Costly Participation and Heterogeneous Preferences in Informational Committees [1]

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Abstract

This paper develops a simple model of committee size based on costly participation and the informational role of committees in collective decision-making. Committee members exert non-verifiable efforts in gathering information and report their findings to a principal, who then chooses policy. They may have policy preferences that differ from the principal's, hence may try to distort their reports. In a setting in which the information structure and policy preferences are both represented by normal random variables, we characterize the most efficient equilibrium under the mean decision rule. We also show that, under certain conditions, it remains an equilibrium when the principal cannot commit to a fixed decision rule. In this equilibrium all information except policy preferences can be truthfully transmitted and incorporated in policy decisions. The optimal committee size and total social surplus can sometimes increase in the heterogeneity of policy preferences, as heterogeneous preferences provide committee members incentives to gather information.

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"As agenda setters, sources of expertise, and policy developers, committees are the lifeblood of the congressional system."

—-Joint Committee on the Organization of Congress, December 1993.

1 Introduction

When participation is costly and individuals cannot be compensated for their participation costs, it is well known that collective decisions suffer from free rider problems. As Campbell (1999) and Osborne, Rosenthal and Turner (2000) show in different settings with costly participation and heterogeneous agents, agents with smaller participation costs or more extreme preferences are more likely to participate in collective decisions. Consequently, collective decisions will tend to be decided by such "active" and "extreme" agents and vacillate between extreme policies, instead of by the median voter's preference. Thus, the combination of costly participation and heterogeneous preferences prevents collective decisions from efficiently aggregating society preferences. When information regarding a society's best course of action is dispersed among individual members, collective decisions have another important function besides preference aggregation: that of information aggregation. Since individual members may have to exert efforts to gather relevant information and such efforts are often hard to verify, costly participation can be more prevalent than in the case of preference aggregating collective decisions. When members have heterogeneous preferences, information aggregation becomes more difficult because members may distort the information they have to try to manipulate the collective decisions in their favor. In such cases, determining how to provide incentives for both participation and information revelation becomes all the more important for society.

In this paper we study the incentives for participation and information revelation in informational committees. Informational committees are committees designated to gather information and help formulate policy recommendations, and include examples such as expert panels, Congressional committees, recruiting committees, sports judging, etc. Informational committees are important in complex collective decisions, because each individual has a limited capacity to gather information. By having multiple committee members gather information, society can help ensure informed collective decisions are made than relying on one person's information.[3] The question we are interested in this paper is how society should design such committees when participation is costly and committee members have heterogeneous preferences? In particular, what determines the optimal committee size? Asides from theoretical interests, this question is practically relevant. For example, the U.S. Congress formed the Joint Committee on the Organization of Congress to examine specifically the effectiveness of its committee system and make suggestions for possible improvements. In its "Final Report" of 1993, the Joint Committee cited committee size (whether it is too big or too small, what should be the optimal size, etc) as the most prominent issue.[4]

We develop a simple model of informational committee in which information gathering is costly and committee members have heterogeneous preferences. In a specific setting in which the information structure and policy preferences are both represented by normal random variables, we characterize the most efficient equilibrium under the mean decision. We also show that, under certain conditions, it remains an equilibrium when the principal cannot commit to a fixed decision rule. In this equilibrium, all information except policy preferences can be truthfully transmitted and incorporated in policy decisions. Preference heterogeneity of members introduces noise into their reports and hence reduces the quality of collective decisions. However, the optimal committee size and total social surplus can sometimes increase rather than decrease in the heterogeneity of committee policy preferences. This can happen when information gathering is quite costly to committee members. In such cases, heterogeneous preferences provide committee members incentives to gather information to offset free rider problems, because only by participating can

[3]As an early statement of this point, the well-known Condorcet Jury Theorem says that compared with an individual decision maker, collective decisions will be more informative when a larger number of people vote between two alternatives under majority rule.

[4]It reported taht "House Rules currently provide for the 22 standing committees and 1 permanent select committee of the House,", with committee size ranging from 12 to 63; while for the Senate "Chamber rules and standing orders provide for the 17 standing and 3 select/special committees", with committee size ranging from 6 to 29.

they influence the collective decisions so that their own interests can be better protected. The incentive effect of preference heterogeneity is reminiscent of that in Campbell (1999) and Osborne *et al* (2000), but the implications are quite different. Besides the implications on welfare and optimal committee size, in contrast to Campbell (1999) and Osborne *et al* (2000), in our model oversized committees (over-participation) can arise in a voluntary participation game if committee membership is not regulated and the participation incentives derived from influencing collective decisions are sufficiently strong.

