# Conflicts and Common Interests in Committees

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*Committees improve decisions by pooling members' independent information, but promote manipulation, obfuscation, and exaggeration of private information when members have conflicting preferences. Committee decision procedures transform continuous data into ordered ranks through voting. This coarsens the transmission of information, but controls strategic manipulations and allows some degree of information sharing. Each member becomes more cautious in casting the crucial vote than when he alone makes the decision based on own information. Increased quality of one member's information results in his casting the crucial vote more often. Committees make better decisions for members than does delegation.* (*JEL* D71, D82, C72)

The subject of this paper is how small groups make decisions when diverse individual preferences are known to all, but when individuals possess private information that must be elicited in committee deliberations. Small-group decisions are ubiquitous for decisions under uncertainty. Judgment by a jury of one's peers, not by a single person, is the hallmark of the American criminal justice system. Committees recommend hiring and tenure decisions, and are essential for project and investment undertakings in business firms and for many administrative decisions in all organizations. Group evaluations bring different points of view to bear on an issue. They allow the pooling of information that is not otherwise available to a single decision-maker. But conflict among committee members limits the possibilities for information pooling. It is in the self interest of committee members to manipulate their evidence—to exaggerate favorable data that support their preferred outcome, or conceal unfavorable data that work against it. This paper studies the tension between information aggregation and strategic manipulation of information in small committee decisions.

The statistical value of aggregating diverse information among group members is an old idea. Condorcet (1785) proved that voting groups with diverse information make better decisions the larger the group size, using an early application of the law of large numbers (see also Alvin Klevorick, Michael Rothschild and Christopher Winship, 1984). The economics literature on group decisions has paid special attention to eliciting private preferences for public goods (Allan Gibbard, 1973; Mark Satterthwaite, 1975). The study of eliciting private information from an expert was initiated by Vincent Crawford and Joel Sobel (1982), who show that the expert's information must be garbled before being used by an uninformed decision maker with different preferences in the decision.[1] In committee decision-making, sharing or pooling of private information is essential. Little has been said about the strategic aggregation problem.[2] We show that when committee members disagree on how their information should be used, committee decisions are made through voting or scoring procedures. Continuous information is garbled and transmitted in ordinal forms. Efficient pooling of private information in a committee is impossible when members' interests conflict. Voting in committees is necessary to control conflicts and allow some degree of information sharing.

In the model set up in section I, a committee must choose between two alternatives. Individual committee members are known to have partially conflicting interests in the decisions. Committee members may disagree, but their disagreement disappears when the evidence is sufficiently strong in either direction. For example, in a recruitment committee, each member may be biased in favor of hiring if the candidate is in his own field, but all are willing to hire a person of sufficiently high quality regardless of field. But private information is an inherent problem in committee decision-making. In the recruitment example, information about candidate qualifications is dispersed in the committee because committee members have different perspectives or abilities to evaluate research in different fields. Since assessments are private, the committee decision can depend only on members' reports about their information, not on the actual information. Conflicting interests and private information give rise to strategic considerations that cause members to exaggerate their information.

In section II we show that information cannot be fully shared among committee members under these circumstances. Efficient sharing requires that the committee decision respond to small changes in any member's data. This property fails in an equilibrium of any decision-making procedure. Incentive compatibility implies that continuous data observed by each person are partitioned and transformed into rank order categories. Perfect inference of private information is impossible. Obfuscation is the rule rather than the exception in committees. The partitioning of continuous data into ordered categories can be interpreted as equilibrium outcomes of voting procedures. Voting is the equilibrium method of reaching decisions in committees. It coarsens the transmission of information among committee members, but is necessary to control strategic manipulations that arise from conflicts of interest.

Section III analyzes two-way partitions in detail. This corresponds to the equilibrium outcome of a simple voting procedure where each member votes "yes" or "no" depending on whether or not the strength of his private evidence exceeds a personal threshold. The voting equilibrium is suboptimal because information is garbled and the thresholds are chosen strategically rather than cooperatively. In the recruitment example, anticipating manipulation of evidence by fellow committee members, an individual "exaggerates" own evidence that the candidate in his field produces high quality research by voting "yes" to his favored candidate even though he would have voted "no" with the same evidence were all information truthfully revealed. He lowers his own hiring bar because he knows that other members will raise theirs.

Incentives for manipulation and counter-manipulation thus generate a larger area of disagreement among members than is implied by their inherent conflicts in preferences. The *ex ante* welfare of each individual committee member decreases as the preferences of fellow members diverge further away from his. When the preferences of fellow members are sufficiently extreme, the benefits to an individual member from sharing information under a given voting procedure can be outweighed by distortions in the committee. Still, equilibrium exaggeration is limited, and information is aggregated by the committee, albeit imperfectly. The area of disagreement is bounded from above by the need for members to share their private information. Regardless of personal preferences, each committee member casts the decisive vote less frequently than if he were to make the decision based on his information only. Moreover, if some committee members are known to have more conclusive evidence, others cast their deciding votes less frequently. Better informed members are decisive more often. Indeed, when the committee rule is chosen appropriately, gains from sharing information outweigh distortions from information manipulation for all members regardless of the extent of conflicts in the committee.

The voting model is used to analyze abstention in section IV. Although members always have incentives to influence the committee decision to advance their own interests, the gains from information sharing may be so large that it is in a member's self interest to abstain when his private information is relatively uninformative. Abstention improves the quality of committee decisions. Voting with abstention is equivalent to a generalized voting procedure that allows each committee member to choose from three categories. Section V studies voting procedures with more categories that allow finer partitions of data and more efficient utilization of private information. Conflicting interests among committee members impose an upper bound on how fine information partitioning can be. Great conflicts within the committee make fine partitions impossible.

## I. A Model of Committee Decision-making

We discuss the problem of strategic information aggregation in the context of hypothesis testing given the data. A committee must decide whether to accept or reject a null hypothesis. For example, a hiring committee must decide whether the candidate is qualified (the null) or unqualified, or a management committee must decide if an investment project is worth undertaking (the null) or not. In a criminal trial jury, the null is that the suspect is innocent. In these situations of binary states and binary decisions, the choice of the null hypothesis is arbitrary and unessential to our results, but it facilitates the discussion.

For simplicity, we consider a committee of two persons, $A$ and $B$. Member $A$'s prior that the null is true is $\gamma^a$, and the personal costs of type I error (false acceptance) and type

II error (false rejection) are $\lambda_1^a$ and $\lambda_2^a$ respectively. Let $k_1^a = \lambda_1^a(1-\gamma^a)$ and $k_2^a = \lambda_2^a\gamma^a$. The ratio $k^a = k_1^a/k_2^a$ represents the cost of false acceptance relative to false rejection. A greater $k^a$ means that $A$ is more prone to reject. There is no difference in this model between bias as manifested in $\gamma$ and preference as manifested in $\lambda$; only the ratio $k^a$ matters. The notation for member $B$'s preference is similar. Conflicts in the committee exist whenever $k^a \neq k^b$, but interests of committee members are not directly opposed as long as $k^a$ and $k^b$ are strictly positive and finite so that both care about false acceptance and false rejection. We assume that $k^a$ and $k^b$ are common knowledge.

Information about the decision is diverse in the committee. Member $A$ receives a private observation, a real number $y^a$ that is realization of a random variable $Y^a$. We assume that $Y^a$ is distributed on a subset $[\underline{y}^a, \overline{y}^a]$ of $\mathbb{R}$, with continuous density functions $f_q^a(\cdot)$ if the null is true and $f_u^a(\cdot)$ if the null is false. The corresponding distribution functions are $F_q^a(\cdot)$ and $F_u^a(\cdot)$. Member $B$'s information structure is similarly denoted. The random variables $Y^a$ and $Y^b$ are independently distributed conditional on the true state. This is a particular way of modeling the idea that committee members have different evidence due to differences in perspectives and capabilities in evaluating the information.

If the data are publicly observable, the optimal committee decision is a standard hypothesis testing problem.[3] By the assumption of conditional independence, given any decision rule of accepting the null hypothesis with probability $p(y^a, y^b)$ when the data are $(y^a, y^b)$, the expected cost to each member ($j = a, b$) (before the data are received) is given by

$$(1)\quad (1-\gamma^j)\lambda_1^j \int p(y^a, y^b) f_u^a(y^a) f_u^b(y^b) dy^a dy^b + \gamma^j \lambda_2^j \int [1 - p(y^a, y^b)] f_q^a(y^a) f_q^b(y^b) dy^a dy^b.$$

Under the optimal decision rule, $p^a(y^a, y^b)$ minimizes the weighted costs of $A$ and $B$. Let positive numbers $\alpha^a$ and $\alpha^b$ be relative weights for $A$ and $B$, and define $k_1 = \alpha^a k_1^a + \alpha^b k_1^b$ and $k_2 = \alpha^a k_2^a + \alpha^b k_2^b$. Then, the optimal decision rule is given by $p(y^a, y^b) = 1$ if $y^a$ and $y^b$ satisfy

$$(2)\qquad l^a(y^a) l^b(y^b) \geq k_1/k_2,$$

and $p(y^a, y^b) = 0$ otherwise, where $l^j$ is the likelihood ratio $f_q^j/f_u^j$ for each $j = a, b$. Throughout this paper, we assume the monotone likelihood ratio property (MLRP) that

