosure of information in conflict with the team's initially preferred alternative. We show that contracts that stipulate transfers from the uninformed to the informed members can restore the team's ability to share information at zero cost but do so only partially. Thus, while it has been argued that those willing to challenge the status quo should be

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.

protected from retaliation by other team members (Janis, 1982, 'T Hart, 1990), in our setting it can be useful to actively reward them.

In the final part of the paper we make standard parametric assumptions about the shape of the team's revenue and the members' cost of effort functions in order to study how the team's potential to share information varies with its size and its revenue–sharing rule. We find that, in order to encourage information-sharing, agents with higher (marginal) effort costs should be awarded higher shares of the team's revenue. This contrasts with the common intuition that in order to minimize free–riding stronger incentives should be given to the agents with lower effort costs (McAfee and McMillan, 1991). We also show that information–sharing becomes more difficult as the team grows larger. The team size that optimizes decision–making is shown to be increasing in the value of adaptation and decreasing in the value of motivation.

Related literature

This paper is related to and draws upon a number of literatures. Attempts to explain why groups often fail to aggregate information efficiently have largely focused on the importance of conflicting preferences (Li, Rosen, and Suen, 2000, Dessein 2007), the existence of career concerns (Levy, 2007, Visser and Swank, 2007) and the distortions generated by voting rules (Feddersen and Pesendorfer, 1998). In our model there is a common preferred project and voting rules and career concerns play no role. Our focus is instead on the trade–off between adaptation and motivation. This emphasis is novel to the literature on group decision-making and complementary to existing work.[3]

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

[3]Persico (2004) and Gerardi and Yariv (2007) also combine decision-making and incentives but their focus is on incentives to acquire information rather than on incentives to implement a common decision.

[4]A related literature studies organizations where different divisions need to be rewarded for effort and encouraged to take decisions that are both coordinated and adapted to local circumstances (Dessein et al. (2009), Rantakari (2008)). We assume a common project choice, so coordination is not an issue.

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 in that we study how delegation and contracts improve decision making.

The notion that motivation to exert effort can be higher when team members have imperfect information about some underlying productivity parameter is related to the work by Teoh (1997) and Hermalin (1998). Teoh studies a social planner restricting access to information at an ex ante stage, while Hermalin considers a setting where one of the members holds private information and is able to signal high productivity via the exertion of high effort. While these papers share our finding that imperfect information can alleviate the team's moral hazard problem, they focus on settings where productivity is fixed and the choice between alternative projects is beyond the scope of the analysis.

Lastly, our finding that commitment to an ex post inefficient decision can improve the communication of information is related to Gerardi and Yariv's (2007) argument that such commitment can induce a committee to acquire costly information. In our model commitment is achieves by delegating decision making to a principal, an argument that is reminiscent of Holmstrom's (1979) well known budget breaking solution and Dessein's (2007) finding that decision making can be improved through leadership.

2 The model

Consider a team with $N \geq 2$ members. The team's purpose is to choose and implement one out of two mutually exclusive projects. "Productivity", $p(x, y)$, is uncertain since it depends both on the state of the world, $x \in \{A, B\}$, and on the choice of project, $y \in \{A, B\}$. It takes a low value $p_y > 0$ when the project fails to match the state of the world and a high value $p_Y > p_y$ otherwise.

Team members share a common prior about the state of the world, i.e. each member believes that $x = A$ with probability $Q \in (0, 1)$. In addition, each member may receive (private) information about x. In particular, conditional on the state being x, member i receives verifiable evidence that the state is x with probability $q_i \in (0, 1)$ and he observes nothing otherwise.[5] We will study the members' incentive to disclose such evidence. If

[5]The assumption that an agent's private information is either perfect or non–existent simplifies

evidence is disclosed it is observed by all team members. We assume that *information is valuable*, i.e. $p_A > p_b$ and $p_B > p_a$. If one of these inequalities was reversed, one project would be more productive than the other independently of the state of the world, i.e. evidence would have no value.

Members exert effort to implement the selected project. We assume that member i's cost $C_i(e_i)$ of exerting effort $e_i \in [0, \bar{e}_i]$ is continuously differentiable and strictly increasing. The team's revenue, $R(e, p)$, depends on the productivity parameter p and on the vector of efforts $e = (e_1, e_2, \ldots, e_N)$. It is assumed to be continuously differentiable in e, continuous in p, and strictly increasing in both variables. The assumption that drives our main results is that decision making and implementation are complements in the sense of monotone comparative statics (Milgrom and Shannon (1994)).[6] In particular, we suppose that marginal revenue $\frac{\partial R}{\partial e_i}$ is strictly increasing in p. In Section 3, we show that due to this assumption, equilibrium efforts depend monotonically on the members' "motivation", i.e. their beliefs about the project's productivity.

In order to focus on the team's ability to share information and to take appropriate decisions we abstract from the possibility of incentive contracts by assuming that each member receives a fixed share $\alpha_i \in (0, 1)$ of the project's revenue and $\sum_{i=1}^{N} \alpha_i = 1$.[7] Contracts which make a team member's compensation depend on the disclosed evidence are the subject of Section 7. Assuming risk–neutrality, member i's payoff is given by

$$\pi_i(e, x, y) = \alpha_i R(e, p(x, y)) - C_i(e_i). \tag{1}$$

The timing is as follows: (I) Nature determines the state of the world and members receive their private information. (II) Each member i who received evidence about the state of the world may either disclose it or conceal it. (III) Based on the disclosed information a project is selected. The precise way in which the project becomes selected will be specified

Bayesian updating in models of joint decision making, see also Persico (2004) or Visser and Swank (2007). In Section 9 we show that our main result remains valid under alternative informational assumptions.

[6] This assumption is standard in the literature on organizations (see for example Van den Steen (2009)). Some empirical support is provided by Rosen (1982).

[7] Our results remain valid when each member receives a constant payment $F_i \in \Re$ and a share α_i of revenue such that $\sum_i F_i + \alpha_i R(e, p) = R(e, p)$. It has been shown that every effort vector that forms an equilibrium under some more general sharing rule can also be implemented by such a linear sharing rule (see Nandeibam (2002)).

in Section 4. (IV) Members choose their efforts simultaneously.[8]

3 Implementation

We start our analysis by considering the simultaneous effort choice game in stage IV. Suppose that in stage III project $y \in \{A, B\}$ has been selected and that based on his private information received in stage I and the evidence disclosed in stage II, member i believes that the decision is appropriate, i.e. $x = y$, with probability $\beta_i \in [0, 1]$. Let $\beta = (\beta_i, \beta_{-i})$ denote the team members' vector of beliefs. Member i's expected payoff is given by

$$\pi_i^y(e, \beta_i) = \alpha_i[\beta_i R(e, p_Y) + (1 - \beta_i)R(e, p_y)] - C_i(e_i). \tag{2}$$

In the Appendix we show that under the conditions of Lemma 1, the simultaneous effort choice game has a unique equilibrium.[9] Given a vector of beliefs β, we denote the equilibrium effort vector by $e^y(\beta)$. In equilibrium member i's expected payoff when project y is implemented and members have beliefs β is then given by $\pi_i^y(\beta) = \pi_i^y(e^y(\beta), \beta_i)$. Lemma 1 establishes conditions on the team's production technology under which team members will be concerned about each others' *motivation* or *morale*.[10] In the remainder of this paper we assume that at least one of these conditions is satisfied.

Lemma 1 *Let $\tilde{\beta} \geq \beta$ be two vectors of beliefs such that $\tilde{\beta}_i > \beta_i$ if and only if $i \in M \neq \emptyset$. Then $\pi_i^y(\tilde{\beta}) > \pi_i^y(\beta)$ for all $i \in N - M$ if one of the following conditions hold:*

C1) Efforts are complements and team members are able to coordinate their effort choices onto their Pareto preferred equilibrium.

[8] While our results remain unchanged when evidence is disclosed sequentially, the sequential choice of effort would allow team members to signal their private information via their effort levels as in Hermalin (1998).

[9] In order to make our results strict we assume that equilibrium efforts are interior. This can be guaranteed by making appropriate assumptions on marginal costs and marginal revenues at the boundaries of the choice sets.

[10] A very different interpretation of group morale is provided by Benabou's (2008) model of collective delusion. In his model, agents decide whether to engage in reality denial about an exogenously given productivity parameter, while we study the choice among alternative projects associated with different productivities.

C2) Revenue is a concave function of aggregate effort and effort costs are strictly convex.

Lemma 1 is the consequence of a positive relationship between the members' beliefs about the appropriateness of the team's decision and their equilibrium effort choice. In particular, if beliefs are increasing for a subset M of members then under C1 equilibrium efforts are increasing for members in M and nondecreasing for members in $N-M$. The fact that efforts are strategic complements prevents a member's equilibrium effort to decrease in response to an increase of another member's effort. If instead efforts are strategic substitutes, equilibrium efforts cannot be guaranteed to move in the same direction. However, if revenue depends only on the sum of efforts, predictions can be made about the change in aggregate effort. Under C2, aggregate effort is strictly increasing even though efforts are strictly decreasing for all members in $N - M$. Hence under both conditions members in $N - M$ strictly benefit from the increase in beliefs of members in M.

Lemma 1 shows that a team member's payoff is strictly increasing in the team's motivation. Hence team members have an incentive to motivate their colleagues by fostering their beliefs about the appropriateness of the team's decision. In the next section we will see how these motivational concerns may interfere with the team's ability to select the most productive project.

4 Decision making

Consider the team's project choice in stage III. As a benchmark we first study the case of symmetric information. This allows us to derive the team's first best decision making rule. Under the assumption that the project is chosen according to the first best rule we then characterize the equilibrium of the simultaneous evidence disclosure game. The main result of this section is that first best decision making and full disclosure of private information cannot coexist in equilibrium.

Benchmark

Consider the case of symmetric information, i.e. suppose that evidence is observed publicly by all members or none. In the Appendix we proof the following:

Lemma 2 *When information is symmetric, i.e.* $\beta_i = \beta_j$ *for all* $i, j \in N$*, then member* i*'s (expected) payoff,* $\pi_i^y(\beta)$*, is increasing in* p_y *and* p_Y *for all* $i \in N$*.*

When members have identical beliefs, an increase in the project's productivity parameters leads to higher efforts and thus higher payoffs for *all* members. Note that although seemingly trivial this result fails to hold when information is asymmetric and efforts are strategic substitutes as under C2.

Since $p_A > p_b$ and $p_B > p_a$, an immediate consequence of Lemma 2 is that in the presence of evidence, all members prefer to select the project in accordance with the state of the world. For the same reason project A is preferred in the absence of evidence if Q is sufficiently large while project B is preferred if Q is sufficiently small. In the following we focus on the case where Q is sufficiently large such that we can make the following:

Definition 1 (First Best Decision Making Rule) *Select project* B *if and only if evidence for* B *has been observed (disclosed).*

It is important to note that in the absence of asymmetric information about the projects' prospects, the team members' interests are aligned. Hence in any equilibrium in which information is shared perfectly, decision–making is first best, i.e. the team's project choice maximizes total surplus.