More specifically, in our model a society makes a policy decision that is represented as a point on the real line. The outcome of a policy decision depends on the state of the world, which also lies on the real line but is unknown to the society. Hence, to make informative decisions, there is a need to learn about the state of the world. The society selects N members to form a committee. Committee members exert non-verifiable efforts (e.g., doing research, consulting specialists, reading files, watching performance and making judgments, etc.) to gather relevant information about the decision problem facing the society. Findings are reported to a decision maker (the principal), who aggregates them and makes a policy decision. Committee members are ex ante identical and unbiased before joining the committee. But once the specific decision problem is identified and the process of information gathering begins, each member learns his own policy preference, which can be biased. For example, an ex ante unbiased juror might develop personal feelings (e.g., sympathy or disliking) about one or both sides of the trial as he learns more about the two sides. Committee members with policy biases may want to distort their information in order to manipulate the principal's decision to their favor.

Supposing that the principal commits to a policy rule equal to the mean report, we characterize a very simple reporting equilibrium in which committee members convey all their information (except their policy preferences) to the principal. In this equilibrium, committee members with no policy biases report truthfully, and those with policy biases exaggerate exactly the amount they want to. We show that this intuitive equilibrium is the most efficient among all equilibria and the most preferred by all committee members. When the principal cannot commit to a policy rule, we show that the intuitive equilibrium remains an equilibrium under non-informative prior. In particular, the principal's best response is to take committee members' reports at face value and choose the mean report as the policy decision. Given this equilibrium, we study the committee members' incentives to gather information and then derive the optimal committee size.

We find that the optimal committee size is always smaller than the first best level. This is because noisy reports by committee members with policy biases reduce committee members' marginal information contributions to collective decisions. In equilibrium, collective decisions will be more volatile than the first best, because of noisy reports from biased committee members and because of the smaller number of signals resulting from suboptimally small committees. We derive comparative statics of the optimal committee size and the total social surplus with respect to parameters of the model. Attendance and information gathering costs, quality of prior knowledge about the state of the world, and signal quality are found to affect the optimal committee size and the total social surplus in economically intuitive ways. Most interestingly, the optimal committee size can decrease or increase in the heterogeneity of committee members' policy preferences. Total social surplus can sometimes increase in the heterogeneity of committee members' policy preferences. This can happen when moral hazard problems in information gathering severely limit the feasible committee size. Because committee members with policy biases can manipulate the policy in their ideal way, the heterogeneity of their policy preferences actually provides additional incentives to gather information, thus mitigating moral hazard problems in information gathering. Of course, the heterogeneity of policy preferences has a direct negative effect on the total social surplus because it increases the noisiness of collective decisions. When the positive participation effect dominates the negative noisiness effect, the heterogeneity of policy preferences can increase the total social surplus.

The rest of the paper is organized as follows. The next section presents the model; Section 3 then solves for the first best solution. In Section 4 we characterize the intuitive equilibrium under the mean decision rule and derive its efficiency properties. We also explore conditions under which the equilibrium still holds up when the principal cannot commit to a policy rule. Section 5 studies the committee members' incentives to gather information and derives the optimal committee size.

Based on the comparative statics, we then discuss the implications of our model. In Section 6, we discuss the related literature. Section 7 concludes.

2 The Model

A society consisting of a large number of members must make a policy decision. The policy objective is to choose a policy x on the real line, i.e., $x \in R$. There is uncertainty about policy outcome. To capture this uncertainty, suppose the outcome of a policy x is given by $y = x - \theta$, where the state of the world $\theta \in R$ is unknown to the society at the time the policy is chosen. The society has a common prior about θ given by distribution $G(.)$. A principal who represents the societal preference (a hypothetical social planner or a real decision maker) is charged to make policy decisions for the society. As a normalization, we suppose that the societal preference is such that the ideal policy outcome is zero (So if θ were known, the principal would simply choose the policy $x = \theta$). For a policy outcome y, we suppose that the principal's payoff is $V(|y|)$, where V is strictly decreasing and concave in $|y|$. The idea is that the further away the actual policy outcome y is from the societal ideal point zero, the worse off the principal (or the society as a whole) becomes. To keep things simple, we assume that $V(|y|) = -y^2 = -(x-\theta)^2$.