$l^j(\cdot)$ is strictly increasing. This assumption simplifies our analysis, and is standard in the literature (see, e.g., Milgrom, 1981).[4] MLRP implies that the optimal decision rule is deterministic and strictly monotone in the observations $y^a$ and $y^b$. In other words, the optimal decision rule can be represented by a "decision function" $S$ that is strictly increasing in each of the two arguments $y^a$ and $y^b$, so that the decision is acceptance if and only if $S(y^a, y^b) \geq 0$. As illustrated in Figure 1, the optimal decision rule partitions the data space into an acceptance region and a rejection region, with a strictly downward sloping boundary between them defined by $S(y^a, y^b) = 0$. The null hypothesis is accepted when the data lie above the boundary, and is rejected when the data lie below it.[5]

The characterization of the optimal decision rule in equation (2) applies to individual decision-making as well. If member $A$ has access to both $Y^a$ and $Y^b$, then his optimal decision rule is to accept the null if and only if

$$l^a(y^a)l^b(y^b) \geq k^a. \tag{3}$$

MLRP implies that the personal optimal decision rule for each member is deterministic and strictly increasing in $y^a$ and $y^b$, but differs from the weighted optimal rule when the two members have conflicting interests ($k^a \neq k^b$). If the decision function $S^j$ ($j = a, b$) represents member $j$'s personal optimal decision rule, then (2) and (3) imply that there is no intersection between $S^a(y^a, y^b) = 0$ and $S^b(y^a, y^b) = 0$ in the data space. Figure 1 illustrates the case where $A$ has a lower standard of acceptance than $B$ ($k^a < k^b$). The region between $S^a = 0$ and $S^b = 0$ is the disagreement zone: for the same data $(y^a, y^b)$ in the region, $A$ prefers to accept and $B$ prefers to reject. The size of the disagreement zone measures how much the members differ in preference and prior. The difference between the members' personal optimal decision rules is the source of their incentives to misrepresent their own evidence and attempt to tilt the committee decision to their own preferences when evidence is not publicly observed.

## II. Manipulation Leads to Garbling

Since information is private, committee decisions are made on the basis of members' reports of their private data. Let us first consider a Bayesian game where the two members report $r^a$ and $r^b$ simultaneously after learning their private evidence $y^a$ and $y^b$, and the decision is made according to the rule "accept if and only if $S(r^a, r^b) \geq 0$." It is easy to see that truthful reporting is not an equilibrium strategy as long as $k^a \neq k^b$. In this case, the two personal optimal decision functions $S^a$ and $S^b$ differ from the committee decision function $S$. Suppose $B$ always reports his observation $y^b$ truthfully. Member $A$ does not know the value of $B$'s observation when he submits his report and treats $B$'s report as the random variable $Y^b$. If $A$ submits report $r^a$, the null is accepted if the realization $y^b$ is such that $S(r^a, y^b) \geq 0$. But conditional on $y^a$, member $A$ prefers to accept whenever $y^b$ satisfies $S^a(y^a, y^b) \geq 0$. Since $S$ differs from $S^a$, reporting $r^a = y^a$ is not optimal for member $A$.

Figure 1 illustrates the optimal report for member $A$ conditional on his evidence $y^a$ when $k^a < k^b$. Member $A$ is biased toward acceptance relative to the committee decision function $S$. Conditional on $y^a$, the committee decision is to accept if $y^b \geq y_2$, but $A$ prefers to accept if $y^b \geq y_1$. If $B$ reports his observations truthfully, member $A$ achieves his lower standard of acceptance by overstating the case for acceptance and reporting $r_1$. Similarly, $B$ has incentives to understate the case for acceptance if $A$ reports truthfully.

The result of nonexistence of truth-telling equilibrium can be generalized. As long as the two members $A$ and $B$ commit to a deterministic and strictly monotone rule such as the one represented by $S$, truth-telling is not an equilibrium. Moreover, given any deterministic and strictly monotone rule, there exists no manipulation equilibrium where members use invertible reporting strategies that allow perfect inference of their private data. The nonexistence of equilibrium with invertible strategies in reporting games with deterministic and strictly monotone rules illustrates the incentives to garble private information in committee decision-making. Indeed, since our argument depends only on the local characteristics of the reporting strategies, there exists no equilibrium with partially invertible strategies (i.e., reporting functions that are invertible for some interval in the support of the evidence). Garbling occurs everywhere.[6]

These generalizations can be made precise and strengthened further from a mechanism design perspective. A limitation of the result above is that it refers to a particular decision-making procedure, where each member is free to report any observation and a deterministic and strictly monotone decision rule maps the reported observations to the decisions. What will happen in equilibrium under commitments to different ways of making decisions? To answer this, the result has to be restated in a way that is independent of the particular information-reporting game. This requires side-stepping the game and the equilibrium strategy and directly examining how the private data are transformed into decisions in the data space.

Formally, a "decision mechanism" here is a commitment by $A$ and $B$ to a "report space" for each member that defines all the reports he can choose, and a "committee rule" that maps a vector of reports to a decision. Since the report spaces and the committee rule can be arbitrary, the concept of a decision mechanism captures all possible ways for the committee to make a decision. The Bayesian reporting game considered above defines a "direct decision mechanism," because each member's report is confined to the range of the observations. One can easily imagine "indirect mechanisms" where members' reports are not restricted to this range. For example, a voting procedure is an indirect mechanism because the report space for each committee member consists of two votes, yes and no. Whether direct or indirect, if a decision-making mechanism has an equilibrium, then the equilibrium defines an "outcome," a mapping from the data space to the decision that is a combination of the equilibrium strategies and the committee rule.

The outcome of efficient information sharing represented in formula (2) is deterministic and strictly monotone. A deterministic outcome divides data space into acceptance and rejection regions. A deterministic and strictly monotone outcome has a boundary that is a strictly decreasing function in the data space, such as $S = 0$ in Figure 1. Another possibility is a deterministic but everywhere weakly monotone outcome, represented by a boundary that is a decreasing step function, as in Figure 2. This is called a "partition outcome," because continuous data of each member are transformed into ordered ranks or categories through partitioning by thresholds. Categorizing data is a particular form of information garbling that restricts information in a natural way and prevents full revelation of private evidence. Applying the revelation principle (due to Roger Myerson (1979) in Bayesian games, and to Gibbard (1973), Partha Dasgupta, Peter Hammond and Eric Maskin (1979), and Milton Harris and Robert Townsend (1981) in other contexts), we can exclude any deterministic outcome whose boundary has a strictly decreasing segment as an equilibrium outcome.[7] The proof of the following proposition, which can be found in the appendix, formalizes the observation that the argument used at the beginning of this section to show that truth-telling is not an equilibrium in the reporting game with decision function $S$, remains valid under any deterministic committee rule that is strictly monotone in a neighborhood of some data point $(y^a, y^b)$.

PROPOSITION 1: *Suppose that the two members have conflicting interests* ($k^a \neq k^b$). *Then deterministic and monotone equilibrium outcomes of any decision mechanism are partition outcomes.*

Committee decision-making can be accomplished only by categorizing private data. Coarsening information through ordered categories controls private incentives to exaggerate the strength of one's private evidence while at the same time affording opportunities to pool everyone's evidence. There is a trade-off between information sharing and manipulation. Later we show that how this trade-off is resolved depends on a priori conflict among the members. The greater the latent consensus among members, the greater are the opportunities for presenting private data in finer categories and greater detail.

Proposition 1 gives a strong sense that we derive "voting" with categories as a necessary method to achieve consensus in committee decision-making. This is the clearest when partition outcomes involve two categories. In section III they are constructed as equilibrium outcomes of voting games, where each member votes "accept" or "reject," and a rule stipulates how many votes are needed to accept the null hypothesis. Section IV modifies the voting games to allow abstention, which corresponds to partition outcomes with three categories for each member.[8] Section V considers voting games with generalized procedures where each member can choose an integer score from a given scale (say, 1 to 10), and a prespecified scoring rule aggregates the scores and compares the sum to a given threshold (say, 9.5) to yield a committee decision. The equilibrium outcomes in these voting games correspond to partition outcomes with multiple categories.

The result that manipulation arising from conflicting interests leads to information garbling is closely related to Crawford and Sobel's (1982) work on cheap talk games. They show that when the preferred decision of a privately informed expert always differs from that of an uninformed decision-maker, the expert's continuous data must be partitioned before being used by the decision-maker. In our model committee decisions are binary instead of continuous, so committee members do not always differ. Yet partition outcomes with multiple categories arise in a similar way. To see this, imagine that in our model member $A$ submits a report of his data to $B$, who chooses between acceptance and rejection based on the report and his own data. Think of $B$'s decision as a threshold level of his data above which the null is accepted, which is a continuous decision variable. Then, $A$ and $B$ always differ in $B$'s decision for any data of $A$: in Figure 1 where we assume $k^a < k^b$, for any data of member $A$, the preferred decision of $B$ is the corresponding point on $S^b = 0$, which is greater than the preferred decision of $A$ (the corresponding point on $S^a = 0$). Thus, we obtain a version of Crawford and Sobel's model by modifying our model and assuming that one member reports to another who makes the decision. Of course, in our original model the two members play symmetric roles, so while the modified model shows that the formal analytical structure is similar in our model and in Crawford and Sobel's model, it also demonstrates the main difference between the two: private information is strategically aggregated in a committee instead of being transmitted from an expert to an uninformed decision-maker. Indeed, if in our model only one member has private information, then one can demonstrate that in any equilibrium outcome this member can partition his data into at most two categories, as there is no credible way for him to convey the strength of his evidence. In our present model with two privately informed members, their common interests in sharing information create potential opportunities to present private data in more categories and finer detail.