Characterization of equilibrium

Suppose that the project is selected according to the first best rule and consider the team members' incentives to disclose evidence. When evidence fails to be disclosed under the first best rule the team may obtain information sharing by committing to another decision making rule ex ante. In the following sections we assume that such commitment is not feasible and postpone the treatment of commitment until Section 6.

Let us start by considering the team members' incentive to disclose evidence in favor of project A. It is straight forward to see that the disclosure of such evidence constitutes a strictly dominant strategy for each team member. Firstly, project A will be selected independently of whether such evidence is disclosed or concealed. Secondly, the motivation to work on project A will be higher in the presence of evidence in favor of A. Hence by disclosing evidence in favor of A team members can increase their colleagues motivation without influencing the team's project choice.

Lemma 3 *The disclosure of evidence in favor of the team's ex ante most preferred project A constitutes a dominant strategy for all team members.*

Consider now the incentive to reveal evidence in favor of project B. Let $d_j \in [0, 1]$ denote the likelihood with which member $j \in N$ discloses evidence for B and suppose that member i has received such evidence. If i discloses his information then project B is selected and all members learn that the state is B, i.e. member i's payoff is $\pi_i^B(\mathbf{1})$. Note that this payoff is independent of the information and strategies of members other than i. In contrast, when member i conceals his information his expected payoff depends on whether his colleagues have also received evidence and the likelihoods with which they disclose it. If member $j \neq i$ has also received evidence for B and discloses it then member i's payoff is $\pi_i^B(\mathbf{1})$ as before. Let

$$\gamma_i^A \equiv \prod_{j\neq i}(1 - q_j) \leq \prod_{j\neq i}(1 - q_j d_j) \equiv \gamma_i^B \tag{3}$$

denote the likelihoods with which members $j \neq i$ fail to disclose evidence when the state is A or B respectively. If no evidence is disclosed, project A becomes selected and member i's payoff, $\pi_i^A(0, \beta_{-i})$, depends on his colleagues' beliefs, β_{-i}. From the viewpoint of member i, the probability that member j has received (and concealed) evidence for $x = B$ and thus has the belief $\beta_j = 0$ is given by

$$\tilde{q}_j = \frac{q_j(1 - d_j)}{1 - q_j + q_j(1 - d_j)}. \tag{4}$$

With probability $1 - \tilde{q}_j$ member j has failed to receive evidence and updates his belief accounting for the fact that no evidence has been disclosed. Bayesian updating leads

$$\beta_j = \frac{Q\gamma_j^A}{Q\gamma_j^A + (1 - Q)\gamma_j^B} \equiv \beta_j^Q. \tag{5}$$

Member i's incentive to conceal evidence for B is thus determined by the difference between his expected payoff conditional on no evidence being disclosed and his payoff from disclosure:

$$\Delta_i(d) \equiv \sum_{\{\beta_{-i} | \beta_j \in \{0, \beta_j^Q\}\}} \left(\prod_{j \in N-i} \tilde{q}_j^{\,1-\beta_j/\beta_j^Q} (1-\tilde{q}_j)^{\beta_j/\beta_j^Q} \right) \pi_i^A(0, \beta_{-i}) - \pi_i^B(\mathbf{1}). \tag{6}$$

Member i prefers to disclose evidence for B if and only if $\Delta_i(d) \leq 0$.

Lemma 4 *Member i's incentive, Δ_i, to conceal evidence in favor of the team's ex ante least preferred project B, is strictly increasing in the likelihoods d_{-i} with which other members disclose such evidence.*

The intuition for this result is as follows. If member i has observed and concealed evidence for B and project A has become selected then the remaining members $j \neq i$ may have low ($\beta_j = 0$) or high ($\beta_j = \beta_j^Q$) motivation to exert effort depending on whether or not they have received (and concealed) evidence themselves. An increase in the probability d_j with which member j discloses evidence for B, raises the likelihood $\tilde{q}_j$ with which member j's motivation is high. It also increases the motivation β_k^Q of those members $k \neq j$ who have failed to observe evidence, since the news that no evidence has been disclosed becomes less negative with respect to project A. Both effects increase member i's expected payoff from concealing.[11]

Lemma 4 shows that the members' decisions whether or not to disclose evidence for B form strategic substitutes. This is driven by the fact that in our model information itself is substitutable. If the members' information was complementary their incentive to share information would be altered. For details see Section 9.

With the help of Lemmas 3 and 4 we can now characterize the equilibrium of the simultaneous information revelation game. Since evidence for A is always disclosed an equilibrium can be completely described by a vector $d \in [0,1]^N$. To build intuition it is helpful to first consider the possibility of a full disclosure equilibrium. For $d = \mathbf{1}$, evidence for B is equally likely to be disclosed as evidence for A, i.e. $\gamma_j^B = \gamma_j^A$ for all $j \in N$. Hence the news that no evidence has been disclosed carries no information about the state of

[11]Note that a member who has concealed evidence never has an incentive to disclose it after the project has been selected. This is because the only evidence that is concealed is evidence for B and project B is only selected if some other member has already disclosed such evidence.

the world which implies that $\beta_j^Q = Q$. Moreover, if no evidence has been disclosed, all members must have failed to receive evidence, i.e $\tilde{q}_j = 0$ for all $j \neq i$. We therefore have

$$\Delta_i(\mathbf{1}) = \pi_i^A(0, \mathbf{Q}) - \pi_i^B(\mathbf{1}). \tag{7}$$

From the viewpoint of member i, disclosing evidence for B has two effects. On the one hand it guarantees that the project with the high productivity p_B is chosen over the project with the low productivity p_a. On the other hand, member i's colleagues may be more motivated to work on project A when they (falsely) believe that project A is appropriate with the prior probability Q. For $p_B \to p_a$ both projects offer the same productivity and i's colleagues are more motivated to work on project A. In particular

$$\lim_{p_B \to p_a} \pi_i^B(\mathbf{1}) = \pi_i^A(\mathbf{0}) < \pi_i^A(0, \mathbf{Q}) \tag{8}$$

where the inequality follows from Lemma 1. Hence for p_B close to p_a, member i prefers to conceal his evidence for B. Moreover, it follows from Lemma 2 that $\Delta_i(\mathbf{1})$ is strictly decreasing in p_B. Hence disclosure is optimal if and only if p_B is sufficiently large. In the Appendix we proof the following:

Proposition 1 *There exist thresholds $\bar{p}^0$ and $\bar{p}^1$ such that $p_a < \bar{p}^0 < \bar{p}^1$ and the following holds:*

1. *In equilibrium all team members disclose evidence in favor of project A. An equilibrium in which all members disclose evidence in favor of project B with probability $d = \mathbf{1}$ $(d = \mathbf{0})$ exists if and only if $p_B \geq \bar{p}^1$ $(p_B \leq \bar{p}^0)$.*

2. *If $d', d'' \in [0,1]^N$ are equilibria for $p'_B, p''_B \in (\bar{p}^0, \bar{p}^1)$ respectively then $d'' > d'$ implies $p''_B > p'_B$. If the team is homogeneous then there exists a unique symmetric equilibrium $d^*(p_B) \in [0,1]$ and d^* is strictly increasing in $(\bar{p}^0, \bar{p}^1)$.*

Figure 1 visualizes the characterization of equilibrium contained in Proposition 1. It shows that the team is unable to implement the first–best decision–making rule when p_B is sufficiently close to p_a. In particular, for $p_B < \bar{p}^1$ project A will be selected with positive probability although some team member has obtained evidence for B. Note that full disclosure and full concealment are the *unique* equilibria for $p_B > \bar{p}^1$ and $p_B < \bar{p}^0$

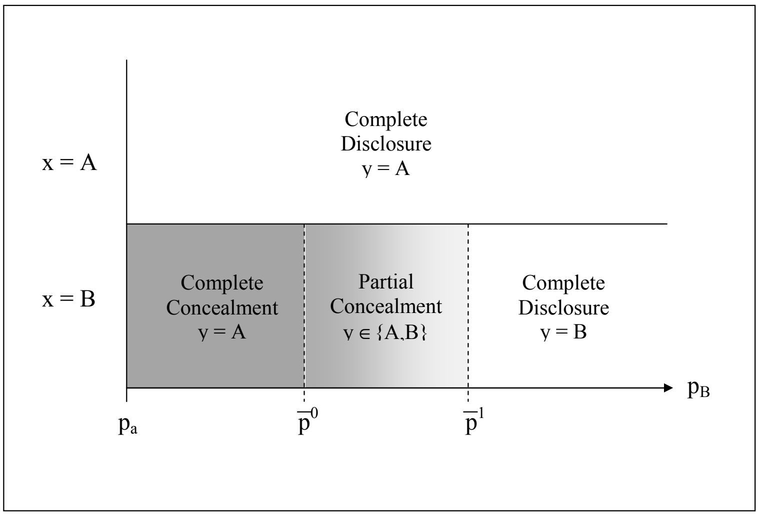

Figure 1: Information sharing under the first best decision making rule.

respectively. For $p_B \in [\bar{p}^0, \bar{p}^1]$ multiple equilibria may exist. Nevertheless, part 2 of Proposition 1 shows that the team's ability to share information and hence the probability with which the first best project becomes selected is (weakly) increasing over this range and even strictly increasing when the team is homogeneous and the equilibrium symmetric.

In order to understand the intuition for this result note that the propensity to conceal in (7) can be decomposed into two parts:

$$\Delta_i = [\pi_i^A(0, \mathbf{Q}) - \pi_i^A(\mathbf{0})] - [\pi_i^B(\mathbf{1}) - \pi_i^A(\mathbf{0})]. \tag{9}$$

The first part represents the value of motivation while the second part represents the value of adaption. Concealment is optimal when the value of motivation exceeds the value of adaption. For $p_B \to p_a$ the value of adaption becomes zero while the value of motivation is strictly positive. It follows from Lemma 2 that the value of adaption is strictly increasing in p_B. In the Appendix we show that the value of motivation is strictly increasing in p_A. We therefore get the following result:

Corollary 1 *The thresholds $\bar{p}^0$ and $\bar{p}^1$ are strictly increasing in p_A, i.e. the team's ability to share information is increasing in the value of adaption but decreasing in the value of motivation.*

Remember that in the above analysis we have treated the team's project choice to be governed by an exogenously given (first best) rule. As argued before, when information is shared perfectly this rule is actually ex post optimal from the viewpoint of *every* team member. Hence if we allow team members to choose their project via some arbitrary voting procedure in stage III then Proposition 1 implies that for $p_B < \bar{p}^1$ the team will fail to make complete use of its available information. It is important to note that the team's failure to share information does not originate from some intrinsic differences in the members' preferences over available alternatives. Li, Rosen, and Suen (2001) have shown that in committees information is revealed only partially when members have conflicting interests. In our model the team fails to share information even though every team member prefers the same project once information is revealed.

5 Efficiency

While in the previous section we have been concerned with the question of whether information sharing is *feasible*, we now ask whether it is *desirable*. The concealment of information, although detrimental for decision making, mitigates the team's free riding problem by increasing the members' motivation to exert effort. In this section we show that although the overall effect may be an *increase* in total surplus, the team members' incentives to conceal information is stronger than socially optimal.