To make informative policy decisions, the principal selects N members to form a committee. All members are identical ex ante. There is a fixed *attendance cost* of c per person to be a committee member (e.g., from attending meetings or hearings), for which the principal must compensate each committee member. This is the only form of monetary transfer to committee members in the model. Committee members' actions other than attendance (information gathering and reporting) are not verifiable and hence cannot be a basis for monetary transfers.

After the committee is formed, individual committee members decide simultaneously and non-cooperatively whether to gather information (This will be called the "information gathering stage"). A committee member i can get at most one signal of θ, $\theta_i = \theta + \epsilon_i$, where ϵ_i is assumed to be independently drawn from an identical distribution function $F(.)$ with mean zero and variance σ_ϵ^2. In the process of gathering information, a committee member also discovers his own policy preference, which is represented by an ideal policy outcome t_i. Ex ante t_i are independent and have the same distribution $T(.)$ with mean zero. All $\{\epsilon_i\}$ and $\{t_i\}$ are independent. We assume that member i's utility function is $u_i(t_i, \theta) = -(y - t_i)^2 = -(x - \theta - t_i)^2$. Hence, the most preferred policy for a committee member with policy preference t_i is $\theta + t_i$.

In some real life cases when committee members' preference biases are caused by tastes over "superficial" characteristics of the decision problem (e.g., gender and ethnicity of job candidates, ideological positions), it is more natural to assume that they learn their preferences before information gathering. However, in such cases, one expects that the society will try to do its best to reduce such superficial preference biases in selecting committee members (e.g., juror selection). In other cases, committee members' preference biases are caused by more "subtle" reasons. For example, a recruiting committee member may take a particular liking or disliking to a job candidate's writing style while reading his or her research papers (or, of his or her political inclinations during a recruiting dinner); a member on an expert panel (who is not considered an environmentalist) may feel strongly about the potential effects of the project he is asked to evaluate on a particular environmental issue (e.g., a particular endangered bird). In such cases committee members only discover their preferences during the information gathering process. Since we assume that committee members discover their preferences during the information gathering process but not before, our model fits the latter cases better than the former. This assumption is made mainly to simplify the analysis of the model. The main insights of the model should still be valid, however, if the assumption is relaxed.

Information gathering is costly (e.g., reading files, doing research): member i has to pay an *information cost* of k if he decides to gather information. We assume that information gathering is nonverifiable by the court, so the principal cannot induce information gathering by making contingent promises to compensate committee members for information costs. For simplicity, we also assume that information gathering is observable: at the end of the information gathering stage, it becomes common knowledge who has gathered information and who has not.[5] The

[5]It is sufficient to assume that information gathering is observable among the committee members. The principal can easily illicit the truth about information gathering by asking committee members to report whether other

assumption that information gathering is observable but not verifiable is consistent with the assumption that information is soft. Since information is soft, a committee member who shirks in gathering information can always make up a random report to avoid financial punishments, introducing more noise into the collective decisions and making everybody worse off. As a result, soft information makes financial punishment for shirking both infeasible and undesirable.

Both t_i and θ_i are member i's private information. Once committee members have gathered information, they report their findings simultaneously and non-cooperatively (This will be called the "information aggregation stage"). We suppose that information is soft so that each informed member can report anything in the support of θ_i, i.e., the real line. Denote a report profile by $\hat{\theta}^N = \{\hat{\theta}_i\}_{i=1}^N$ where $\hat{\theta}_i$ is the report of committee member i. Note that it is without loss of generality to restrict a report to be a single number: if asked to report t_i, a committee member i can always say $t_i = 0$.

There are two kinds of collective decision-making environments in the application of the model. In some cases, the society specifies a pre-set decision rule based upon the reports of the committees (e.g., sports judge panels), usually constituting some sort of averaging over reports by individual members. In many other cases, the society does not pre-commit to a decision rule; rather, there is a real decision-maker who acts on the reports of the committees. Examples of the latter include the president and his security council, congress/government agencies and scientific advisory committees or expert panels, a dean and department recruiting committees, or fund-managers/investors and a group of analysts. We will consider both kinds of collective decision-making environments.

Any equilibrium in which all committee members collect information must satisfy the following two conditions.[6]

(i) **Incentive Compatible Signal Reporting:** Suppose the decision rule is $x(\hat{\theta}^N)$. In the information aggregation stage, given his private signal and the set of members who

members have gathered information.