## III. Voting as Equilibrium Garbling

This section considers voting games in which each member chooses between "accept" or "reject." Two different voting procedures are possible: "unilateral acceptance" where the hypothesis is accepted if there is at least one "accept" vote, and "unilateral rejection" where acceptance requires two "accept" votes. Each procedure defines a different voting game, with an equilibrium in which each member votes "accept" when his observation is above a threshold. An equilibrium with such threshold strategies results in a partition outcome with two categories.

### A. Characterization of the two-category equilibria

For each $j = a, b$, denote $L_*^j = F_q^j / F_u^j$ and $L_{**}^j = (1 - F_q^j)/(1 - F_u^j)$. Suppose that there exist a pair of thresholds $(t_*^a, t_*^b)$ that satisfy

$$l^a(t_*^a) L_*^b(t_*^b) = k^a, \quad l^b(t_*^b) L_*^a(t_*^a) = k^b. \tag{4}$$

Similarly, suppose that a pair of thresholds $(t_{**}^a, t_{**}^b)$ satisfy

$$l^a(t_{**}^a) L_{**}^b(t_{**}^b) = k^a, \quad l^b(t_{**}^b) L_{**}^a(t_{**}^a) = k^b. \tag{5}$$

Consider unilateral acceptance; the case of unilateral rejection is similar. Suppose that member $B$ adopts the strategy of voting "accept" if and only if $y^b \geq t_*^b$. Given an observation $y^a$, to member $A$ the probability that the null hypothesis is true is $\eta\gamma^a f_q^a(y^a)$, and the probability that it is false is $\eta(1 - \gamma^a) f_u^a(y^a)$, where $\eta$ equals the reciprocal of $\gamma^a f_q^a(y^a) + (1 - \gamma^a) f_u^a(y^a)$. Member $A$ ensures acceptance by voting "accept." His expected cost (from false acceptance) is $\eta k_1^a f_u^a(y^a)$. If he votes "reject" instead, the verdict depends on $B$'s vote. From $A$'s point of view, the null will be wrongly accepted with probability $1 - F_u^b(t_*^b)$, and wrongly rejected with probability $F_q^b(t_*^b)$. Member $A$'s total expected cost from the two types of errors is then $\eta k_1^a f_u^a(y^a)[1 - F_u^b(t_*^b)] + \eta k_2^a f_q^a(y^a) F_q^b(t_*^b)$. Comparing the costs of these two votes shows that "accept" is preferred to "reject" if and only if $l^a(y^a) L_*^b(t_*^b) \geq k^a$. By MLRP and the definition of the thresholds $t_*^a$ and $t_*^b$, "accept" is preferred to "reject" if and only if $y^a \geq t_*^a$. The argument for $B$ is symmetric. We have proved the following:

PROPOSITION 2: *Suppose that there exist thresholds $t_*^j$ and $t_{**}^j$ $(j = a, b)$ that satisfy (4) and (5). Then, in the voting game with unilateral acceptance, there is an equilibrium where* *each member $j$ votes "accept" if and only if $y^j \geq t^j_*$; in the voting game with unilateral rejection, there is an equilibrium where each $j$ votes "accept" if and only if $y^j \geq t^j_{**}$.*

The equilibrium conditions (4) and (5) in the voting games can be understood in terms of a "pivotal voting" argument (Austen-Smith and Banks, 1996; Feddersen and Pesendorfer, 1997).[9] In our model, strategic voting requires that each member choose his vote as if it were pivotal. With unilateral acceptance, $A$'s vote is pivotal if $B$ votes for rejection, which occurs when $y^b < t^b_*$. The likelihood ratio for the event that $A$'s observation is $y^a$ and $y^b < t^b_*$ is given by $l^a(y^a)L^b_*(t^b_*)$. This represents the relative probability of the null is true to the null is false. The voting strategy for $A$ is to accept if $l^a(y^a)L^b_*(t^b_*)$ exceeds $k^a$, the relative costs of false acceptance and false rejection. To see why pivotal voting is optimal is to consider how members choose the threshold rule before receiving the observations. Anticipating that $B$ uses a voting strategy with threshold $t^b_*$, member $A$ chooses $t^a$ to minimize the expected cost $k^a_1[1 - F^a_u(t^a)F^b_u(t^b_*)] + k^a_2 F^a_q(t^a)F^b_q(t^b_*)$. In the above expression, member $A$'s choice of threshold $t^a$ affects his expected cost only when $y^b < t^b_*$. The first order condition for an optimal threshold $t^a$ is precisely (4).

Information aggregation with discontinuous data and strategic voting is analyzed in a series of interesting papers by Austen-Smith and Banks (1996) and Feddersen and Pesendorfer (1996; 1997; 1998).[10] In their model, private signals are binary, a feature that limits their analysis of information manipulation to mixed strategies. Our model differs in several respects. By using an information structure with continuously distributed private observations, we are able to study a richer set of information manipulations in committee decision-making. Instead of the mixed-strategy equilibria of Feddersen and Pesendorfer, we characterize partition outcomes and analyze obfuscation, exaggeration, and abstention as distinctive forms of evidence manipulation. More importantly, we do not impose voting as the collective decision procedure. We start with an information aggregation procedure that is optimal in the absence of strategic manipulation and derive voting as an equilibrium outcome of information garbling. In the following analysis of the two-category equilibrium outcomes, we go beyond the pivotal voting argument of Feddersen and Pesendorfer, emphasizing the role of conflicting interests in committee decision-making, and addressing how conflicts in the committee affect manipulation and sharing of information.

For unilateral acceptance, equations (4) define reaction functions in the $(t^a, t^b)$ plane, and determine the equilibrium thresholds. MLRP implies that $L^j_*(\cdot)$ is increasing, and the two reaction functions are downward sloping. Equilibrium exists under appropriate boundary conditions on the likelihood ratios. Suppose that for each $j = a, b$, there exists a finite, proper subset $[y^j_{\min}, y^j_{\max}]$ of the support $[\underline{y}^j, \overline{y}^j]$ of $Y^j$ such that

$$\begin{aligned} l^a(y^a_{\min})L^b_*(y^b_{\max}) < k^a < l^a(y^a_{\max})L^b_*(y^b_{\min}), \\ l^b(y^b_{\min})L^a_*(y^a_{\max}) < k^b < l^b(y^b_{\max})L^a_*(y^a_{\min}). \end{aligned} \tag{6}$$

Under these conditions, MLRP implies that $A$'s reaction function is defined for any $t^b \in [y^b_{\min}, y^b_{\max}]$, and vice versa for $B$. Then, the Brouwer fixed-point theorem applies to equations (4) and proves that an equilibrium exists on $[y^a_{\min}, y^a_{\max}] \times [y^b_{\min}, y^b_{\max}]$. As long as the likelihood ratios $l^j$ are unbounded (i.e., $l^j$ is arbitrarily large at $\overline{y}^j$ and $l^j$ is arbitrarily close to zero at $\underline{y}^j$), one can appropriately select the finite intervals $[y^j_{\min}, y^j_{\max}]$ to satisfy (6). For example, when $Y^j$ is normally distributed with a shift of the mean conditional on the true state of the null hypothesis, an equilibrium exists regardless of $k^a$ and $k^b$.

A sufficient condition for a unique intersection is that one reaction function is steeper than the other one whenever the two functions intersect. This condition is satisfied if the ratio $l^j(\cdot)/L^j_*(\cdot)$ is monotone. Throughout this section, we maintain the assumption that $l^j(\cdot)/L^j_*(\cdot)$ is strictly increasing on $[\underline{y}^j, \overline{y}^j]$. Under this assumption $A$'s reaction function is steeper than $B$'s when they intersect. Then, the equilibrium is unique and globally "stable," in a pseudo-dynamic sense that starting from any initial values the trajectory of the two thresholds converges to the intersection of the reaction curves. As is the case for many static games, stability in the pseudo-dynamic sense produces comparative statics results that are easy to understand (Avinash Dixit, 1986). Figure 3 depicts the reaction functions for the case where conditional on the true state $Y^a$ and $Y^b$ are normally distributed. This case satisfies the assumption that $l^j(\cdot)/L^j_*(\cdot)$ is increasing.

The case of unilateral rejection is analogous. MLRP implies that $L^j_{**}(\cdot)$ is increasing. Conditions similar to (6) guarantee that there exist $t^a_{**}$ and $t^b_{**}$ that satisfy (5). As in the case of unilateral acceptance, the assumption that the ratio $l^j(\cdot)/L^j_{**}(\cdot)$ is increasing is sufficient to ensure that equilibrium is unique and stable. For example, when $Y^j$ is normally distributed conditional on the true state, both $l^j/L^j_*$ and $l^j/L^j_{**}$ are increasing. In this case, there is a unique and stable equilibrium both in unilateral acceptance and in unilateral rejection.