Let us compare team surplus in the full disclosure equilibrium with team surplus in the full concealment equilibrium. When evidence for A is observed then both are equal since evidence for A is disclosed in every equilibrium. With probability $\gamma = \prod_{i \in N}(1 - q_i)$ no evidence is observed and project A is selected. In this case concealment is costly, because under disclosure every member chooses his effort in accordance with the true likelihood Q that the state is A while under concealment members have the incorrectly low beliefs β^Q. Finally, with probability $(1 - Q)(1 - \gamma)$ evidence for B is observed and project B is selected under disclosure while project A is selected under concealment. For $p_B \to p_a$ both projects are equally productive but those team members who have failed to observe evidence for B are more motivated to work on project A. Since their beliefs are incorrectly high, their efforts may exceed the efficient levels. This happens if and only if p_A is larger than some threshold. Hence if evidence for B is observed then concealment is beneficial, if the projects' actual productivities, p_a and p_B, are similar and project A's potential productivity p_A is sufficiently small to keep efforts below first best for those members who failed to observe evidence. When the probability γ with which the team fails to observe evidence is sufficiently small the benefits of concealment outweigh its costs.

Proposition 2 *There exists a $\bar{p}^* \geq p_a$ with the following properties:*

1. *Team surplus is higher when all evidence in favor of project B is concealed than when it is disclosed if and only if $p_B \in (p_a, \bar{p}^*)$. This interval is non–empty if p_A and γ are sufficiently small.*

2. *The team members' incentive to conceal evidence in favor of project B is stronger than socially optimal, i.e. $\bar{p}^* < \bar{p}^1$, if efforts are not too complementary.*

Note that in large teams, the likelihood γ that evidence is observed by no member at all is small. Moreover, in large team the incentive the free–ride is particularly strong and efforts are unlikely to exceed their efficient levels even if members have very optimistic beliefs, i.e. even when p_A is large. Part 1 of Proposition 2 therefore shows that in large teams, the concealment of information leads to a welfare increase when the value of adaption is small compared to the value of motivation. This may explain why in military settings the communication of negative information is often discouraged by the threat of punishments.

In order to understand Part 2 of Proposition 2 consider the case where $p_B = \bar{p}^1$. It follows from the definition of $\bar{p}^1$ that disclosure leads to higher payoffs than concealment for all members who observed evidence for B. Consider a member who failed to observe evidence for B. We now argue that his payoff under concealment is smaller than the payoff he would have obtained if he had observed (and concealed) the evidence himself. This is immediate when efforts are substitutes, since the observation of evidence allows a member to adjust his effort (downwards) to the project's true productivity p_a leading to an increase in his colleagues' efforts. Only when efforts are very complementary a team member may actually benefit from an over–estimation of the project's productivity due to the positive influence of his own effort on other members' efforts. Hence if efforts are not too complementary then a member's payoff from being concealed is smaller than his payoff from concealing himself, which in turn is smaller than his payoff under disclosure since $p_B = \bar{p}^1$. This shows that for $p_B = \bar{p}^1$ payoffs under concealment are smaller than payoffs under disclosure for *all* members of the team which implies that $\bar{p}^* < \bar{p}^1$.

Of course, any equilibrium in which evidence for B is concealed partially is dominated either by full disclosure or by full concealment. This implies that in the range $(\bar{p}^*, \bar{p}^1)$ the team conceals evidence with positive probability although team surplus would be higher under full disclosure. This range is depicted in Figure 2. In this range motivating the

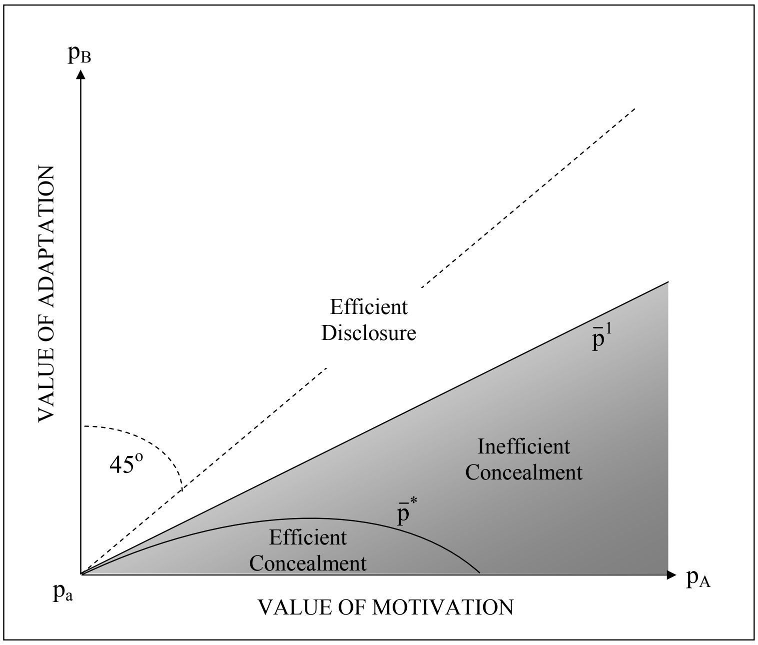

Figure 2: The efficiency of information sharing.

team via the selection of its ex ante preferred alternative is optimal from the individual but not from the social perspective.

In this section we have shown that the team's inability to share information leads to a welfare loss if the value of adaption lies in some intermediate range. It is therefore important to think about means to improve the team's information sharing. In the remainder of the paper we consider three possibilities: delegation of decision making rights to an outsider; contracts that reward members for the supply of information; and changes to the team's organizational features, i.e. its size and sharing rule.

6 Delegation

Our analysis so far has shown that full information sharing cannot be obtained when the team is unable to commit to a project selection rule ex ante. In the absence of any external party this assumption is most reasonable. In this section we allow the team to achieve commitment by delegating decision making rights to an outsider, i.e. a manager.

We suppose that the manager observes the evidence that is disclosed by the team and subsequently chooses the project to be implemented. The manager does not receive any evidence himself neither does he participate in the project's implementation. We assume that in the presence of evidence the manager selects the project in accordance with the state of the world. However, in the absence of evidence, the manager is assumed to select project B rather than the team's preferred project A. 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 the introduction of changes, a manager who has been hired from outside may be keen to implement changes. Second, the manager may share the team's preferences but be able to commit to a decision making rule by announcing his plans or "vision" ex ante as in Rotemberg and Saloner (2000).

First note that the manager removes the team members' incentive to conceal evidence for B. Since the manager selects project B in the absence of evidence, the concealment of information in favor of B can only lead to a *reduction* rather than an increase in motivation. What about member i's incentive to disclose evidence in favor of project A? If all other members share their information, member i prefers disclosure if and only if $\pi_i^A(\mathbf{1}) > \pi_i^B(0, \mathbf{1} - \mathbf{Q})$. Since $p_A > p_b$, a sufficient condition for member i to share his information is that effort under disclosure $e_j^A(\mathbf{1})$ is at least as high as effort under concealment $e_j^B(0, \mathbf{1} - \mathbf{Q})$ for all other members $j \neq i$. Under C1 this holds trivially since efforts are complements. Under C2 efforts are substitutes and member i's decrease in effort due to the selection of the less productive project may lead to an increase in the other members' efforts. Hence under C2 revenue should not be too concave for the results in this section to hold.

Proposition 3 *The team can obtain full information sharing by delegating decision making to an outsider who selects the team's ex ante preferred project A only if the team* *discloses evidence in favor of A.*

Under the manager's project selection rule the team members' two objectives become aligned. The disclosure of information guarantees both, the selection of the most productive project *and* the maximization of the team members' motivation. In the absence of the manager, both objectives collide since the team cannot commit to select the less "popular" project, i.e. the one that is expected to be less productive, in the absence of evidence.

Note that in order to achieve information sharing, the team does not have to transfer *all* of its decision–making power to the manager. In particular, if the manager's contract allows him to select the project with probability δ while with probability $1-\delta$ decision-making rights remain within the team, then in order to obtain full disclosure it is sufficient to choose δ such that

$$\pi_i^B(\mathbf{1}) \geq \delta \pi_i^B(1, \mathbf{1}-\mathbf{Q}) + (1-\delta)\pi_i^A(0, \mathbf{Q}) \tag{10}$$

for all $i \in N$. Since in the absence of evidence the manager chooses project B although project A is expected to be more productive, delegation comes at a cost. A manager may stick to the plans he announced ex ante instead of implementing the project that looks most promising ex post. Similarly a manager who has an intrinsic preference for change may implement a change even when the status quo looks more viable. Team surplus will therefore be maximized by limiting the manager's control, i.e. by choosing the smallest δ that satisfies (10). Denoting this value as δ^* it is immediate that that full delegation can never be optimal, i.e. $\delta^* < 1$, since under full delegation information sharing is *strictly* preferred by all members. Moreover, since for $p_B < \bar{p}^1$, δ^* is strictly decreasing in p_B and strictly increasing in p_A we get the following:

Corollary 2 *To achieve full information sharing through delegation, the team optimally transfers only a fraction δ^* of its decision–making power to an outsider. This fraction is decreasing in the value of adaption and increasing in the value of motivation.*

Since the manager interferes with the team's decision making only in a fraction δ^* of cases and only when convincing evidence for one of the alternatives is missing, the task taken by the manager can be described as "management by exception" as in Garicano (2000). Moreover, if one interpretes $1-\delta^*$ as the team's degree of autarky then Corollary 2 suggests that self–managed work teams should be given greater independence when the value of adaption is high i.e. when the information residing within the team is valuable. When the value of adaption is high, teams are less prone to motivational concerns and more independence improves ex post decision making without harming the team members' incentive to share information.

7 Rewards

The delegation of decision–making rights considered in the previous section can be understood as a contract that makes project choices contingent on the evidence disclosed by the team. The role of the manager was to enforce such a contract. Another possibility is to consider contracts that stipulate transfers amongst team members. In this section we consider whether the team's ability to share information can be improved with the help of such contracts.

For this purpose we propose a reward–contract which is similar to a Groves (1973) mechanism in that it induces transfers amongst team members whenever a member's information is pivotal for the outcome of the team's production. More specifically, suppose that a member i who discloses evidence for B in stage (III) and is the only member to do so receives a reward $T_i > 0$ in stage (IV).[12] In order to keep the team's budget balanced this reward is financed via transfers from the other members. In particular, member $j \neq i$ pays the share σ_{ij} of member i's reward and $\sum_{j \in N-i} \sigma_{ij} = 1$ for all $i \in N$. Given any $p_B < \bar{p}^1$, the aim is to choose the rewards $(T_1, \ldots, T_N)$ and the shares (σ_{ij}) such that all members disclose evidence for B in equilibrium.