[6]If some committee members will not collect information in equilibrium, they will not be chosen in the optimal committee design.

collected information and their reporting strategies, each informed member chooses a report to maximize his expected utility. Formally, consider any member $i \in N$ with a signal θ_i and a policy preference t_i. We denote his reporting strategy by $\hat{\theta}_i = s_i(\theta_i, t_i)$, and other members' reporting strategies by $\hat{\theta}^{-i} = s_{-i}(\theta_{-i}, t_{-i}) = \{s_j(\theta_j, t_j)\}_{j \neq i}$, where $\theta_{-i} = \{\theta_j\}_{j \neq i}$ and $t_{-i} = \{t_j\}_{j \neq i}$. Given other members' reporting strategy, member i's expected utility is

$$u_i(\theta_i, t_i)(s_i, s_{-i}) = -E_{\{\theta, \theta_{-i}, t_{-i}\}}[(x(\hat{\theta}^N) - \theta - t_i)^2 | t_i, \theta_i] = -E_{\{\theta, \theta_{-i}, t_{-i}\}}[(x(\hat{\theta}^N) - \theta - t_i)^2 | \theta_i]$$

Since t_i is independent of t_{-i} and θ_{-i}, the expectation term above does not depend on t_i. The incentive compatibility condition for the information aggregation stage requires that for every (θ_i, t_i), given $s^*_{-i}(\theta_{-i}, t_{-i})$,

$$-E_{\{\theta, \theta_{-i}, t_{-i}\}}[(x(s^*_i, s^*_{-i}) - \theta - t_i)^2 | \theta_i] \geq -E_{\{\theta, \theta_{-i}, t_{-i}\}}[(x(s_i, s^*_{-i}) - \theta - t_i)^2 | \theta_i] \qquad (1)$$

Let $s^* = (s^*_i, s^*_{-i})$ be an equilibrium in the signal reporting game. We denote $u_i(\theta_i, t_i)(s^*)$ as member i's expected equilibrium utility when his signal is θ_i and his policy preference is t_i.

(ii) **Incentive Compatible Information Production:** In the information production stage, given that other members will gather information, each committee member must be willing to gather information as well. Formally, suppose (i) members $N \backslash i$ will collect information; (ii) if member i also collects information, the subsequent reporting game with all informed N members is played according to an equilibrium $s^* = (s^*_i, s^*_{-i})$; (iii) if member i does not collect information, the subsequent reporting game with $N \backslash i$ informed members is played according to an equilibrium $\tilde{s}^*_{-i}$ under a decision rule $x(\hat{\theta}_{-i})$. The incentive compatibility condition for the information production stage requires that for each member i, there exists an equilibrium s^* for the N member game and an equilibrium $\tilde{s}^*_{-i}$ for the $N \backslash i$ member game such that

$$E_{\{\theta_i, t_i\}}[u_i(\theta_i, t_i)(s^*)] - k \geq E_{\{t_i\}}[u_i(t_i, x(\tilde{s}^*_{-i}))] \qquad (2)$$

where $u_i(t_i, \tilde{s}^*_{-i})$ is i's expected utility with policy preference t_i in the equilibrium $\tilde{s}^*_{-i}$.

The above standard incentive compatibility (IC) condition for information gathering is rather weak in our context. The reason is that $\tilde{s}^*_{-i}$ can be chosen in such a way that the punishment for shirking in gathering information is quite severe. Specifically, let $\tilde{s}^*_{-i}$ be the "babbling" equilibrium in the cheap talk game between the principal and the $N-1$ informed committee members in which every informed member sends a message uncorrelated with his signal and the principal ignores all the messages. In this equilibrium, all the information ($N-1$ signals) is wasted and the principal chooses an uninformed policy $x=0$. Obviously, this outcome will be rather bad for all players including the shirking member i, so he will refrain from shirking (as long as k is not too large). As is well understood, this type of punishment scheme is subject to renegotiation and is hardly credible. To strengthen the IC condition, we rule out such harsh and noncredible punishments for shirking in information production by requiring that when one member shirks on information gathering, the other players ignore him and play according to the original equilibrium adjusted for a smaller committee size. Specifically, if only member i deviates in the information production stage, the equilibrium $\tilde{s}^*_{-i}$ of the subsequent game with the $N \backslash i$ informed members must be consistent with the original equilibrium play adjusted for a committee of $N-1$ members. For example, if in the original equilibrium member j with information θ_j and bias t_j should report $s^*_j(\theta_j, t_j) = \theta_j + Nt_j$, then he must report $\theta_j + (N-1)t_j$ in the event member i shirked in information production.