### B. Information manipulation and information sharing

This section presents a few comparative statics results for the voting game and illustrates the tension between information manipulation and information sharing. From equations (4) under unilateral acceptance, since $l^j/L^j_*$ is increasing, if $Y^a$ and $Y^b$ have the same conditional distributions, then $k^a < k^b$ implies $t^a_* < t^b_*$. That is, if member $A$ is more biased toward acceptance than member $B$, then $A$'s equilibrium threshold for acceptance is lower than $B$'s. For the same observation value $y^a = y^b = y$, member $A$ votes for acceptance while $B$ votes for rejection if $y$ is between $t^a_*$ and $t^b_*$. Therefore $|t^a_* - t^b_*|$ can be thought of as the "area of disagreement" between the two members.

Since $l^j/L^j_*$ is increasing, $dt^a_*/dk^b < 0$ and $dt^b_*/dk^b > 0$, so the area of disagreement increases as conflict of interests, $|k^a - k^b|$, increases. As $B$ becomes more biased toward rejection and his standard for acceptance increases, $A$ counters by lower his own standard. This induces $B$ to raise $t^b_*$ further. The increase in $t^b_*$ can be decomposed into two parts: one due to the shift of $B$'s reaction function, and the other due to a move along $B$'s reaction function because $t^a_*$ decreases. See Figure 3. The second part shows that the area of disagreement in committee decision-making is larger than that implied by inherent conflicts in preferences: strategic manipulation by one member leads to counter-manipulation by the other. Conflicts lead to the exaggeration. When $B$ is more biased toward rejection than $A$, member $B$ raises his threshold not only because of the concern for false acceptance, but also to balance $A$'s opposite tendency to vote "accept." Member $B$ votes for rejection more often than in the absence of information manipulation by $A$.

Although conflicts cause manipulation, incentives to exaggerate evidence are balanced in equilibrium by incentives to share information. Comparing the equilibrium with how each member would make the decision based on his own private information illustrates sharing of information in the committee. If a member makes the decision alone, the optimal decision is acceptance if and only if his evidence $y^j$ $(j = a, b)$ exceeds a threshold $\hat{t}^j$ determined by

$$l^j(\hat{t}^j) = k^j. \tag{7}$$

Compare (7) with (4). Since $L^j_*(\cdot) < 1$, $\hat{t}^j$ is lower than $t^j_*$. When $j$ observes evidence $y^j$ between $\hat{t}^j$ and $t^j_*$, he votes for rejection in the committee even though he would have chosen acceptance if he were the only decision-maker. Member $j$ thus utilizes the information of the other member by casting the decisive "accept" vote less frequently. Note that this is true independent of member $j$'s preferences. Even if member $j$ is strongly biased toward acceptance, the need to utilize the other member's information still makes him more "conservative" towards acceptance. In the case of unilateral rejection, the decisive vote is rejection instead of acceptance: each member utilizes the information of the other member by voting for rejection less frequently than if the decision were made on the basis of own information.

Incentives to share information under conflicting interests can also be examined by considering how voting behavior changes when quality of the observation received by one member, say $B$, becomes higher. If evidence were public, higher quality data receive greater weight in the decision rule.[11] But since evidence is private, changes in weights can be easily undone by information manipulation. Instead, changes in information quality changes equilibrium thresholds. Consider a modification of the information structure available to members. Member $B$ still observes $Y^b$. Member $A$ observes $Y^a$ with probability $1-\pi$, and observes the true state of the null hypothesis with probability $\pi$. An increase in $\pi$ improves the quality of $A$'s data. The pivotal event that $A$ votes "reject" now has a likelihood ratio $\tilde{L}^a_*$ given by

$$\tilde{L}^a_* = \frac{(1-\pi)F^a_q(t^a_*)}{\pi + (1-\pi)F^a_u(t^a_*)}. \tag{8}$$

From equation (4), since $\tilde{L}^a_*$ is decreasing in $\pi$, an increase in $\pi$ causes $B$'s reaction function to shift upwards. The effect is that $t^a_*$ decreases and $t^b_*$ increases. See Figure 3. The interpretation is straightforward. Voting for acceptance decides the verdict regardless of the value of the other member's observation. Voting for rejection, on the other hand, defers the decision to the other member. When $A$ gains access to data of a higher quality, $B$ takes advantage of the improved information by raising $t_*^b$ and deferring the decision to $A$, so $A$ is decisive more often.

The analysis is symmetric for the case of unilateral rejection. Given the modified information structure, the likelihood ratio for the event that $A$ votes for acceptance is

$$\tilde{L}_{**}^a = \frac{\pi + (1-\pi)[1 - F_q^a(t_{**}^a)]}{(1-\pi)[1 - F_u^a(t_{**}^a)]}. \tag{9}$$

An increase in $\pi$ increases $\tilde{L}_{**}^a$, so $t_{**}^a$ rises and $t_{**}^b$ falls. Voting for rejection decides the case. Member $B$ avoids submitting a decisive vote in order to take advantage of the higher quality of $A$'s evidence. He lowers $t_{**}^b$ and votes for rejection less often.

### C. Delegation versus committee decision-making

Conflicts reduce welfare because strategic manipulation reduces efficiency of information aggregation. To see this, note that the extent of divergence in preferences $|k^a - k^b|$ directly affects expected cost to each member in the voting game. With unilateral acceptance, equilibrium expected cost to member $A$ is

$$C_*^a = k_1^a[1 - F_u^a(t_*^a)F_u^b(t_*^b)] + k_2^a F_q^a(t_*^a)F_q^b(t_*^b). \tag{10}$$

Differentiating with respect to $k^b$, we have

$$\frac{dC_*^a}{dk^b} = [-k_1^a f_u^b(t_*^b)F_u^a(t_*^a) + k_2^a f_q^b(t_*^b)F_q^a(t_*^a)]\frac{dt_*^b}{dk^b}. \tag{11}$$

From the equilibrium condition (4) for member $A$, since $dt_*^b/dk^b > 0$ when $l^j/L_*^j$ is increasing, $dC_*^a/dk^b$ has the same sign as $k^b - k^a$. For example, if $k^a < k^b$, a further increase in $k^b$ raises member $A$'s expected cost in the equilibrium. Equation (11) shows that $dC_*^a/dt_*^b$ has the same sign as $k^b - k^a$. Similarly $dC_*^b/dt_*^a$ has the same sign as $k^a - k^b$. If $k^a = k^b$, equilibrium thresholds minimize the expected cost to both members. But if $k^a < k^b$ for example, the expected cost to both members would fall if $A$'s threshold increased and $B$'s decreased. Thus, strategic manipulation implies that equilibrium thresholds are Pareto inefficient.

Since conflicting preferences reduce welfare, are the gains from information sharing sufficient to outweigh the losses from strategic voting? To answer this question, we compare committee decision-making to delegation of the decision to one member. Let $\hat{C}^a$ denote $A$'s expected cost when he alone makes the decision based on his own information. Then $\hat{C}^a = k_1^a[1 - F_u^a(\hat{t}^a)] + k_2^a F_q^a(\hat{t}^a)$, where the optimal threshold $\hat{t}^a$ satisfies condition (7). Consider the difference $D^a = C_*^a - \hat{C}^a$ as a function of $k^b$. We showed above that $dC_*^a/dk^b < 0$ for $k^b < k^a$ and $dC_*^a/dk^b > 0$ for $k^b > k^a$. Since $\hat{C}^a$ is independent of $k^b$, the difference $D^a$ decreases for $k^b < k^a$ and then increases for $k^b > k^a$, reaching a minimum at $k^b = k^a$. In the limiting case where $k^b$ approaches infinity, member $B$ always votes for rejection and lets member $A$ make the decision. Therefore, $D^a = 0$. At the other limit, when $k^b$ approaches zero, $B$ ensures acceptance by himself. Member $A$'s expected cost is then simply $k_1^a$, and the difference $D^a$ is given by $k_1^a F_u^a(\hat{t}^a) - k_2^a F_q^a(\hat{t}^a)$. By the definition of $\hat{t}^a$, we have $k_1^a f_u^a(y^a) > k_2^a f_q^a(y^a)$ for all $y^a < \hat{t}^a$. Integrating over the range $y^a \leq \hat{t}^a$ then establishes that $D^a > 0$ when $k^b$ approaches zero.

Figure 4 shows that $D^a$ is negative at $k^b = k^a$: with no conflict of preferences, committee decision-making dominates do-it-alone decision-making because more information is better. It shows also that for $A$ committee decision-making continues to dominate so long as $B$ is relatively biased toward rejection ($k^b > k^a$), because the unilateral acceptance rule allows $A$ to control the acceptance decision while at the same time deferring to $B$ when the latter has strong evidence for rejection. Moreover, if $k^b > k^a$ then $B$ also prefers the committee decision to delegation to $A$. The reason is that $A$ controls the decision process in both cases but with committee decision-making $B$'s information is sometimes used.[12] Thus, delegation from a member biased toward rejection to a member biased toward acceptance is Pareto dominated by unilateral acceptance.

When the committee rule is unilateral rejection, the decisive vote is rejection. Committee decision-making allows the member who is relatively biased toward rejection to control the decision process. Unilateral rejection therefore dominates delegation of the decision to a member relatively biased toward rejection. When the committee rule can be chosen, delegation is Pareto dominated regardless of preferences of committee members.