If member i discloses evidence for B then with probability $\prod_{j \neq i}(1-q_j)$ he will be the only member to do so in which case he receives the reward T_i. His expected payoff from

[12]Rewarding a member by increasing his share of revenue has the negative effect of decreasing the remaining members' efforts. Contracts that make the members' shares contingent on the disclosed information therefore seem sub–optimal.

disclosure is therefore

$$\pi_i^B(\mathbf{1}) + T_i \prod_{j \neq i}(1 - q_j). \tag{11}$$

If he conceals the evidence then with probability $q_j \prod_{k \neq i,j}(1 - q_k)$ member $j \neq i$ will be the only member to disclose evidence in which case member i has to make the transfer $\sigma_{ji} T_j$ to member j. Member i's expected payoff from concealment is

$$\pi_i^B(\mathbf{1})(1 - \prod_{j \neq i}(1 - q_j)) + \pi_i^A(0, \mathbf{Q}) \prod_{j \neq i}(1 - q_j) - \sum_{j \neq i} \sigma_{ji} T_j q_j \prod_{k \neq i,j}(1 - q_k). \tag{12}$$

Full information sharing is an equilibrium if and only if the reward contract satisfies

$$T_i + \sum_{j \neq i} \sigma_{ji} T_j \frac{q_j}{1 - q_j} \geq \pi_i^A(0, \mathbf{Q}) - \pi_i^B(\mathbf{1}) \tag{13}$$

for all $i \in N$. The left hand side represents the sum of member i's reward and his savings in transfers payable to other members. The right hand side is member i's benefit from concealing in the absence of the reward–contract.

By choosing $(T_1, \ldots, T_N)$ sufficiently large the above system of inequalities can always be satisfied. However, in stage (IV) those team members who are supposed to pay transfers would refuse to do so if these transfers exceeded their payoffs from participating in the team's production. In particular, it is reasonable to assume that for all $i \in N$ the reward T_i has to be such that the following interim participation constraints are satisfied for all members $j \neq i$:

$$\sigma_{ij} T_i \leq \pi_j^B(\mathbf{1}). \tag{14}$$

The incentives for information sharing are maximized by choosing $(T_1, \ldots, T_N)$ to make (14) binding. Substituting into (13) shows that full information sharing can be obtained via a reward–contract if and only if $\Delta_i^R(\mathbf{1}) \leq 0$ for all $i \in N$ where

$$\Delta_i^R(\mathbf{1}) = \pi_i^A(0, \mathbf{Q}) - \pi_i^B(\mathbf{1}) - \sum_{j \in N-i} \pi_j^B(\mathbf{1}) - \pi_i^B(\mathbf{1}) \sum_{j \in N-i} \frac{q_j}{1 - q_j}. \tag{15}$$

The incentives for information sharing in (15) differ from the incentives without rewards in (7) by the last two terms. Since these terms are strictly increasing in p_B but independent of the remaining productivity parameters we have the following:

Proposition 4 *There exists a* $\bar{p}^R \in [p_a, \bar{p}^1)$ *such that full information sharing can be obtained via a reward contract if and only if* $p_B \geq \bar{p}^R$. $\bar{p}^R = p_a$ *if* $p_A \leq p_A^R$ *and* $\bar{p}^R$ *is strictly increasing in* p_A *for all* $p_A > p_A^R$.

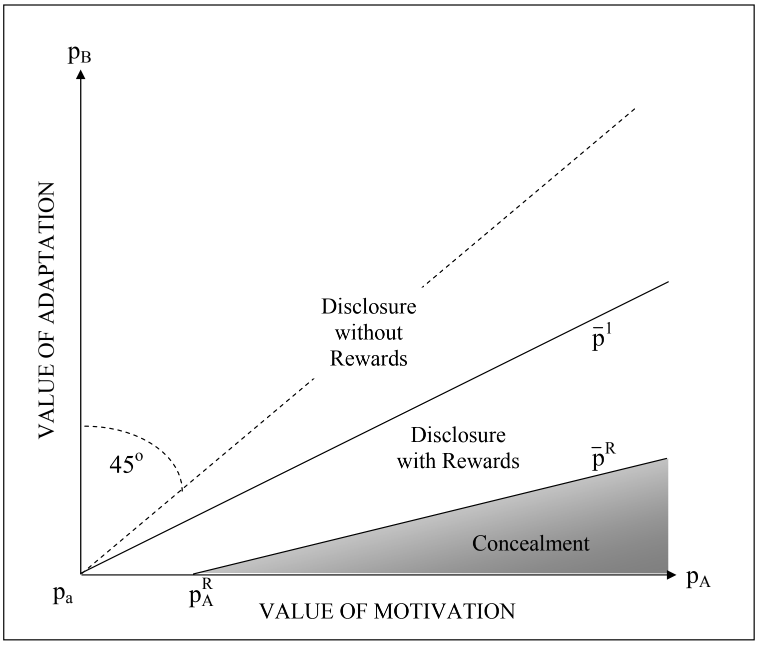

Figure 3: Comparison of information sharing with and without reward contracts.

Figure 3 depicts the result contained in Proposition 4. It shows that even when the team is able to strengthen the incentives for disclosure with the help of transfers, information sharing cannot be obtained for some range of parameters. Note however, that when the value of motivation is sufficiently low ($p_A \leq p_A^R$), incentives for disclosure can be provided by a reward contract independently of the value of adaption, i.e. for *all* $p_B > p_a$. Since reward contracts induce information sharing at zero cost whereas delegation is costly, the team prefers rewards over delegation. Hence if motivational concerns are sufficiently weak, teams should be given full autarky since they are able to overcome their information sharing problem completely by offering rewards to those members who dare to announce opinions in conflict with the team's preferred course of action. This adds to our results in Section 6.

Note that the incentives for information sharing can be strengthened even further by the use of more complicated reward contracts than the ones considered in this section. In particular, incentives are maximized by a contract that rewards the disclosure of evidence by *any* (not only single–member) subset $M \subset N$ by stipulating payments from the members in $N - M$. Allowing for such contract reduces the area of concealment in Figure 3 even further but Proposition 4 remains qualitatively unchanged.

8 Team design

In this section we consider how the team's ability to share information depends on certain organizational features. In particular, we determine the team size and the revenue–sharing rule that maximize the likelihood with which the team is able to select the project in accordance with the state of the world. In order to do so we make the following assumptions about the functional form of the team's revenue and the members' cost of effort. We assume that member i's cost of exerting implementation effort e_i has the constant–elasticity form

$$C_i(e_i) = \frac{c_i}{(1+t)} e_i^{1+t} \tag{16}$$

where $t > 0$ and $c_i > 0$. We say that member i has higher effort costs than member j if $c_i > c_j$. Revenue is assumed to be multiplicative with respect to the productivity parameter p and linear in aggregate effort, i.e.

$$R(e,p) = p \sum_{i \in N} e_i. \tag{17}$$

Note that the above specification satisfies conditions C1 and C2 of Lemma 1 simultaneously and is used in some of the applications referred to in Section 10. We normalize by setting $p_A = 1$ and it will be convenient to define

$$m = \frac{Q + (1-Q)p_a}{p_a} > 1 \tag{18}$$

which represents the ratio between the expected productivities of project A without and with evidence for B. In the Appendix we derive the threshold $\bar{p}_i^1 \in (p_a, 1)$ for which disclosure becomes a dominant strategy for member i as

$$\bar{p}_i^1 = p_a \left[\frac{\frac{t}{1+t} + \sum_{k \neq i} \left(\frac{m c_i \alpha_k}{c_k \alpha_i} \right)^{\frac{1}{t}}}{\frac{t}{1+t} + \sum_{k \neq i} \left(\frac{c_i \alpha_k}{c_k \alpha_i} \right)^{\frac{1}{t}}} \right]^{\frac{t}{1+t}} . \tag{19}$$

Optimal sharing rule

How do the incentives to disclose information depend on the members' shares of revenue? Our next result sheds light on this questions. Consider equation (19) and suppose that $\frac{\alpha_i}{c_i} > \frac{\alpha_j}{c_j}$ either because member i has lower costs of effort than member j or because he is entitled to a strictly larger share of revenue, or both. Obviously, member i obtains a larger payoff than member j. In the Appendix we show that the difference in payoffs is larger when evidence for B is disclosed than when it is concealed. We can therefore formulate the following result:

Proposition 5 *Team members with high shares of revenue and low costs of effort have a weaker incentive to conceal information than members with low shares and high costs, i.e.* $\bar{p}_i^1 < \bar{p}_j^1$ *if and only if* $\frac{\alpha_i}{c_i} > \frac{\alpha_j}{c_j}$.

The reason for this result is that team members with low effort costs (high shares) exert a large fraction of the team's overall effort on their own. The importance of the contributions of other team members is relatively small. As a consequence such team members have relatively little incentive to increase their colleagues' motivation at the expense of a sub–optimal project choice.

Proposition 5 has immediate consequences for the team's optimal revenue–sharing contract. Taking the team members' effort costs as exogenously given, we can determine the contract that maximizes the team's ability to share information. Since $\bar{p}^1 = \max_{i \in N} \bar{p}_i^1$ Proposition 5 implies that in order to minimize $\bar{p}^1$ one has to choose α_i and α_j such that $\frac{\alpha_i}{c_i} = \frac{\alpha_j}{c_j}$ for all $i, j \in N$. We therefore get the following result:

Corollary 3 *The distribution of revenues* $(\alpha_1^*, \ldots, \alpha_N^*)$ *that maximizes the team's ability to share information is given by*

$$\alpha_i^* = \left(1 + \sum_{j \neq i} \frac{c_j}{c_i}\right)^{-1} \tag{20}$$

i.e. members with lower effort costs should receive smaller shares of revenue.

This finding contrasts with the conventional wisdom that in order to increase efficiency, members with lower costs should be given stronger incentives to exert effort. In a standard team setting where decision–making is absent this wisdom is indeed correct (see for example McAfee and McMillan (1991)). However, in the presence of decision–making, the distribution of revenue not only influences the team members' incentives to exert effort, but also their incentives to share information. Corollary 3 shows that both effects should be taken into account when team members participate in the selection and not only the implementation of projects.

Optimal team size

In order to discuss the issue of team size we consider a homogeneous team, Setting $\alpha_i = \frac{1}{N}$, $q_i = q$, and $c_i = c$ for all $i = 1, \ldots, N$, (19) simplifies to

$$\bar{p}^1 = p_a \left[\frac{1 + (N-1)m^{\frac{1}{t}} - \frac{1}{1+t}}{N - \frac{1}{1+t}}\right]^{\frac{t}{1+t}}. \tag{21}$$

In the Appendix we show that $\bar{p}^1$ is strictly increasing in N with $\lim_{N\to\infty} \bar{p}^1 = p_a m^{\frac{1}{1+t}} < p_A$. We can therefore formulate the following:

Proposition 6 *In a homogeneous team the ability to share information is strictly decreasing in the number of members.*

To understand the intuition for this result consider the members' efforts when member i has concealed evidence for B and project A has become selected. In a homogeneous team, the proportional increase in effort due to members $j \neq i$ expecting productivity $Q + (1-Q)p_a$ rather than the true productivity p_a is given by $e_j^A/e_i^A = m^{\frac{1}{t}} > 1$. It is independent of the size of the team and it is the same for each of member i's colleagues. The larger the number of colleagues, the greater is the overall increase in effort. An increase in N raises the value of motivation and to keep members indifferent between disclosing and concealing, the critical value of adaption $\bar{p}^1$ needs to increase as well.