The societal preference (hence the principal's payoff) is the expected information efficiency of committee decisions EV, minus the total attendance costs Nc (The analysis below will not be affected much if we include information costs Nk). Formally, the principal's payoff is

$$EV(x(\hat{\theta}^N) - \theta) - Nc = -E[x(\hat{\theta}^N) - \theta)]^2 - Nc \tag{3}$$

In the commitment case when the society commits to a fixed decision rule $x(\hat{\theta}^N)$, the committee members' IC conditions discussed above define an equilibrium under $x(\hat{\theta}^N)$. Anticipating such an equilibrium, the principal will choose an optimal N to maximize Equation 3 at the beginning of the game. In the non-commitment case when the principal acts on the committee's information, her optimal policy will depend on her updated belief about θ following the information production and reporting stages. Formally, let H be a history before the principal makes the policy decision, that is, who gathered information and what their reports are. Given H, let $\tilde{\theta}$ be the principal's Bayesian updated belief of θ, and $\tilde{\mu}$ and $\tilde{\sigma}^2$ be $\tilde{\theta}$'s expectation and variance. Then, the principal chooses a policy x to

$$\max_{x} \quad E_{\theta}[V|H] - Nc = -E_{\theta}[(x-\theta)^2|H] - Nc = -(x-\tilde{\mu})^2 - \tilde{\sigma}^2 - Nc$$

Clearly, given the principal's posterior belief $\tilde{\theta}$, she will simply choose $x^* = \tilde{\mu}$. This and the committee members' IC conditions constitute a Perfect Bayesian Nash Equilibrium (PBNE) of the game with a committee size N. Anticipating this equilibrium at the beginning of the game, the principal will choose an optimal N to maximize Equation 3.

3 The First Best Solution

We derive the first best solution as a benchmark. In the first best solution, there are no incentive problems in the information production and aggregation stages, hence the principal only needs to determine how many signals to get and what decision rule to use.

Given a signal profile θ^N, let $\bar{\theta}$ be the posterior belief of θ, and $\bar{\mu}$ and $\bar{\sigma}_N^2$ be $\bar{\theta}$'s expectation and variance. The subscript N of the posterior variance indicates that the posterior variance depends on the number of signals N. With the signal profile θ^N, $E[V(x-\theta)|\theta^N]$ equals $-(x-\bar{\mu})^2 - E[(\bar{\mu}-\theta)^2|\theta^N] = -(x-\bar{\mu})^2 - \bar{\sigma}_N^2$. Clearly the principal's optimal policy is $x^* = \bar{\mu}$. Under this policy, her expected utility is simply the posterior variance, which is independent of the specific signal profile. Hence, for any N, the expected total social surplus is

$$TS = EV(x^* - \theta) - Nc = -\bar{\sigma}_N^2 - Nc \tag{4}$$

Since $\bar{\sigma}_N^2$ is decreasing in N, there exists an N^* maximizing Equation 4 that satisfies

$$\bar{\sigma}^2_{N-1} - \bar{\sigma}^2_N \geq c \geq \bar{\sigma}^2_N - \bar{\sigma}^2_{N+1} \tag{5}$$

Thus we have the following proposition.

Proposition 1 *In the first best solution, the committee size (i.e. number of signals to be collected) is N^*, the integer that maximizes Equation 4. The optimal policy for any given signal profile θ^{N^*} is $x^* = \bar{\mu}$, the posterior mean of θ given θ^{N^*}.*

Proposition 1 is easy to understand. Given any signal profile, the principal maximizes her expected utility by choosing the policy equal to her best estimate of θ, which is the posterior mean. Consequently, her expected utility simply becomes the negative of the posterior variance. Then the optimal number of signals (hence optimal committee size) trades off the value of information (in terms of reduction in posterior variance) with attendance costs.

When information gathering efforts cannot be monitored and information is private and soft, the first best solution is generally not attainable. The next proposition shows two special cases when the first best solution is attainable.