### D. Voting procedures and voting behavior

This section compares the equilibrium with unilateral acceptance to the equilibrium with unilateral rejection. It might seem that requiring two votes for acceptance instead of one is a more "stringent" standard of proof. But this statement ignores strategic responses to the voting procedure. When unanimity in acceptance is required, each member lowers his threshold for acceptance and votes for acceptance less cautiously, because he knows that the other member may have information that will lead to a vote against acceptance. On the other hand, if acceptance is unilateral, each member is more cautious in casting a vote for acceptance, because such a vote would be decisive regardless of the other member's information. More precisely, MLRP implies that for each $j = a, b$, $L^j_*(\cdot) < 1$ and $L^j_{**}(\cdot) > 1$. It then follows from conditions (4) and (5) that $t^j_* > t^j_{**}$.

The above result is illustrated in Figure 5. Under unilateral acceptance, the hypothesis is accepted unless the data lie in the region below both of the two lines through $t^a_*$ and $t^b_*$. With unilateral rejection, it is accepted only when the data lie in the region above both lines through $t^a_{**}$ and $t^b_{**}$. Since the two regions overlap, the comparison between unilateral acceptance and unilateral rejection depends on the precise shapes of the conditional distributions of $Y^a$ and $Y^b$. In particular, unanimous acceptance does not necessarily lead to lower acceptance rates.[13]

The extent of conflict affects members' preference over voting procedures. When interests are identical, the two members agree on which procedure should be used. By continuity, small differences in preference do not generate disagreement about the *ex ante* choice of voting procedure. However, as conflicts increase, strategic manipulations of information amplify the differences in personal preference over voting procedures. For a numerical example, let $F_q \sim N(0,1)$ and $F_u \sim N(1,1)$ be the common distribution functions, conditional on the true state. If the common preference $k$ exceeds 1, both members prefer unilateral rejection to unilateral acceptance. Now, consider the following parameterization: $k^a_1 = k - d$, $k^b_1 = k + d$, and $k^a_2 = k^b_2 = 1$. As $d$ increases from 0 to $k$, $k^a$ decreases and $k^b$ increases. Define a "cooperative" threshold $\bar{t}_*$ under unilateral acceptance by the equation $l(\bar{t}_*)L_*(\bar{t}_*) = k$. With this specification, $\bar{t}_*$ minimizes the equally-weighted sum of expected costs to the two members under unilateral acceptance, regardless of the extent of conflicts $d$. Similarly, define the cooperative threshold $\bar{t}_{**}$ under unilateral rejection according to $l(\bar{t}_{**})L_{**}(\bar{t}_{**}) = k$. Figure 6 (with $k = 2$) illustrates how each member $j$'s preference over plurality changes with $d$, as measured by the ratio of expected cost $\bar{C}^j_*$ under unilateral acceptance to cost $\bar{C}^j_{**}$ under unilateral rejection.

With cooperative thresholds, member $B$'s preference for unilateral rejection becomes stronger as he becomes more biased toward rejection ($\bar{C}^b_*/\bar{C}^b_{**}$ increases with $d$). Member $A$'s preference over the two procedures, shown by $\bar{C}^a_*/\bar{C}^a_{**}$, initially coincides with $B$'s, but switches to unilateral acceptance as he becomes more concerned with false rejection. In Figure 6 this happens around $d = 1.36$. In contrast, equilibrium manipulation implies a larger difference in personal preference over voting procedures. Figure 6 also plots the ratio of each member $j$'s equilibrium expected cost $C^j_*$ under unilateral acceptance to the cost $C^j_{**}$ under unilateral rejection. As with cooperative decision-making, the difference between $C^b_*/C^b_{**}$ and $C^a_*/C^a_{**}$ becomes greater as $d$ increases, but the divergence grows much faster. Member $A$ switches his preferred voting procedure from unilateral rejection to unilateral acceptance around $d = 0.38$.

## IV. Abstention

This section allows committee members to abstain in the voting games, which corresponds to a three-way partition of each member's data. Abstention improves the quality of decision-making in equilibrium, because it allows each member to signal that his data are inconclusive and reduces harmful strategic manipulations. This result is obtained for the case of unilateral acceptance. The case of unilateral rejection is symmetric.

We need to specify what happens when both members abstain. The simplest way is to specify a "default decision" when both abstain. If the default is rejection, abstention is equivalent to voting for rejection and has no effect on the equilibrium. But suppose the default is acceptance. Then a vote for rejection by $A$ results in acceptance only if $B$ votes for acceptance, while abstention by $A$ results in acceptance when $B$ either votes for acceptance or abstains. Now equilibrium strategies involve two thresholds, $t^j_1 < t^j_2$, such that a member strategy votes "accept" if $y^j \geq t^j_2$, votes "reject" if $y^j < t^j_1$, and abstains if $t^j_2 > y^j \geq t^j_1$.

For each $j = a, b$ and any $y_2^j > y_1^j$, denote the ratio $[F_q^j(y_2^j) - F_q^j(y_1^j)]/[F_u^j(y_2^j) - F_u^j(y_1^j)]$ as $\mathcal{L}^j(y_2^j, y_1^j)$. Using similar reasoning as in the proof of Proposition 2, we can show that the thresholds for $A$ satisfy:

$$\begin{aligned} l^a(t_1^a)\mathcal{L}^b(t_2^b, t_1^b) &= k^a, \\ l^a(t_2^a)L_*^b(t_1^b) &= k^a. \end{aligned} \tag{12}$$

A symmetric pair of equations holds for $B$. The term $\mathcal{L}^b(t_2^b, t_1^b)$ in the first equation of (12) is the likelihood ratio for the event that $B$ abstains. In that case, $A$ can guarantee rejection only if he votes for rejection. The term $L_*^b(t_1^b)$ in the second equation is the likelihood ratio for the event that $B$ votes for rejection, when $A$ can guarantee rejection if he abstains. MLRP implies that $\mathcal{L}^j(t_2^j, t_1^j) > l^j(t_1^j) > L_*^j(t_1^j)$. Then, if $t_2^b > t_1^b$, (12) implies that $t_2^a > t_1^a$, and vice versa. Thus, the thresholds $(t_1^a, t_2^a, t_1^b, t_2^b)$ defined by (12) form an equilibrium of the voting game. We assume that the equilibrium exists and is unique.

Comparing the thresholds in the equilibrium with abstention with the equilibrium thresholds without abstention shows that allowing abstention makes committee members more "careful" in casting their votes. Formally, for each $j = a, b$, we have $t_2^j > t_*^j > t_1^j$ (the proof is in the appendix). Thus, if the evidence is not very strong either way, a member chooses to abstain.[14] Standards of evidence for voting for acceptance or for rejection are raised so that the probability of voting either way is reduced for both members. Efficiency in information sharing improves. The proof is in the appendix.

PROPOSITION 3: *Equilibrium expected cost to each member in the voting game with abstention is lower than that in the voting game without abstention.*

With conflicts in the committee, allowing abstention reduces the tension. Finer partitioning of information improves the welfare of each member of the committee. However, finer partitions are possible only when conflicts are bounded: Proposition 3 assumes that an equilibrium exists with three-categories, but the existence depends on the extent of conflicts. If conflicts are too great, three-category equilibrium outcomes do not exist and allowing abstention has no effect on committee decisions. We show this point next.

## V. More Categories

This section shows that the degree of conflict among members limits the fineness of data partitioning under any decision mechanism. For expositional convenience, we consider a voting game with a specific scoring rule that implements a unilateral acceptance outcome with $N$ thresholds and $N+1$ categories for each member. Each member chooses an (integer) score from 0 to $N$. The committee decision is "acceptance" if the sum of the two scores is greater than $N - \frac{1}{2}$ and "rejection" otherwise. We construct an equilibrium where each member $j$ ($j = a, b$) uses an $N$-threshold strategy, such that for each $n = 0, \ldots, N$, the score $n$ is chosen if $y^j \in [t^j_n, t^j_{n+1})$, where $t^j_1, \ldots, t^j_N$ are the $N$ thresholds ($t^j_0 = \underline{y}^j$ and $t^j_{N+1} = \overline{y}^j$ are defined as the lower and upper bound of the support of $Y^j$.) Each member can convey the strength of his evidence by choosing different scores. A score of $N$ ensures acceptance regardless of the other score, while a score of $n \leq N-1$ results in acceptance only when the other score is at least $N - n$.

Deriving conditions for thresholds in the $(N+1)$-category equilibrium is a straightforward extension of the proof of Proposition 2. By construction, for each $n = 1, \ldots, N$, a choice between two scores $n-1$ and $n$ for member $A$ is pivotal only if member $B$ chooses $N-n$: if $A$ chooses $n-1$ rejection results, and if he chooses $n$ acceptance results. Member $A$ therefore makes the choice between the two scores conditional on his evidence $y^a$ and on $B$'s choice of $N-n$ (that is, on $y^b \in [t^b_{N-n}, t^b_{N-n+1})$). See Figure 2. The expected cost to $A$ from choosing $n$ is $\eta k^a_1 f^a_u(y^a)[F^b_u(t^b_{N-n+1}) - F^b_u(t^b_{N-n})]$, and from choosing $n-1$ is $\eta k^a_2 f^a_q(y^a)[F^b_q(t^b_{N-n+1}) - F^b_q(t^b_{N-n})]$, where $\eta$ is a normalization factor under Bayesian updating, and the terms in the brackets are the probability that $B$'s evidence lies in the interval that allows $A$'s choice to be pivotal. Thus, choosing $n$ instead of $n-1$ is optimal if and only if $y^a \geq t^a_n$ where the threshold $t^a_n$ satisfies

$$l^a(t^a_n)\mathcal{L}^b(t^b_{N-n+1}, t^b_{N-n}) = k^a. \tag{13}$$

MLRP implies that $\mathcal{L}^j(u, v)$ is increasing in both $u$ and $v$ for all $u > v$.[15] Since the above argument holds for $n = 1, \ldots, N$, the thresholds defined by equations (13) satisfy $t^a_1 < \ldots < t^a_N$. Thus, if member $B$ uses a voting strategy with thresholds $t^b_1 < \ldots < t^b_N$, the threshold strategy defined by (13) is optimal for member $A$.