So how many members should the team have in order to maximize the likelihood with which the team selects the project in accordance with the state of the world? On the one hand, adding an additional member increases the amount of potentially available evidence since each member receives information about the state of the world with a strictly positive probability. On the other hand Proposition 6 has shown that it may be costly to increasing the team's membership. The cost is endogenously determined by the team's reduced ability to make use of its available information. In the Appendix we prove the following:

Corollary 4 *If $p_B < p_a m^{\frac{1}{1+x}}$ then there exists a unique team size $N^* < \infty$ for which the team's decision making is optimized. N^* is strictly increasing in the value of adaptation.*

To understand the intuition for the comparative statics of this result it is important to note that the optimal team size is such that members are just indifferent between disclosure and concealment. As p_B increases, the value of adaptation goes up and the incentive to disclose evidence for B becomes stronger. In order to keep team members indifferent the value of motivation has to increase. Since motivational gains are higher the greater the number of colleagues, N^* is strictly increasing in p_B. Corollary 4 thus shows that large teams make better decisions than small teams when the value of adaptation is high relative to the value of motivation.

Our finding that in order to optimize decision making the size of the organization should be limited is shared by Persico (2004). However, while in our model an increase in the number of team members harms their ability to truthfully reveal their available information, in Persico (2004) an increase in the size of the committee makes individual members less likely to be pivotal thereby decreasing their incentive to acquire information in the first place.

9 Robustness

In this section we show that the team's inability to share information does not depend on the simple information structure posited in Section 2. We present a modification of our model where team members receive soft signals that cannot be verified by their colleagues. Our new information structure is quite standard. Conditional on the state of the world being x, member i observes a signal $s_i = x$ with probability $q_i \in (\frac{1}{2}, 1)$ and the opposite signal with probability $1 - q_i$. In order to simplify the algebra, we focus on a team with only two members and set $q_1 = q_2 = q$, $p_a = p_b = 0$, and $Q = 1/2$. We also assume that revenue takes the functional form specified in (17) and that effort costs are strictly convex.

Under the new information structure team members send non–verifiable messages $m_i \in \{A, B\}$ to each other in stage (II). In stage (III) a decision, $y(m_1, m_2)$, is taken on the basis of those messages. We consider the case where the first best decision-making rule selects project B when both agents observe signal B and project A otherwise, i.e. we require

$$\frac{(1-q)^2}{q^2} p_A < p_B < p_A. \tag{22}$$

In the following we explore whether truthful revelation of information is possible if $y(m_1, m_2) = B$ if and only if $(m_1, m_2) = (B, B)$. If project y has been selected, and agent i believes that $x = y$ with probability $\beta_i^y(s_i, m_j)$, then the linearity of revenue implies that member i's effort, $e_i^y(s_i, m_j)$, is independent of member j's effort and hence his own message m_i, and due to the convexity of costs it is given explicitly by $e_i^y(s_i, m_j) = C_i^{\prime -1}(\alpha_i p_Y \beta_i^y(s_i, m_j))$. Hence the only way in which member i's message influences his payoff is through its effect on the project choice and on member j's effort. If project $y(m_i, m_j)$ becomes selected, signals s_i and s_j have been observed, and productivity turns out to be $p(x, y)$ then member i's payoff is

$$\pi_i = \alpha_i p(x, y(m_i, m_j))[e_i^y(s_i, m_j) + e_j^y(s_j, m_i)] - C_i(e_i^y(s_i, m_j)). \tag{23}$$

Member i's message influences the team's productivity as well as member j's effort. For a given level of effort, member i would aim to maximize (expected) productivity by making first best use of his information, i.e. by issuing $m_i = s_i$. However, for a given level of productivity, member i has an incentive to choose the message that maximizes member j's (expected) effort. If $s_j = m_j = A$ then $m_i = A$ leads to higher effort since $p_A \beta_j^A(A, A) = p_A q^2 > p_A/2 = p_A \beta_j^A(A, B)$. If $s_j = m_j = B$ then $m_i = B$ maximizes motivation if and only if $p_B \beta_j^B(B, B) = p_B q^2 > p_A/2 = p_A \beta_j^A(B, A)$. Hence if p_B is sufficiently small, then in order to maximize member j's expected effort, member i should choose $m_i = A$ independently of his signal. This shows that for p_B sufficiently small, team members have to compromise between maximizing productivity by issuing $m_i = s_i$ and maximizing motivation by issuing $m_i = A$. As in the model with verifiable evidence we therefore get the following result:

Proposition 7 *If each team member receives a non–verifiable private signal with precision $q \in (\frac{1}{2}, 1)$ about the state of the world then there exists a $\bar{p} \in (\frac{(1-q)^2}{q^2} p_A, p_A)$ such that:*

1. *An equilibrium in which all team members report their signals truthfully exists if and only if the value of adaptation is sufficiently large, i.e. $p_B \geq \bar{p}$.*
2. *There always exists an equilibrium in which all team members issue message A regardless of their signal.*

In the model with signals the economic mechanisms involved are similar to the ones in the model with verifiable evidence. However, there exists one additional mechanism which is similar to the subordinates' incentive to conform with the views of their superiors in Prendergast (1993), or to the leader's incentive to follow hard rather than soft information in Blanes i Vidal and Möller (2007). In the model with signals each team member has an incentive to issue a message that reinforces rather than contradicts the other member's private signal. Since messages are issued simultaneously and signals are more likely to coincide than to contradict each other, team members therefore have an additional incentive to tell the truth. It is reassuring to find that our main result remains unchanged even in the presence of such a *propensity to agree*.

Also note a second novelty. In the model with signals, the first best decision–making rule requires *both* signals to point towards B for project B to be optimal. This implies that the agents' messages are strategic complements rather than strategic substitutes as in the model in Section 2. As a result, an equilibrium in which both agents issue message A regardless of their signal can be sustained. The reason is that unilateral deviations from this equilibrium have no effect on the decision being taken but induce a loss in motivation.

10 Applications

Apart from its straightforward application to standard team production frameworks a la Holmstrom (1982), our theory applies more generally to any situation that meets Marchak's (1955) definition of a team as a "group of persons each of whom takes decisions about something else but who receive a common reward as the joint result of all those decisions." In the remainder of this section we provide examples from Industrial Organization, Public Economics, and Political Economy.

R&D Cartels

Following D'Aspremont and Jacquemin (1988) and Kamien et al. (1992) consider a cartel consisting of N firms producing a homogeneous product in a market with inverse demand $P = a - Q$ where P denotes market price, Q is aggregate output, and $a > 0$ denotes the demand intercept. Each firm can undertake an R&D effort at cost $C_i(e_i)$. Research efforts are non–contractible and determine production costs. Firms share the results of their research efforts and the production cost of firm i is given by $[c - r(e)]q_i$ where q_i denotes firm i's output, and $c \in (0, p)$ is the marginal cost of production in the absence of R&D. The function $r(e)$ represents the cost reduction due to R&D and is strictly increasing in e_i for all $i \in N$. Firms collude in the output market, each producing the cartel quota, and the monopoly profits are shared equally. Defining $p \equiv a - c$, firm i's payoff is given by

$$\pi_i = \frac{1}{4N}(p + r(e))^2 - C_i(e_i). \tag{24}$$

D'Aspremont and Jacquemin (1988) assume that $r(e) = \sum_{i \in N} e_i$ which implies that R&D efforts are strategic complements and C1 holds.

Suppose that in an initial stage, firms make a joint decision about the characteristics of their product. The demand intercept $a(x, y)$ depends on the product characteristics $y \in \{A, B\}$ and the consumers' taste $x \in \{A, B\}$. The consumers' taste is uncertain and ex ante both tastes are equally likely. Let demand be higher when the product characteristics match the consumers' taste, i.e. $a(A, A) > a(B, A)$ and $a(B, B) > a(A, B)$. Moreover, suppose that while there is symmetry with respect to the demand parameters, i.e. $a(A, A) = a(B, B)$ and $a(A, B) = a(B, A)$, production costs in the absence of R&D are lower for product A than for product B, i.e. $c(A) < c(B)$. Finally in order to rule out the trivial case in which profits are always higher for product A assume that $c(A) > c(B) + a(B, A) - a(B, B)$. Given $p(x, y) = a(x, y) - c(y)$ it is easy to check that this model satisfies the assumptions of Section 2. Proposition 1 therefore implies that the firms will be unable to communicate demand information if their cost–bias is sufficiently strong. As a consequence product A may be produced even when firms hold (private) demand information showing that A is less profitable than B. According to Corlollary 1 the likelihood that market information is ignored and product choices are suboptimal is increasing in the size of the technological bias. A classical example where the existence of a strong technological bias lead to the ignorance of market information is the Iridium consortium's failure to acknowledge the rise of the cellular phone. As in our model, the members of the consortium had an incentive to conceal from each other any negative information with respect to the demand for their satellite phones in order to maintain high levels of R&D efforts. Another reason for the Iridium failure that is brought forward frequently is the fact that most of the Iridium board consisted of directors designated by the consortium's members. For example, Finkelstein and Sanford (2002) claim that as a consequence"the board lacked the insight of outside directors who could have provided a diversity of expertise and objective viewpoints." This is in line with Proposition 3 which shows that the consortium's ability to share information could have been improved by delegating decision–making rights to outsiders with no share in revenue.

Public Good Provision

Following Ray and Vohra (2001), consider the following model of public good provision. There are N countries each producing a public good (pollution control) e_i at cost $C_i(e_i)$.

Costs are assumed to be increasing and strictly convex. Public good provisions are not contractible. Benefits accrue equally to all countries, i.e. the payoff of country i is

$$\pi_i = p \sum_{j \in N} e_j - C_i(e_i) \tag{25}$$

where $p > 0$ denotes the public good's per–unit benefit. Using our notation we have $R = Np \sum_j e_j$ and $\alpha_i = \frac{1}{N}$. Both conditions C1 and C2 of Lemma 1 are satisfied.

Suppose that in an initial stage countries make a common decision about the target of their pollution control by choosing between two chemicals $y \in \{A, B\}$. There is uncertainty about the per–unit benefits of pollution control, i.e. $p(x, y)$ depends on the target and the state of the world $x \in \{A, B\}$. Countries know that in state x it is more beneficial to control $y = x$ and ex ante countries expect the control of A to be more beneficial. Under these conditions Proposition 1 implies that countries will conceal any evidence favoring the control of B if the two potential targets are sufficiently heterogeneous ex ante. Moreover if costs are as in (16) then Proposition 5 shows that countries with lower costs of pollution control have a weaker incentive to conceal such evidence. This suggests that the effects of pollution control are best investigated by those countries with the lowest costs of control.