Proposition 2 *When $c \geq k$, the first best solution is attainable if either:*

(i) Information is hard, $\hat{\theta}_i = \theta_i$: informed members must report their signals truthfully; or

(ii) committee members have no policy biases: for every i, $t_i = 0$ with probability one.

Proof: See the Appendix.

Proposition 2 (i) shows that even though individual members incur information costs and efforts cannot be monitored, the first best solution can be achieved if information is hard and information cost is not greater than attendance cost. The reason is as follows. Each committee member's expected utility as a function of the number of signals can be expressed as some constant (reflecting his policy preference) plus the information value of the signals (in terms of the reduction of the posterior variance), provided the policy is always the posterior mean for any signal profile. Consequently, the marginal value of one additional signal to a committee member is the same as that to the principal. So when the committee size is set at the first best level N^* and the information cost is no greater than the attendance cost, each member has the right incentives to collect information if other members collect information. Of course, if $c < k$, then it is not an equilibrium anymore that all members in an N^* member committee gather information, and hence the first best is not achievable.

While Proposition 2 indicates that incentives for information production alone do not necessarily pose problems for efficient collective decisions in our model, incentives to report information truthfully can be troublesome in general. When individual members have different policy preferences, they are motivated to distort their information in order to bias the policy in their favor. The special case of Part (ii) of Proposition 2 indicates that if there are no heterogeneous preferences among committee members incentives to distort information do not arise. In contrast, the recent literature on the Condorcet Jury Theorem, e.g., Austen-Smith and Banks (1996), Feddersen and Pesendorfer (1997, 1998), and Persico (2000), shows that even with homogenous policy preferences information may not be fully revealed under unanimity voting.[7] The reason is that unanimity is not the socially optimal decision rule and hence is not implementable with homogenous jurors.[8] In contrast, Proposition 2 says that in our context the first best decision rule is implementable when committee members have homogenous policy preferences (despite moral hazard problems in information gathering).

For the rest of the paper we focus on the normal distribution case where the prior belief about θ, signal noises ϵ_i, and policy biases t_i are all normally distributed. One reason is for tractability. As will be clear below, the normal distribution case has a very simple and clean solution, which provides clear insights into the problem we are interested in. Moreover, because of the central

[7] The "swing voter's curse" phenomenon, termed by Feddersen and Pesendorfer, arises under unanimous voting because one member's vote is decisive precisely when all other members have different signals. Feddersen and Pesendorfer (1997) show that information aggregation is asymptotically efficient when the group grows unboundedly in size.

[8] However, the optimal decision rule can be implemented with unanimous voting preceded by a communication stage (Coughlan, 2000). This is not true when players have different policy preferences (Doraszelski, Gerardi and Squintani, 1999).

limit theorem, the normal distribution case can be used as a natural first approximation in applications. For example, when considering stock analysts reporting their estimations of the valuation of a company, the normal distribution may be an appropriate assumption. Following Crawford and Sobel (1982), the existing literature on strategic information transmission has largely focused on a leading example in which the principal believes that the state of the world is uniformly distributed and her expert agent observes it perfectly. For our purpose, we cannot adopt such an information structure because if the state of the world is perfectly observable the question about committee becomes trivial.[9]

Specifically, we suppose that the prior distribution of the true state $G(\theta)$ is normal with mean μ and variance σ_θ^2. Denote $\tau_\theta = 1/\sigma_\theta^2$ as the precision of $G(\theta)$. Suppose $\theta_i = \theta + \epsilon_i$, where ϵ_i is drawn independently from a normal distribution with mean zero and variance σ_ϵ^2. Denote $\tau_\epsilon = 1/\sigma_\epsilon^2$ as the precision of $F(\epsilon)$. Then the standard Bayesian updating rule says that the posterior of θ given a signal profile θ^N, $\bar{\theta}$, has a normal distribution with mean $\bar{\mu} = (\tau_\theta\mu + N\tau_\epsilon\zeta)/(\tau_\theta + N\tau_\epsilon)$ and variance $(\tau_\theta + N\tau_\epsilon)^{-1}$, where $\zeta = \sum_{i\in N}\theta_i/N$ is the sample mean. Then Equation 4 becomes

$$EV(x^* - \theta) - Nc = -(\tau_\theta + N\tau_\epsilon)^{-1} - Nc$$

This function is concave in N, and the first order condition gives the optimal number of signals $N^* = (\tau_\epsilon c)^{-0.5} - \tau_\theta/\tau_\epsilon$ ($N^* = 0$ when $c \geq \tau_\epsilon/\tau_\theta^2$). We will ignore the integer problem.