The equilibrium thresholds are described by the $N$ equations in (13), and a symmetric set of $N$ equations for member $B$. Conditions (4) for the two-category equilibrium outcome and conditions (12) for the three-category equilibrium outcome are special cases of (13). If members have identical preferences, categorization can get finer and finer as $N$ increases. The solution converges to that implied by the Neyman-Pearson lemma, and full information revelation occurs. However, conflicts in preferences place an upper bound on how fine categorization can be in equilibrium. This is illustrated with the help of Figure 2, where we assume without loss of generality that $k^a < k^b$. The area above $S^a = 0$ (represented by $l^a l^b = k^a$) and below $S^b = 0$ (represented by $l^a l^b = k^b$) is the disagreement zone. Since $\mathcal{L}^j(u,v)$ is increasing in both $u$ and $v$ for all $u > v$, we have $l^j(u) > \mathcal{L}^j(u,v) > l^j(v)$. Then, for any two adjacent equilibrium thresholds $t_n^a$ and $t_{n+1}^a$, from the equilibrium conditions (13),

$$
\begin{aligned}
l^a(t_n^a) l^b(t_{N-n}^b) &< k^a, \\
l^a(t_{n+1}^a) l^b(t_{N-n}^b) &> k^b.
\end{aligned}
\tag{14}
$$

Thus, the threshold point $(t_n^a, t_{N-n}^b)$ is below $S^a = 0$, and the point $(t_{n+1}^a, t_{N-n}^b)$ is above $S^b = 0$. That $A$'s observation $y^a$ lies between $t_n^a$ and $t_{n+1}^a$ is pivotal for determining $B$'s threshold $t_{N-n}^b$. This means that the line segment connecting the two points $(t_n^a, t_{N-n}^b)$ and $(t_{n+1}^a, t_{N-n}^b)$ is on the decreasing step function that separates the acceptance region from the rejection region. Since the argument applies to any two adjacent thresholds of $A$, any "horizontal" segment on the decreasing step function must "cross" the disagreement zone. Moreover, the same conditions (14) imply that any "vertical" line segment of the decreasing step function must also cross the disagreement zone: for example, in Figure 2 the point $(t_n^a, t_{N-n}^b)$ is below $S^a = 0$ and the point $(t_n^a, t_{N-n+1}^b)$ is above $S^b = 0$. We summarize this result in the following proposition. We say that a partition outcome with $N$ thresholds $t_1^j, \ldots, t_N^j$ for each member ($j = a, b$) "crosses the disagreement zone" in the data space, if the thresholds satisfy (14) for any $n$ (the conditions are reversed for the case of $k^a > k^b$).

PROPOSITION 4: *If $k^a \neq k^b$, then any equilibrium partition outcome crosses the disagreement zone in the data space.*

Greater conflicts create a greater disagreement zone. The decreasing step function associated with any equilibrium partition outcome must then cross a larger disagreement zone, and the lower bound on the distance between adjacent thresholds for each member becomes larger. The maximum possible number of thresholds for each member in any equilibrium partition outcome is finite on any proper subset of the support of data, and depends negatively on the difference in preferences $|k^a - k^b|$.[16] Great conflicts within the committee make fine categorization impossible.

Proposition 4 directly implies that any equilibrium partition outcome is *ex post* Pareto inefficient. In Figure 2, where we assume $k^a < k^b$, when the data $(y^a, y^b)$ fall into any triangular region above $S^b = 0$ and below the step function, both $A$ and $B$ would like to accept the null, but the equilibrium decision is rejection. Similarly, in any triangular region below $S^a = 0$ and above the step function, both $A$ and $B$ would like to reject but the equilibrium decision is acceptance. Proposition 4 thus demonstrates that *ex post* inefficiency is a necessary consequence of sharing private information. As partitioning becomes finer, the regions of *ex post* Pareto inefficiency shrink. As a result, each member becomes better off. The proof of Proposition 3 directly extends to establish that the expected cost of each member decreases as the number of equilibrium thresholds increases for each member.

Since the maximum number of categories is limited by the extent of conflict, Proposition 4 raises the question of whether committee decision rules must be frequently adjusted to accommodate changes in preferences of committee members. The answer is "no," because a scoring rule that allows fine partitioning of data can also produce equilibrium outcomes with coarser partitioning. For example, suppose that the scoring rule allows a maximum of 10 categories, in which each member can choose a score from 0 to 9, and the threshold is 8.5. If the extent of conflict is so great that only two-category partitioning of private data is possible, then one equilibrium is where each member chooses the score 0 when his private data are below his personal threshold and the score 9 otherwise. This equilibrium yields the unilateral acceptance outcome with two categories.

Voting procedures and scoring games considered in this paper are also robust in a different sense. The same equilibrium partition outcomes arise if, instead of submitting votes or scores simultaneously, the two members in a committee express their positions one by one, or they are allowed to change after all positions are known.[17] The reason is that under pivotal voting, each member chooses a vote or score conditional on his data and on the assumption that his fellow member has taken up a position to make his own pivotal. Thus, no one wants to change after knowing the other side's position.[18]

## VI. Conclusion

Committee members' incentives to manipulate private information to tilt decisions toward their personally preferred outcome imply that information cannot be efficiently aggregated by committees. Perhaps this is the basis for the old joke: "Q. How do committees make decisions? A. Badly." Nonetheless, committees are used to make many business and other decisions. We have illuminated some of the reasons for their continued use and survival. True, self interest and strategic considerations make information pooling in committees imperfect, but that is relative to some unattainable ideal. Garbled information still leads to better decisions for all members than if one of them acted as "dictator" and made the decision without benefit of other, albeit strategically manipulated, information.

The reason is that viable committees must share some common goals, even though individual committee members might weigh outcomes somewhat differently. All members certainly want to gain the statistical advantages of information sharing. What makes the process work is that the committee rules and procedures are themselves chosen to temper and control strategic misrepresentations and filter the data, given self-interested behavior. Procedures are adopted that coarsen the content of information and put a natural limit on feasible manipulations. They control conflict in an acceptable way. The smaller the differences of a priori opinion among committee members, the less coarsening the rules can be while keeping conflict in control. The quality of committee decisions improves with the degree of consensus.

The two-category voting procedures studied in detail here are a very clear analytical representation of these ideas. In the statistical decision problem from which it is constructed, all sample information is perfectly aggregated into a "score." Minimizing the loss function sets a critical score. If the sample score exceeds the threshold, the committee makes one decision, and if it falls short of the threshold another decision is chosen. But this perfect aggregation scheme does not work when there is conflict in the committee. Voting in a committee is a cruder kind of scoring system, but a scoring system nonetheless. The committee decision depends on the proportion of members whose sample information places it above or below their own strategically determined personal thresholds. Personal thresholds are chosen to "undo" the presumed biases of other committee members, but not by enough to completely nullify the information of others. For instance, members defer to those who have more informed sample information—committee members who have greater expertise and whose data have a higher quality. The better informed members are decisive more often.

The framework of this paper can be used to understand a host of issues related to committee decision-making. We give three examples here, management of expert teams, side payments, and arbitration. (i) In some environments, an uninformed decision maker may seek opinion from experts who are privately informed about the decision but have different interests. A team of experts is a committee with conflicts and common interests in influencing the decision maker. One can show that when the decision maker finds it necessary to bring in a second expert, he will not choose someone with the same preference as himself, because doing so forces the incumbent expert to be more strategic and lowers the quality of his information. Instead, a second expert with a preference closer to that the first serves the decision maker better.[19] (ii) Monetary side payments can be used to improve quality of committee decisions. For example, suppose that in a two-category voting procedure each member must pay a fine to the other one if he chooses the position he favors a priori. When such *ex post* transfers are properly chosen, the members can be induced to vote cooperatively to minimize the sum of expected errors. With appropriate *ex ante* side transfers, each member is better off than under strategic voting without side transfers. (iii) Suppose that in a two-category voting procedure when votes differ the case goes to an arbitrator whose decision is stochastic. Under the unilateral procedures, when votes differ the decision is deterministic and may favor one side over the other. In contrast, the presence of an exogenous stochastic decision by an arbitrator can reduce manipulation of information and improve the quality of committee decision.