Collective Action and Lobbying

Consider the following collective action model by Esteban and Ray (2001). An interest group consisting of N members lobbies a political party by making campaign contributions during an electoral period. Each member can make a contribution e_i incurring a private cost $C_i(e_i)$ which is assumed to be increasing and convex. Lobbying benefits $R(E, p) = \frac{pE}{E+E'}$ depend positively on the group's aggregate contribution $E = \sum_i e_i$ but negatively on the aggregate contribution of other groups E'. The parameter p measures the effectiveness of the lobbying effort. Lobbying benefits are shared equally amongst members so that member i's payoff is given by

$$\pi_i = \frac{1}{N} \frac{pE}{E + E'} - C_i(e_i). \tag{26}$$

In this example efforts are strategic substitutes and condition C2 is satisfied.

Suppose that there are two political parties A and B competing in the election and the interest group has to decide which party to lobby. Lobbying a party is more beneficial, i.e. p is higher, when the party wins the election than when it looses it. Suppose that if the interest group knew the outcome of the election it would prefer to have lobbied the winning party. Moreover, suppose that ex ante, the interest group prefers to lobby party A. For example the interest group may have closer personal relations within party A or party A may be the favorite in the election. Under these assumptions Corollary 1 shows that the likelihood with which information in support of party B fails to be shared amongst interest group members is increasing in the probability with which party A is expected to win the election. As suggested by Proposition 4 the interest group may solve this problem by offering rewards to those members who dare to voice opinions in conflict with the group's expectations.

11 Conclusion

In this paper we have identified an important link between decision making and implementation in teams. When implementation efforts are non–contractible, team members have to be concerned about each other's motivation to implement common decisions. In the presence of asymmetric information these motivational concerns can influence the organization's ability to make the right decisions. When members have private information they may favor decisions which their fellow members consider appropriate in the absence of such information. As a consequence information fails to be shared and/or the organization takes sub–optimal decisions.

We have shown that the team's decision making may be improved through contracts that reward members for the provision of pivotal/crucial information via the redistribution of revenue. However, when the projects' outcomes are sufficiently uncertain then such contracts fail to be feasible. In such a situation the team may restore full information sharing by delegating decision making rights to an outsider who helps the team to commit to take unpopular decision in the absence of evidence for the best course of action.

Our results have further been concerned with a team's optimal organizational structure in dependence of the characteristics of the team's decision making problem, i.e. the heterogeneity of the set of feasible projects and the projects' underlying uncertainty. They have the following testable implications. When projects are fairly homogeneous but subject to a large degree of uncertainty teams can be expected to be relatively large and decision making rights are likely to be delegated to an outsider. In the opposite case, when projects are fairly homogeneous and subject to a small degree of uncertainty, teams will be smaller and are likely to refrain from delegation. One may conclude that delegation is more likely in large teams than in small teams. Although intuitive and a consequence of the decreasing returns to scale in the team's aggregation of information note that in our model the effectiveness of communication has been derived endogenously by taking into account the team members' concern for each others' motivation to implement the joint decision.

Appendix

Proof of Lemma 1

Under C1, $\pi_i^y(e, \beta_i)$ is continuously differentiable in e and $\frac{\partial \pi_i^y}{\partial e_i}$ is nondecreasing in e_{-i}. Hence the simultaneous effort choice game constitutes a supermodular game (Topkis 1979). A supermodular game has a smallest and a largest pure Nash equilibrium (Milgrom and Roberts, 1990). Since revenue is strictly increasing in efforts, the latter is Pareto preferred to all other equilibria. If the team can coordinate onto the Pareto preferred equilibrium then the largest pure Nash equilibrium will be the unique outcome of the simultaneous effort choice game. Under C2 the strict concavity of the members' objective functions implies that the simultaneous effort choice game has a unique equilibrium. In the following let $e^y = e^y(\beta)$ and $\tilde{e}^y = e^y(\tilde{\beta})$ denote the equilibrium effort vectors for beliefs β and $\tilde{\beta}$ respectively.

Condition C1

Since $\frac{\partial \pi_i^y}{\partial e_i}$ is strictly increasing in β_i, Theorem 6 of Milgrom and Roberts (1990) implies that $\tilde{e}^y \geq e^y$. We now argue that $\tilde{e}_i^y > e_i^y$ for all $i \in M$. Consider member i's best response correspondence

$$\mathcal{E}_i^y(e_{-i}, \beta_i) = \arg \max_{e_i \in [0, \bar{e}_i]} \pi_i^y(e, \beta_i). \tag{27}$$

Since $\frac{\partial \pi_i^y}{\partial e_i}$ is strictly increasing in β_i it follows from the Monotone Selection Theorem of Milgrom and Shannon (1994) that every selection from $\mathcal{E}_i^y(e_{-i}, \beta_i)$ is nondecreasing in β_i. In particular member i's largest best response $\epsilon_i^y(e_{-i},\beta_i)$ is nondecreasing in β_i. Moreover, since π_i^y is continuously differentiable in e_i the Strict Monotonicity Theorem of Edlin and Shannon (1998) implies that $\epsilon_i^y(e_{-i},\beta_i)$ is strictly increasing in β_i on the interior of $[0,\bar{e}_i]$. Since efforts are strategic complements it follows from the Monotonicity Theorem of Milgrom and Shannon (1994) that $\epsilon_i^y(e_{-i},\beta_i)$ is nondecreasing in e_{-i}. Hence for $i \in M$, $\tilde{e}_{-i}^y \geq e_{-i}^y$ and $\tilde{\beta}_i > \beta_i$ imply that $\tilde{e}_i^y = \epsilon_i^y(\tilde{e}_{-i}^y,\tilde{\beta}_i) \geq \epsilon_i^y(e_{-i}^y,\tilde{\beta}_i) > \epsilon_i^y(e_{-i}^y,\beta_i) = e_i^y$. Since revenue is strictly increasing in efforts this implies that $\pi_i^y(\tilde{\beta}) > \pi_i^y(\beta)$ for all $i \in N - M$.

Condition C2

Let $E^y = \sum_i e_i^y$ and $\tilde{E}^y = \sum_i \tilde{e}_i^y$. We first show that $\tilde{E}^y > E^y$. By contradiction, suppose that $\tilde{E}^y \leq E^y$. For $i \in M$

$$\begin{aligned} \alpha_i[\tilde{\beta}_i R'(\tilde{E}^y,p_Y)+(1-\tilde{\beta}_i)R'(\tilde{E}^y,p_y)] &> \alpha_i[\beta_i R'(\tilde{E}^y,p_Y)+(1-\beta_i)R'(\tilde{E}^y,p_y)] \\ &\geq \alpha_i[\beta_i R'(E^y,p_Y)+(1-\beta_i)R'(E^y,p_y)]. \end{aligned} \quad (28)$$

The first inequality follows from $\tilde{\beta}_i > \beta_i$ and the fact that R' is strictly increasing in p. The second inequality follows from $\tilde{E}^y \leq E^y$ and the concavity of R. From the first order conditions of member i we therefore get $C_i'(\tilde{e}_i^y) > C_i'(e_j^i)$. The convexity of C_i implies that $\tilde{e}_i^y > e_i^y$. Hence it has to hold that $\tilde{e}_i^y > e_i^y$ for all $i \in M$. If $M = N$ this contradicts $\tilde{E}^y \leq E^y$. Otherwise, $\tilde{E}^y \leq E^y$ implies that $\tilde{e}_i^y < e_i^y$ for some $i \in N - M$. The strict convexity of C_i implies that $C_i'(\tilde{e}_i^y) < C_i'(e_i^y)$. Using the first order conditions for member i we thus get

$$\begin{aligned} \alpha_i[\beta_i R'(E^y,p_Y)+(1-\beta_i)R'(E^y,p_y)] &> \alpha_i[\tilde{\beta}_i R'(\tilde{E}^y,p_Y)+(1-\tilde{\beta}_i)R'(\tilde{E}^y,p_y)] \\ &= \alpha_i[\beta_i R'(\tilde{E}^y,p_Y)+(1-\beta_i)R'(\tilde{E}^y,p_y)]. \end{aligned} \quad (29)$$

which together with the concavity of R contradicts $\tilde{E}^y \leq E^y$. We have therefore shown that $\tilde{E}^y > E^y$. From the first order conditions is follows immediately that $\tilde{e}_i^y \leq e_i^y$ and thus $\pi_i^y(\tilde{\beta}) > \pi_i^y(\beta)$ for all $i \in N - M$. ■

Proof of Lemma 2

Suppose that $\beta_i = \beta \in (0,1)$ for all $i \in N$. Let $\tilde{p}_Y \geq p_Y$ and $\tilde{p}_y \geq p_y$ with strict inequality for at least one of the two. Denote by $e^y(\beta)$ and $\tilde{e}^y(\beta)$ the corresponding equilibrium effort vectors. Since each member's marginal payoff is strictly increasing in p_y and p_Y repeating the argument in the proof of Lemma 1 shows that under C1 $e_i^y(\beta)$ and thus $\pi_i^y(\beta)$ are strictly increasing in p_y and p_Y for all $i \in N$. Under C2 it has to hold that

$$\beta R'(\tilde{E}^y(\beta),\tilde{p}_Y)+(1-\beta)R'(\tilde{E}^y(\beta),\tilde{p}_y) > \beta R'(E^y(\beta),p_Y)+(1-\beta)R'(E^y(\beta),p_y). \quad (30)$$

Otherwise it follows from the first order conditions that $C_i'(\tilde{e}_i^y(\beta)) \leq C_i'(e_i^y(\beta))$ and thus $\tilde{e}_i^y(\beta) \leq e_i^y(\beta)$ for all $i \in N$ which in turn implies $\tilde{E}^y(\beta) \leq E^y(\beta)$ leading to a contradiction. It follows that $C_i'(\tilde{e}_i^y(\beta)) > C_i'(e_i^y(\beta))$ and thus $\tilde{e}_i^y(\beta) > e_i^y(\beta)$ for all $i \in N$. We have therefore shown that $e_i^y(\beta)$ and thus $\pi_i^y(\beta)$ are strictly increasing in p_y and p_Y for all $i \in N$. For $\beta = \mathbf{0}$ or $\beta = \mathbf{1}$ a similar argument shows that $\pi_i^y(\beta)$ is strictly increasing in p_y or p_Y respectively. ∎

Proof of Lemma 3

If member i received evidence for A and another member discloses such evidence then i's payoff is $\pi_i^A(\mathbf{1})$. If no other member discloses such evidence then i's payoff is $\pi_i^A(\mathbf{1})$ if he discloses and $\pi_i^A(1, \beta_{-i})$ if he conceals where $\beta_j < 1$ for all members who have failed to observe evidence. Lemma 1 implies that $\pi_i^A(1, \beta_{-i}) < \pi_i^A(\mathbf{1})$ for all $\beta_{-i} \neq \mathbf{1}$. Since all members fail to observe evidence with positive probability, disclosing evidence for $x = A$ therefore constitutes a strictly dominant strategy for member i. ∎