Proposition 3 *In the normal distribution case, the first best committee size is* $N^* = (\tau_\epsilon c)^{-0.5} - \tau_\theta/\tau_\epsilon$*, and the first best decision rule is* $x^* = (\tau_\theta\mu + N^*\tau_\epsilon\zeta)/(\tau_\theta + N^*\tau_\epsilon)$.

The first best solution for the normal distribution case is very intuitive. The first best decision rule is the posterior mean, which is simply a linear combination of the prior mean and the sample

[9]If the state of the world is perfectly observable, the principal can always get the truth with at most three experts through the following scheme. If at least two experts report a same state, then she believes that state is the true state. Easily, it is an equilibrium for all three experts to report the true state, because one expert cannot change the policy given the other two experts report truthfully. This equilibrium does not involve any punishment for lying and hence is renegotiation-proof.

mean with the relative weights depending on the relative precision of the prior and sample signals. The sample mean has a greater weight if the number of signals is larger. Expectedly, the optimal number of signals (hence optimal committee size) N^* decreases in attendance cost. It also decreases in the precision of the prior τ_θ, because the better the prior information is about the state of the world, the less need there is for new signals. Since $\partial N^*/\partial \tau_\epsilon = \tau_\epsilon^{-2}[\tau_\theta - 0.5(\tau_\epsilon/c)^{0.5}]$, N^* is not globly monotonic in the signal precision τ_ϵ. When $\tau_\epsilon \leq 4c\tau_\theta^2$, N^* is increasing in τ_ϵ; when $\tau_\epsilon > 4c\tau_\theta^2$, N^* is decreasing in τ_ϵ. The reason is roughly the following. When signal precision is relatively small, N^* is increasing as signals are more informative. But as signal precision increases beyond a certain level, the marginal value of signal begins to decline, as existing signals are already sufficiently informative. Note that when signal precision is sufficiently low ($\tau_\epsilon < c\tau_\theta^2$), the marginal value of signal is less than the marginal cost, so no signal should be collected. This is an example of the nonconcavity first identified by Radner and Stiglitz (1984).

Without loss of generality, the prior mean μ can be normalized to zero, and hence $x^* = N^*\tau_\epsilon\zeta/(\tau_\theta + N^*\tau_\epsilon)$. A special case is under the noninformative prior when $\tau_\theta = 0$, in which case $x^* = \zeta = \sum_i \theta_i/N$ and the posterior variance of θ is σ_ϵ^2/N. It reflects the situation where there is no prior knowledge about the state of the world except that a prior θ does not take some values more likely than others, hence all information comes from the sample. The optimal committee size is $N^* = (\tau_\epsilon c)^{-0.5}$ and is decreasing in the precision of signals.

The corollary below follows immediately from Propositions 2 and 3 and will be useful later.

Corollary 1 *In the normal distribution case, when either information is hard or committee members have no policy biases, the optimal committee size is* $N^* = (\tau_\epsilon c)^{-0.5}$ *if* $c \geq k$, *and is* $(\tau_\epsilon k)^{-0.5} - \tau_\theta/\tau_\epsilon < N^*$ *if* $c < k$.

We assume that committee members' policy biases $\{t_i\}$ are independently and identically distributed with mean zero and variance σ_t^2. The variance σ_t^2 represents the uncertainty about a member's policy preference. In our model, σ_t^2 can be interpreted as indicating the (ex ante) heterogeneity of members' policy preferences, because a large σ_t^2 means that committee members' ideal policies are more likely to be far from that of the principal's and to be far from each other's.

Since σ_t^2 is known but the realizations of $\{t_i\}$ are not known before the formation of the committee, the ex ante notion of heterogeneity is what matters for committee size.

4 Intuitive Equilibrium

Assuming that all N committee members have gathered information in the information production stage, in this section we focus on the information aggregation and decision-making stages. Incentives to gather information and optimal committee size will be studied in the next section. We first consider the commitment case and then the non-commitment case.