While there are few general analytical results on how voting plurality— simple majority, super-majority, or unanimity—affects the quality of committee decisions, the analysis illuminates some of the economic considerations involved in these debates. It is interesting that though requiring unanimity for acceptance makes each member decisive for acceptance, self-interest makes them less cautious in voting for acceptance because others may have information against acceptance. Similarly, requiring unanimity for rejection makes voters more cautious in voting for acceptance. These are precisely the reasons why Condorcet's Theorem fails when strategic considerations play a role in voting (Austin-Smith and Banks, 1996; Feddersen and Pesendorfer, 1998). Our model needs to be enriched before it can be used to understand the issue of optimal plurality. Committee rules are chosen to achieve a certain kind of durability to a broad variety of issues that come before it. The nature of preferences, voting rules, incentives to collect information (Li, forthcoming), the presentation of arguments and rhetoric in committee deliberations (Richard Posner, 1998; Dewatripont and Tirole, 1999), and intertemporal vote trading for ongoing committees are all likely to be important for understanding the choice of committee rules.

In conclusion, voting is often said to be an inferior decision mechanism because it does not allow the intensity of one's preferences to be expressed in the final tally. But in group decisions where social gains arise from the pooling of information, the intensity of differences in preferences and opinion leads to discordance among group members that causes trouble. Voting procedures bound the expression of intensity and discordance among group members and lead to better informed group decisions. Perhaps this is the main lesson in this paper.

# APPENDIX

PROOF OF PROPOSITION 1:

Fix any deterministic and monotone equilibrium outcome. By the revelation principle, it can be replicated by a truth-telling equilibrium of a direct mechanism. Since it is deterministic and monotone, this outcome can be represented by a downward sloping boundary that divides the acceptance region and the rejection region in the data space. For a given equilibrium outcome, let the boundary be represented by a function $T$ of $y^a$. (For each vertical segment of $T$ that corresponds to some point $y^a$, we choose $T(y^a)$ to be the highest point of the segment; this arbitrary choice does not affect the proof.) We claim that if $T$ is differentiable at some $y^a$, then $T'(y^a) = 0$. The proposition then follows from the observation that a monotone function $T$ is almost everywhere differentiable. To prove the claim, we assume by way of contradiction that there exists $y^a$ such that $T'(y^a) \neq 0$. Conditional on $y^a$, to member $A$ the probability that the null hypothesis is true is $\eta\gamma^a f_q^a(y^a)$, and the probability that it is false is $\eta(1-\gamma^a)f_u^a(y^a)$, where the normalizing factor $\eta$ equals the reciprocal of $\gamma^a f_q^a(y^a) + (1-\gamma^a)f_u^a(y^a)$. By choosing an arbitrary report $r^a$, the hypothesis is accepted whenever $B$ submits a report $r^b \geq T(r^a)$. Since $B$ reports truthfully, $A$'s expected cost conditional on $y^a$ and report $r^a$ is $\eta k_1^a f_u^a(y^a)[1 - F_u^b(T(r^a))] + \eta k_2^a f_q^a(y^a) F_q^b(T(r^a))$. Truth-telling by $A$ requires that the derivatives of $A$'s expected cost with respect to $r^a$ be zero at $y^a$. Since $T'(y^a) \neq 0$, we have

$$(A1) \qquad k_1^a f_u^a(y^a) f_u^b(y^b) = k_2^a f_q^a(y^a) f_q^b(y^b),$$

where $y^b = T(y^a)$. Since $T$ is strictly downward sloping at $y^a$, its inverse exists and has nonzero derivatives at $y^b$. Then truth-telling by $B$ implies a similar condition:

$$(A2) \qquad k_1^b f_u^b(y^b) f_u^a(y^a) = k_2^b f_q^b(y^b) f_q^a(y^a).$$

The above two equations contradict the assumption that $k^a \neq k^b$.

PROOF OF PROPOSITION 3:

We consider a Cournot tatonnement process that begins with the two-category equilibrium without abstention and converges towards the three-category equilibrium with abstention. First note that any one-threshold strategy can be viewed as a two-threshold strategy by adding an additional threshold for each member appropriately. If $z_1^a = \underline{y}^a$ and $z_2^a = t_*^a$ are member $A$'s two thresholds, and $z_1^b = t_*^b$ and $z_2^b = \overline{y}^b$ are $B$'s two thresholds, then the voting outcome is the same as the two-category equilibrium defined by (4). In each iteration of the Cournot tatonnement, the new thresholds are chosen as best responses to the previous thresholds. The proof proceeds in two steps. First we show that the two-category equilibrium converges monotonically to the three-category equilibrium in a Cournot tatonnement process. Then we show that expected cost to each member falls in each iteration of the tatonnement.

The equilibrium conditions for the thresholds of member $A$ specified in (12) can be used to define the reaction functions $z_1^a = g_1(z_1^b, z_2^b)$ and $z_2^a = g_2(z_1^b)$. The reaction functions for member $B$ can be specified analogously. Note that all the reaction functions are strictly decreasing in their arguments. If we denote $x = (z_1^a, z_2^a, -z_1^b - z_2^b)$ and let $h : \mathbb{R}^4 \to \mathbb{R}^4$ be the reaction function in the redefined variables, then $h(x)$ is increasing in $x$. The Cournot tatonnement is defined by the process $x(t) = h(x(t-1))$. The initial thresholds are specified at the two-category equilibrium, $x(0) = (\underline{y}^a, t_*^a, -t_*^b, -\overline{y}^b)$. An induction argument establishes that $x(t)$ increases monotonically. Suppose $x(t) \geq x(t-1)$. Because $h(\cdot)$ is monotonic, $x(t+1) = h(x(t)) \geq h(x(t-1)) = x(t)$. Furthermore, using the conditions for the two-category equilibrium and (6), it can be verified that $x(1) = h(x(0)) \geq x(0)$, and the induction argument is complete. A bounded and monotonic sequence converges to a limit point $\hat{x}$. By the continuity of each member's expected cost in the thresholds, this point must also be an equilibrium point, $\hat{x} = h(\hat{x})$. To see this, note that $C^a(x^a(t), x^b(t-1)) \leq C^a(x^a, x^b(t-1))$ for all $x^a$, because $x(t)$ is the best response to $x(t-1)$. Since $C^a$ is continuous in $x(t)$ and $x(t) \to \hat{x}$, we have $C^a(\hat{x}^a, \hat{x}^b) \leq C^a(x^a, \hat{x}^b)$ for all $x^a$. A similar condition holds for $B$. Therefore $\hat{x}$ is a three-category equilibrium point.

Because the convergence of the thresholds is monotonic, we have $t_2^a > t_*^a$ and $t_1^b < t_*^b$. A symmetric Cournot tatonnement process, in which $A$'s thresholds begin with $z_1^a = t_*^a$ and $z_2^a = \overline{y}^a$ and monotonically decrease, and $B$'s thresholds begin with $z_1^b = \underline{t}^b$ and

$z_2^b = y_*^b$ for $B$ and monotonically increase, establishes that $t_1^a < t_*^a$ and $t_2^b > t_*^b$. Therefore, $t_1^j < t_*^j < t_2^j$ for each $j = a, b$.

For the second step of the proof, we assume that $k^a < k^b$ and use the Cournot tatonnement process with $A$'s thresholds increasing and $B$'s decreasing. (When $k^a > k^b$, we use the symmetric process.) Let the expected cost to juror $j$ be

$(A3)$

$$\begin{aligned} C(z^a, z^b, k^j) =& k^j\{[1 - F_u^a(z_2^a)] + [F_u^a(z_2^a) - F_u^a(z_1^a)][1 - F_u^b(z_1^b)] + F_u^a(z_1^a)[1 - F_u^b(z_1^b)]\} \\ &+ \{[F_q^a(z_2^a) - F_q^a(z_1^a)]F_q^b(z_1^b) + F_q^a(z_1^a)F_q^b(z_2^b)\}. \end{aligned}$$

The change in cost to juror $A$ between two successive iterations is

$$\begin{aligned} & C(z^a(t+1), z^b(t+1), k^a) - C(z^a(t), z^b(t), k^a) \\ (A4) \qquad =& [C(z^a(t+1), z^b(t+1), k^a) - C(z^a(t), z^b(t+1), k^a)] \\ &+ [C(z^a(t), z^b(t+1), k^a) - C(z^a(t), z^b(t), k^a)]. \end{aligned}$$

We claim that (i) $\partial C(z^a, z^b(t+1), k^a)/\partial z^a < 0$ for $z^a(t) \le z^a \le z^a(t+1)$; and (ii) $\partial C(z^a(t), z^b, k^a)/\partial z^b > 0$ for $z^b(t+1) \le z^b \le z^b(t)$. Hence both terms in brackets are negative.

To establish claim (i), note that the derivative $\partial C(z^a, z^b(t+1), k^a)/\partial z_1^a$ has the same sign as $l^a(z_1^a)\mathcal{L}^b(z_2^b(t+1), z_1^b(t+1)) - k^a$. Since $z_1^a < z_1^a(t+2)$ for $z_1^a \in [z_1^a(t), z_1^a(t+1)]$, we have $l_1^a(z_1^a) < l_1^a(z_1^a(t+2))$. Then it follows from the definition of $z_1^a(t+2)$ that $\partial C(z^a, z^b(t+1), k^a)/\partial z_1^a < 0$. Similarly, the derivative $\partial C(z^a, z^b(t+1), k^a)/\partial z_2^a$ has the same sign as $l^a(z_2^a)L_*^b(z_1^b(t+1)) - k^a$. Since $z_2^a(t+2) > z_2^a$, we have $\partial C(z^a, z^b(t+1), k^a)/\partial z_2^a < 0$. This establishes (i).