Proof of Lemma 4

An increase in d_j has two effects. First, it decreases γ_k^B and thus increases β_k^Q for all $k \neq j$. According to Lemma 1 this implies an increase in $\pi_i^A(0, \beta_{-i})$ for all β_{-i} such that $\beta_k = \beta_k^Q$ for some $k \in N - \{i, j\}$. Second, an increase in d_j leads to a decrease in $\tilde{q}_j$ making it more likely that $\beta_j = \beta_j^Q$ and less likely that $\beta_j = 0$. According to Lemma 1, $\pi_i^A(0, \beta_j^Q, \beta_{-i,j}) > \pi_i^A(0, 0, \beta_{-i,j})$. Hence both effects lead to an increase in $\Delta_i(d)$. ∎

Proof of Proposition 1

Part 1

It follows from Lemma 3 that in equilibrium evidence for A is fully disclosed. Full disclosure of evidence for B, $d = \mathbf{1}$, is part of an equilibrium if and only if $\Delta_i(\mathbf{1}) \leq 0$ for all $i \in N$. Due to Lemma 2, $\Delta_i(\mathbf{1})$ is strictly decreasing in p_B and from (8) we have $\lim_{p_B \to p_a} \Delta_i(\mathbf{1}) > 0$. Let $\bar{p}_i^1$ be such that $\Delta_i(\mathbf{1}) = 0$ for $p_B = \bar{p}_i^1$ and define $\bar{p}^1 \equiv \max_{i \in N} \bar{p}_i^1$. Then $d = \mathbf{1}$ is part of an equilibrium if and only if $p_B \geq \bar{p}^1$. Similarly, full concealment of B, $d = \mathbf{0}$, is part of an equilibrium if and only if $\Delta_i(\mathbf{0}) \geq 0$ for all $i \in N$. Since $\lim_{p_B \to p_a} \pi_i^B(\mathbf{1}) = \pi_i^A(\mathbf{0}) < \pi_i^A(0, \beta_{-i})$ for all $\beta_{-i} \neq \mathbf{0}$ it holds that $\lim_{p_B \to p_a} \Delta_i(\mathbf{0}) > 0$. Moreover, $\Delta_i(\mathbf{0}) < \Delta_i(\mathbf{1})$ and from Lemma 2 it follows that $\Delta_i(\mathbf{0})$ is strictly decreasing in p_B. Hence there exists a unique $\bar{p}_i^0 \in (p_a, \bar{p}_i^1)$ such that $\Delta_i(\mathbf{0}) = 0$. Defining $\bar{p}^0 \equiv \min_{i \in N} \bar{p}_i^0$ it holds that $d = \mathbf{0}$ is part of an equilibrium if and only if $p_B \leq \bar{p}^0$.

Part 2

According to Lemma 2, $\Delta_i(d)$ is strictly decreasing in p_B for all d. Hence there exists a $\bar{p}_i(d)$ such that $\Delta_i(d) = 0$ if and only if $p_B = \bar{p}_i(d)$. Lemma 4 has shown that $\Delta_i(d)$ is strictly increasing in d_j for all $j \in N - i$. In the same way one can show that $\Delta_i(d)$ is strictly increasing in d_i. It follows that $\bar{p}_i(d)$ is strictly increasing in d_j for all $j \in N$.

Consider $i \in N$ s.t. $d_i'' > d_i'$. Since $d_i' < 1$ and d' is an equilibrium for $p_B = p_B'$ it follows that $p_B' \leq \bar{p}_i(d')$. Since $d_i'' > 0$ and d'' is an equilibrium for $p_B = p_B''$ it holds that $p_B'' \geq \bar{p}_i(d'')$. Since $\bar{p}_i(d') < \bar{p}_i(d'')$ it follows that $p_B'' > p_B'$.

Finally consider a homogeneous team where $C_i = C$, $\bar{e}_i = \bar{e}$, and $\alpha_i = \alpha$ and hence $\Delta_i = \Delta$ for all $i \in N$. Suppose that each member discloses evidence for B with probability $d^* \in [0, 1]$. We have already shown that in equilibrium $d^* = 0$ if and only if $p_B \leq \bar{p}^0$ and $d^* = 1$ if and only if $p_B \geq \bar{p}^1$. Since $\Delta(d)$ is strictly increasing in d and strictly decreasing in p_B, for all $p_B \in (\bar{p}^0, \bar{p}^1)$ there exists a unique $d^* \in (0, 1)$ that solves $\Delta(d^*) = 0$ and d^* is strictly increasing in p_B. ■

Proof of Corollary 1

If suffices to show that $\pi_i^A(0, \beta_{-i})$ is strictly increasing in p_A for all $\beta_{-i} \neq \mathbf{0}$. Under C1 this holds trivially. Under C2 consider $\tilde{p}_A > p_A$ and let $\tilde{e}^A$ and e^A denote the corresponding equilibrium efforts when project A has been selected and beliefs are $\beta = (0, \beta_{-i})$. Let $\tilde{E}^A$ and E^A denote the corresponding aggregate effort levels and $\tilde{E}_{-i}^A$ and E_{-i}^A be the aggregate efforts of members other than i. We show that $\tilde{E}_{-i}^A > E_{-i}^A$. Assume the contrary, i.e. let $\tilde{E}_{-i}^A \leq E_{-i}^A$. If $\tilde{e}_i^A$ is such that $\tilde{E}^A \leq E^A$ then the first order condition of member j implies that $\tilde{e}_j^A \geq e_j^A$ for all $j \neq i$ with strict inequality for all j such that $\beta_j > 0$, leading to a contradiction. If instead $\tilde{e}_i^A$ is such that $\tilde{E}^A > E^A$ then the first order condition of member i implies that $\tilde{e}_i^A < e_i^A$ again leading to a contradiction. ■

Proof of Proposition 2

Let $\pi_i^y(\beta, p)$ denote member i's payoff when project y is selected, the projects productivity is p, and members have beliefs β. Let $S^y(\beta, p) = \sum_{i \in N} \pi_i^y(\beta, p)$ denote the corresponding surplus. Consider the difference Δ^* between total surplus under full concealment ($d = \mathbf{0}$) and full disclosure ($d = \mathbf{1}$) . When evidence for A is observed then $\Delta^* = 0$. When no evidence is disclosed then project A is selected and for all $i \in N$ beliefs are $\beta_i = Q$ under disclosure and $\beta_i = \beta_i^Q$ under concealment where

$$\beta_i^Q = \frac{Q \prod_{j \neq i}(1 - q_j)}{Q \prod_{j \neq i}(1 - q_j) + 1 - Q} < Q. \tag{31}$$

With probability $\gamma \equiv \prod_{i \in N}(1 - q_i)$ no evidence is observed and

$$\Delta^* = Q[S^A(\beta^Q, p_A) - S^A(\mathbf{Q}, p_A)] + (1 - Q)[S^A(\beta^Q, p_a) - S^A(\mathbf{Q}, p_a)] < 0. \tag{32}$$

Δ^* is negative because Q is the correct belief and efforts under belief $\beta^Q < Q$ are even further away from the efficient levels than efforts under belief Q.

Finally with probability $(1-Q)[1-\gamma]$ the state is B and evidence is observed by some member(s). In this case

$$\Delta^* = \frac{1}{1-\gamma} \sum_{\{\beta \neq \beta^Q | \beta_i \in \{0, \beta_i^Q\}\}} \left[\prod_{i \in N} q_i^{1-\beta_i/\beta_i^Q} (1-q_i)^{\beta_i/\beta_i^Q} \right] S^A(\beta, p_a) - S^B(\mathbf{1}, p_B) \tag{33}$$

Note that in this case Δ^* is strictly decreasing in p_B. Hence there exists a $\bar{p}^* \geq p_a$ such that $\Delta^* > 0$ if and only if $p_B \leq \bar{p}^*$. If N is large the probability that no evidence is observed is small and Δ^* is approximately equal to (33). If p_A is not too large, then the incorrectly high beliefs under concealment lead to higher but not inefficiently high effort levels and (33) is strictly positive for $p_B \to p_a$. Hence if γ and p_A are sufficiently small then $\bar{p}^* > p_a$. It remains to show that $\bar{p}^* < \bar{p}^1$. Except for the term where $\beta = \beta^Q$, the sum in (33) is identical to

$$\sum_{i \in N} \sum_{\{\beta_{-i} | \beta_j \in \{0, \beta_j^Q\}\}} \left[\prod_{j \in N-i} q_j^{1-\beta_j/\beta_j^Q} (1-q_j)^{\beta_j/\beta_j^Q} \right] \left[q_i \pi_i^A((0, \beta_{-i}), p_a) + (1-q_i) \pi_i^A((\beta_i^Q, \beta_{-i}), p_a) \right].$$

From Lemma 1 $\pi_i^A((0, \beta_{-i}), p_a) < \pi_i^A((0, \mathbf{Q}), p_a)$ and $\pi_i^A((\beta_i^Q, \beta_{-i}), p_a) < \pi_i^A((\beta_i^Q, \mathbf{Q}), p_a)$ for all β_{-i} in the sum. Moreover, $\pi_i^A((\beta_i^Q, \mathbf{Q}), p_a) \leq \pi_i^A((0, \mathbf{Q}), p_a)$ from $e_i^A(\beta_i^Q, \mathbf{Q}) > e_i^A(0, \mathbf{Q})$ (see proof of Lemma 1) and the fact that member i's belief $\beta_i^Q > 0$ is incorrectly high. Member i can benefit from an incorrectly high belief only if complementarities are so strong that his increase in effort leads to a sufficiently large increase in his colleagues' efforts. We have therefore shown that

$$\Delta^* < \sum_{i \in N} \left[\pi_i^A((0, \mathbf{Q}), p_a) - \pi_i^B(\mathbf{1}, p_B) \right] \tag{34}$$

By the definition of $\bar{p}^1$, for $p_B = \bar{p}^1$ it holds that $\pi_i^B(\mathbf{1}, p_B) \geq \pi_i^A((0, \mathbf{Q}), p_a)$ for all $i \in N$. Hence $\Delta^* < 0$ for $p_B = \bar{p}^1$ and $\bar{p}^* < \bar{p}^1$. ■

Proof of Propositions 3 and 4 and Corollary 2

In text.

Derivation of $\bar{p}^1$ for linear revenue

Define $a_i \equiv \frac{\alpha_i}{c_i}$. If evidence for B is disclosed equilibrium efforts are $e_j^B = (a_j p_B)^{\frac{1}{t}}$ for all $j \in N$. Member i's payoff from disclosure is

$$\pi_i^B(\mathbf{1}) = \alpha_i p_B \sum_{j \in N} e_j^B - \frac{c_i}{1+t} (e_i^B)^{1+t} = (\alpha_i p_B)^{\frac{1+t}{t}} c_i^{-\frac{1}{t}} \left[\frac{t}{1+t} + \sum_{k \neq i} \left(\frac{a_k}{a_i} \right)^{\frac{1}{t}} \right]. \tag{35}$$

If evidence for B is concealed by member i and project A is selected then equilibrium efforts are $e_i^A = (a_i p_a)^{\frac{1}{t}}$ and $e_j^A = (a_j m p_a)^{\frac{1}{t}}$ for all $j \in N - i$. Member i's payoff from concealment is

$$\pi_i^A(0, \mathbf{Q}) = \alpha_i p_a \sum_{j \in N} e_j^A - \frac{c_i}{1+t}(e_i^A)^{1+t} = (\alpha_i p_a)^{\frac{1+t}{t}} c_i^{-\frac{1}{t}} \left[\frac{t}{1+t} + \sum_{k \neq i} \left(m \frac{a_k}{a_i} \right)^{\frac{1}{t}} \right]. \tag{36}$$

From $\pi_i^B(\mathbf{1}) - \pi_i^A(0, \mathbf{Q}) = 0$ we obtain the threshold $\bar{p}_i^1$ in (19). ■

Proof of Proposition 5

Define $a_i \equiv \frac{\alpha_i}{c_i}$ and suppose that $a_i > a_j$. Consider

$$\bar{p}_i^1 = p_a m^{\frac{1}{1+t}} \left[\frac{m^{-\frac{1}{t}} \frac{t}{1+t} a_i^{\frac{1}{t}} + \sum_{k \neq i} a_k^{\frac{1}{t}}}{\frac{t}{1+t} a_i^{\frac{1}{t}} + \sum_{k \neq i} a_k^{\frac{1}{t}}} \right]^{\frac{t}{1+t}}. \tag{37}$$

The nominator is strictly smaller than the denominator. If we compare with the corresponding term for member j the nominator increases by $(a_i - a_j)\left(1 - m^{-\frac{1}{t}} \frac{t}{1+t}\right)$ while the denominator increases only by $(a_i - a_j)\left(1 - \frac{t}{1+t}\right)$. Hence $\bar{p}_i^1 < \bar{p}_j^1$. ■

Proof of Corollary 3

Since $\bar{p}^1 = \max_{i \in N} \bar{p}_i^1$ in order to minimize $\bar{p}^1$ one has to minimize the maximal $\bar{p}_i^1$. This amounts to setting $\frac{\alpha_i^*}{c_i} = \frac{\alpha_j^*}{c_j}$ for all $i, j \in N$. Together with the requirement that $\sum_{i \in N} \alpha_i^* = 1$ this implies the optimal shares defined in Corollary 3. ■

Proof of Proposition 6

Since

$$\frac{d}{dN} \left[\frac{1 + (N-1)m^{\frac{1}{t}} - \frac{1}{1+t}}{N - \frac{1}{1+t}} \right] = \frac{(m^{\frac{1}{t}} - 1)(1 - \frac{1}{1+t})}{(N - \frac{1}{1+t})^2} > 0 \tag{38}$$

$\bar{p}^1$ is strictly increasing in N. Moreover $\lim_{N \to 1} \bar{p}^1 = p_a$ and $\lim_{N \to \infty} \bar{p}^1 = p_a m^{\frac{1}{1+t}}$. Since

$$\frac{d}{dp_a} \left[p_a m^{\frac{1}{1+t}} \right] = m^{-\frac{t}{1+t}} \left(\frac{Q}{p_a}(1 - \frac{1}{1+t}) + 1 - Q \right) > 0 \tag{39}$$

and $\lim_{p_a \to 1} \left[p_a m^{\frac{1}{1+t}} \right] = 1$ it holds that $p_a m^{\frac{1}{1+t}} < 1 = p_A$ for all $p_a < p_A$. ■

Proof of Corollary 4

For $p_B < \lim_{N\to\infty} \bar{p}^1$ let $\bar{N} < \infty$ denote the smallest N such that $\bar{p}^1 \leq p_B$. Full disclosure is an equilibrium if and only if $N \leq \bar{N}$. Since $\bar{p}^1$ is strictly increasing in N, $\bar{N}$ is strictly increasing in p_B. We now argue that $N^* = \bar{N}$ maximizes the likelihood with which the team selects the project in accordance with the state of the world.

Conditional on the state of the world being $x \in \{A, B\}$ the likelihood that *some* member receives evidence is given by $1 - (1-q)^N$ and is strictly increasing in N. If the state of the world is A then independently of whether evidence for A is observed or not, the team will select project A. Hence in state A the team's quality of decision making is perfect and does not depend on team size. Now suppose that the state of the world is B. By the definition of $\bar{N}$ it holds that $p_B > \bar{p}^1$ when $N = \bar{N}$ but $p_B < \bar{p}^1$ when $N = \bar{N}+1$. When we increase the team size from $\bar{N}$ to $\bar{N}+1$ full information sharing ceases to be an equilibrium. Instead there exists an equilibrium in which $N \leq \bar{N}$ members disclose evidence for B while the remaining members conceals their information. Hence increasing the team size beyond $\bar{N}$ fails to increase the probability with which the team is able to choose project B when the state is B. Moreover increasing N further will eventually lead to an equilibrium in which all members conceal their evidence for B. Hence $N^* = \bar{N}$. ■

Proof of Proposition 7

Let $\beta_i^y(s_i, m_j)$ denote the belief of agent i when he has observed signal s_i, message m_j has been issued by agent j and decision y has been taken. Define $g = \frac{q^2}{q^2+(1-q)^2}$. Member i's profit $\pi_i = \pi_{i,i} + \pi_{i,j}$ can be decomposed into a part $\pi_{i,i} = \alpha_i p e_i - C_i(e_i)$ which depends on his own effort and a part $\pi_{i,j} = \alpha_i p e_j$ which depends on his colleague's effort. We consider both parts separately. Expected payoffs from following the equilibrium strategy are denoted as π_i^* while $\tilde{\pi}_i$ denote deviation payoffs.

Part 1

Suppose that both members tell the truth and consider member i's incentive to issue $m_i = A$ after receiving $s_i = A$. If $s_j = A$, then $\pi_{i,i}^* = \tilde{\pi}_{i,i}$. For $s_j = B$ we have

$$\pi_{i,i}^* = \frac{\alpha_i p_A}{2} e_i^A(\beta_i^A(A,B)) - C_i(e_i^A(\beta_i^A(A,B))) > \frac{\alpha_i p_B}{2} e_i^B(\beta_i^B(A,B)) - C(e_i^B(\beta_i^B(A,B))) = \tilde{\pi}_{i,i}$$

where the inequality follows from $p_A > p_B$ and the optimality of $e_i^A(\beta_i^A(A,B))$. Moreover, using the fact that $\beta_j^A(A,A) = \beta_j^B(B,B) = g$ and $\beta_j^A(B,A) = \beta_j^A(A,B) = \frac{1}{2}$ we have

$$\pi_{i,j}^* - \tilde{\pi}_{i,j} = q^2 \alpha_i [p_A e_j^A(g) - p_A e_j^A(1/2)] - q(1-q)\alpha_i [p_B e_j^B(g) - p_A e_j^A(1/2)] > 0 \qquad (40)$$

where the inequality follows from $p_A > p_B$ and $q > 1/2$. We have therefore shown that $m_i = s_i$ is always optimal if $s_i = A$. Now consider member i's incentive to issue $m_i = B$ after receiving $s_i = B$. We find

$$\pi^*_{i,i} - \tilde{\pi}_{i,i} = q^2 \alpha_i p_B e_i^B(g) - C(e_i^B(g)) - (1-q)^2 \alpha_i p_A e_i^A(1-g) + C(e_i^A(1-g)). \tag{41}$$

Note that $\pi^*_{i,i} - \tilde{\pi}_{i,i}$ is strictly increasing in p_B. For $p_B \to \frac{(1-q)^2}{q^2} p_A$, $e_i^B(g) \to e_i^A(1-g)$ and $\pi^*_{i,i} \to \tilde{\pi}_{i,i}$. Finally, we have

$$\pi^*_{i,j} - \tilde{\pi}_{i,j} = q^2 \alpha_i p_B e_j^B(g) + (1-q) q \alpha_i p_A e_j^A(\frac{1}{2}) - (1-q)^2 \alpha_i p_A e_j^A(\frac{1}{2}) - (1-q) q \alpha_i p_A e_j^A(g) \tag{42}$$

Again, $\pi^*_{i,j} - \tilde{\pi}_{i,j}$ is strictly increasing in p_B. Furthermore,

$$\lim_{p_B \to p_A} (\pi^*_{i,j} - \tilde{\pi}_{i,j}) = (2q-1) \alpha_i p_A [q e_j^A(g) - (1-q) e_j^A(1/2)] > 0 \tag{43}$$

and

$$\lim_{p_B \to \frac{(1-q)^2}{q^2} p_A} (\pi^*_{i,j} - \tilde{\pi}_{i,j}) = \alpha_i p_A [(1-q)^2 [e_j^B(g) - e_j^A(1/2)] + (1-q) q [e_j^A(1/2) - e_j^A(g)]] < 0 \tag{44}$$

where the last inequality arises from the fact that for $p_B \to \frac{(1-q)^2}{q^2} p_A$, $e_j^B(g) \to e_j^A(1-g)$ and $e_j^A(1-g) < e_j^A(1/2) < e_j^A(g)$.
Taken together these results imply that there exists a $\bar{p}_i$ such that truth telling is optimal for member i if and only if $p_B \geq \bar{p}_i$. Letting $\bar{p} = \max\{\bar{p}_1, \bar{p}_2\}$, this proves Part 1.

Part 2

Given $m_j = A$ the team always chooses $y = A$. Hence $\pi_{i,i}$ is independent of m_i and we can focus our analysis on $\pi_{i,j}$. Suppose that $s_i = B$. If $m_i = A$ then

$$\pi^*_{i,j} = q(1-q) \alpha_i p_A e_j^A(\beta_j^A(A,A)) + (1-q)^2 \alpha_i p_A e_j^A(\beta_j^A(B,A)) \tag{45}$$

while for $m_i = B$ we have

$$\tilde{\pi}_{i,j} = q(1-q) \alpha_i p_A e_j^A(\beta_j^A(A,B)) + (1-q)^2 \alpha_i p_A e_j^A(\beta_j^A(B,B)). \tag{46}$$

In a Bayesian equilibrium off–equilibrium beliefs can be chosen arbitrarily. In order to show that the equilibrium is robust to the Intuitive Criterion we suppose that agent j, after observing the off–equilibrium message $m_i = B$, believes that $s_i = B$ with certainty. It follows that $\beta_j^A(B,B) = 1-g < 1-q = \beta_j^A(B,A)$ and $\beta_j^A(A,B) = 1/2 < q = \beta_j^A(A,A)$. Hence $\pi^*_{i,j} > \tilde{\pi}_{i,j}$.

Now suppose that $s_i = A$. In this case we have

$$\pi^*_{i,j} = q^2 \alpha_i p_A e_j^A(\beta_j^A(A,A)) + q(1-q) \alpha_i p_A e_j^A(\beta_j^A(B,A)) \tag{47}$$

$$\tilde{\pi}_{i,j} = q^2 \alpha_i p_A e_j^A(\beta_j^A(A,B)) + q(1-q) \alpha_i p_A e_j^A(\beta_j^A(B,B)) \tag{48}$$

Since $\beta_j^A(B,B) = 1-g < 1-q = \beta_j^A(B,A)$ and $\beta_j^A(A,B) = 1/2 < q = \beta_j^A(A,A)$ it follows that $\pi^*_{i,j} > \tilde{\pi}_{i,j}$. ∎

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