To establish claim (ii), note that the derivative $\partial C(z^a(t), z^b, k^a)/\partial z_1^b$ has the same sign as $l^b(z_1^b)\mathcal{L}^a(z_2^a(t), z_1^a(t)) - k^a$. Since $k^a < k^b$ and $z_1^b \ge z_1^b(t+1)$ for $z_1^b \in [z_1^b(t+1), z_1^b(t)]$, we have $\partial C(z^a(t), z^b, k^a)/\partial z_1^b > 0$. Similarly, the derivatives $\partial C(z^a(t), z^b, k^a)/\partial z_2^b$ have the same sign as $l^b(z_2^b)L_*^a(z_1^a(t)) - k^a$. Since $z_2^b \ge z_2^b(t+1)$, $\partial C(z^a(t), z^b, k^a)/\partial z_2^b > 0$. This establishes (ii).

For juror $B$, we follow a different decomposition to get

$$\begin{aligned} & C(z^a(t+1), z^b(t+1), k^b) - C(z^a(t), z^b(t), k^b) \\ (A5) \qquad =& [C(z^a(t+1), z^b(t+1), k^b) - C(z^a(t+1), z^b(t), k^b)] \\ &+ [C(z^a(t+1), z^b(t), k^b) - C(z^a(t), z^b(t), k^b)] \end{aligned}$$

We can follow similar steps as above to show (i) $\partial C(z^a(t+1), z^b, k^b)/\partial z^b > 0$ for $z^b(t+1) \leq z^b \leq z^b(t)$; and (ii) $\partial C(z^a, z^b(t), k^b)/\partial z^a < 0$ for $z^a(t+1) \geq z^a \geq z^a(t)$. Then (i) and (ii) imply juror $B$'s expected cost also falls with each iteration.

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1. See also Jerry Green and Nancy Stokey (1980). Bengt Holmstrom (1983) studies how a principal can delegate to an agent. The problem of eliciting private information from experts appears in a number of economic and political models: allocating burden of proof among experts (Paul Milgrom and John Roberts, 1986; Hyun Song Shin, 1994; John Morgan and Vijay Krishna, forthcoming), agenda-setting in legislatures (Thomas Gilligan and Keith Krehbiel, 1989; David Austen-Smith, 1990), and providing incentives for investment in expertise (Canice Prendergast, 1993; Pilippe Aghion and Jean Tirole, 1997; Mathias Dewatripont and Tirole, 1999).

2. Exceptions are, in the context of large elections, Austen-Smith and Jeffrey Banks (1996), and Timothy Feddersen and Wolfgang Pesendorfer (1996; 1997).

3. See, for example, Morris DeGroot (1970). This optimal decision rule derived below is a special case of the Neyman-Pearson lemma.

4. Suppose $f_q^j$ and $f_u^j$ ($j = a, b$) differ only by a location parameter. That is, $f_u^j(x) = h(x)$ and $f_q^j(x) = h(x - d)$ where $d > 0$. Then $l^j$ is increasing if $h$ is log-concave. Of course, MLRP is more general than log concavity, as there is no reason to assume that $f_q^j$ and $f_u^j$ differ only by a location parameter.

5. Figure 1 assumes that $Y^a$ and $Y^b$ have the same normal distributions that differ by a locational parameter conditional on the true state. The mean of the observations is a sufficient statistic and the optimal statistical decision rule (2) takes a linear form, "accept if and only if $y^a + y^b \geq \delta$," where $\delta$ is a function of the preference and distribution parameters. Under the assumption of conditional independence, regardless of whether $Y^a$ and $Y^b$ have the same conditional distributions, the optimal rule can be generally expressed in a linear aggregation of the log likelihood ratios. See, for example, Anthony Edwards (1992).

6. There are two types of garbling: introducing noise to data by randomization, and partitioning data into intervals. In any Bayesian reporting game with a deterministic and strictly monotone decision rule, besides the partition equilibria studied in this paper, there are also mixed-strategy equilibria where data are partitioned into intervals but for some or all intervals a report is randomly chosen. In both types of equilibria, each member's equilibrium report is a random variable with discontinuous distributions (conditional on the true state). One can show that there exist no mixed-strategy equilibria where each member's report has continuous conditional distributions. Since the underlying data have continuous conditional distributions, equilibrium reporting strategies must involve partitioning of data.

7. Stochastic outcomes cannot be excluded as candidates for equilibrium outcomes. The reporting game with the rule "accept if $S(r^a, r^b) \geq 0$" has mixed strategy equilibria where data are partitioned and in some regions the null is accepted with probabilities strictly between 0 and 1. One such equilibrium can be alternatively implemented by the following decision mechanism. Each member chooses "accept" or "reject." If they agree, that choice is carried out. If they disagree, a lottery with predetermined odds is used to decide. One can show that this mechanism has a stochastic outcome with threshold strategies. Examples can also be constructed to show that MLRP does not by itself rule out nonmonotone outcomes, but we do not consider them.

8. If only one member is allowed to abstain, then one can generate partition outcomes with three categories for this member and two categories for the other. This corresponds to a voting game where the member allowed to abstain has veto rights to both acceptance and rejection. Note that Proposition 1 implies that in any equilibrium partition outcome, either both members have the same number of thresholds, or one member has exactly one more threshold than the other. Only the simplest partition outcome with unequal numbers of thresholds is considered in the paper (section III), in which one member has one threshold and the other has none. This corresponds to delegation of the committee decision to the first member.

9. The pivotal voting argument remains valid when there is incomplete information about preferences and biases of committee members. Such incomplete information can be mod-

eled as different types of members. Derivation of the equilibria of the voting games is not affected as long as probability distributions of types are common knowledge.

10. John Duggan and Cesar Martinelli (1999) uses a setup similar to ours to extend the results of Feddersen and Pesendorfer on the Condorcet Jury Theorem. They characterize the two-category equilibrium outcomes, assuming common preferences among members.

11. For example, in Figure 1 where $Y^j$ is normally distributed with a shift of the mean conditional on the true state of the null hypothesis, when the precision of $Y^a$ increases, the committee decision function $S$ becomes steeper in the data space, representing the fact that the decision becomes more sensitive to $A$'s data.

12. The precise argument that $B$ prefers committee decision-making to delegating to $A$ when $k^b > k^a$ follows the proof of Proposition 5.1. For $B$, letting $A$ decide is equivalent to the committee decision with thresholds set at $\hat{t}^a$ and $\bar{y}^b$. Start the iteration at $z_0^a = \hat{t}^a$, and $z_0^b = \bar{y}^b$. Define a Cournot tatonnement process with increasing threshold for $A$ and decreasing threshold for $B$. Then $B$'s expected cost falls in each step of the iteration, until the thresholds reach $t_*^a$ and $t_*^b$.

13. Our comparison of voting procedures complements the works of Raaj Sah and Joseph Stiglitz (1986; 1988), who consider committees without the strategic manipulations that arise from conflicting interests.

14. If we think of abstention as skipping the decision-making meeting in an endogenous participation model, then only members with extreme preferences based on their information participate. Matthew Turner, Martin Osborne, and Jeffrey Rothenthal (2000) obtain a related result in a model of preference aggregation where agents incur a fixed cost to influence the collective decision.

15. The derivative of this ratio with respect to $u$ has the same sign as $f_q^j(u)[F_u^j(u)-F_u^j(v)]-f_u^j(u)[F_q^j(u)-F_q^j(v)]$. By MLRP, $f_q^j(u)f_u^j(y) > f_u^j(u)f_q^j(y)$ for all $y < u$. Integrating over $y$ from $v$ to $u$ gives $f_q^j(u)[F_u^j(u)-F_u^j(v)] > f_u^j(u)[F_q^j(u)-F_q^j(v)]$. Monotonicity in $v$ can be proved in a similar manner.

16. Members can have countably infinite number of equilibrium thresholds over the entire support of the data, either when the supports are unbounded (as in normal distributions), or when the supports are finite but the likelihood ratios are unbounded (as in the beta distributions).

17. In a different setup, Dekel and Piccione (2000) show that sequential and simultaneous voting procedures have the same equilibrium outcomes. In our model the equivalence between sequential and simultaneous voting requires that the first mover be unable to commit to a threshold rule. Inability to commit follows because a strategy in a voting or scoring game is not observable even when positions are sequentially submitted.

18. Green and Jean-Jacques Laffont (1987) propose the concept of "posterior implementation" to capture the idea of robustness of group decisions under private information: a decision is posterior implementable if it is an equilibrium outcome of a Bayesian incentive compatible mechanism, with the additional property that the information conveyed in the implementation does not invalidate the optimality of the equilibrium strategy of any player. In a model similar to ours, with two group members and a binary group decision between the status quo and an alternative, they show that any posterior implementable group decision can have only two values in terms of the probability of adopting the alternative. In any partition outcome, the committee decision has two values—the probability of accepting the null hypothesis is either zero or one. One can easily verify that all equilibrium partition outcomes considered in this paper are posterior implementable in the sense of Green and Laffont.

19. These and other issues of choosing experts and delegating decisions are discussed in Hao Li and Wing Suen (2001).

Figure 1. Optimal decision rules and information manipulation.

Figure 2. A partition outcome.

Figure 3. Reaction functions in the voting game with unilateral acceptance.

Figure 4. Welfare comparison: do-it-alone versus committee.

Figure 5. Comparison of unilateral acceptance and unilateral rejection procedures.

Figure 6. Conflicts and personal preference over voting procedures.