4.1 Commitment Case: Mean Decision Rule

In the first case we consider, the society commits to a fixed decision rule equal to the mean of the reports by the N committee members. In our context with continuous signals and decisions, such a "mean decision rule" is simple and natural.[10] It is commonly used in sports judging, for example, figure skating, gymnastics, diving, boxing, fencing, etc. In many other collective decision situations, the principal often implicitly commits through reputation mechanisms (e.g. reputation of rubber-stamping) to some decision rule that depends only on the aggregate information of the committee, in which cases the mean decision rule can be thought as a first approximation. For example, for academic appointments in a department, sometimes one can approximate the probability of university level personnel authorities approving an appointment as proportional to the percentage of favorable votes by the department.

Define $M = N + \tau_\theta/\tau_\epsilon$, which has a very intuitive interpretation. With a signal serving as the measurement unit, M is the total amount of information contained in the sample and the prior knowledge, where the prior knowledge counts as $\tau_\theta/\tau_\epsilon$ signals. So M can be thought of as the "adjusted" sample size. Then the posterior mean of θ given a true signal profile θ^N can

[10] Similar decision rules are analyzed in other (quite different) contexts. For example, Gibbons (1988) studies equilibrium models of split-the-difference arbitration, and De Sinopoli and Iannantuoni (2000) analyze a spatial voting model in which the policy is a linear combination of positions of all elected parties.

be conveniently written as $\sum_i \theta_i/M$, or the "adjusted" sample mean. The proposition below presents a reporting equilibrium under the mean decision rule.

Proposition 4 *Under the mean decision rule $x = \sum_{i\in N} \hat{\theta}_i/N$, the following strategy profile is a reporting equilibrium: for any committee member i with a policy preference t_i, $s_i^*(\theta_i, t_i) = N\theta_i/M + Nt_i$.*

Proof: See the Appendix.

The equilibrium identified in Proposition 4 is quite simple and intuitive. For the ease of exposition, let us call it the "intuitive equilibrium". In this equilibrium, the reporting strategies of committee members and the mean decision rule imply that given a true signal profile θ^N, the final decision is $x = \sum_{i\in N} \hat{\theta}_i/N = \sum_{i\in N} \theta_i/M + \sum_{i\in N} t_i$. Those committee members without policy biases report truthfully after making the adjustment from N to M; and those with policy biases exaggerate by N times their policy bias. The intuition of Proposition 4 is as follows. Consider any committee member i. If all other committee members follow their equilibrium strategies, then on expectation the sum of reports by those $N\backslash i$ members will be unbiased. So when i finds out that he does not have any policy bias ($t_i = 0$), reporting truthfully will keep the sum of all reports unbiased and hence will result in an unbiased policy, which is exactly what he wants. When he has a policy preference t_i, he would like to distort the policy by t_i. To do so, he needs to exaggerate by Nt_i under the mean decision rule, so reporting $N\theta_i/M + Nt_i$ is optimal for him.

Note that in the intuitive equilibrium, committee members' information about the state of the world θ is truthfully transmitted and incorporated in the society's decisions. Moreover, committee members' policy biases enter the society's decisions as additional noise. Specifically, given the committee members' reporting strategies, the collective decision is $x = \sum_i \theta_i/M + \sum_i t_i$, where the first term is precisely the posterior mean of θ given the true signal profile θ^N and the second term is the sum of committee members' policy biases. It follows that the expected social surplus is simply

$$E[V] = -E[(x-\theta)^2] = -N\sigma_t^2 - \sigma_\epsilon^2/M \tag{6}$$

This is easy to understand. Given the committee members' reporting strategies, the only uncertainty the principal has about the true signal profile is from the uncertainty about committee members' policy preferences. Consequently, the expected loss of her policy is the sum of two terms (by independence): $N\sigma_t^2$ reflects the uncertainty about committee members' preferences, and σ_ϵ^2/M (the posterior variance based on true signals) reflects the residual uncertainty about the true state of the world.

For any committee member i with a signal θ_i and policy preference t_i, his expected utility in the intuitive equilibrium is given by

$$u_i(\theta_i, t_i) = -(N-1)\sigma_t^2 - \sigma_\epsilon^2/M \tag{7}$$

Note that this is independent of his signal and preference realizations, so it is also member i's expected utility before he knows his policy preference and gets his private information. The reason for this is simple. Because a committee member with a policy bias t_i exaggerates by Nt_i, his expectation is that the policy will be biased from the true posterior mean by t_i, which is ideal from his point of view. Hence, given any θ_i and t_i, committee member i's expected utility depends on only two terms: $(N-1)\sigma_t^2$ reflects his uncertainty about other $N-1$ members' preferences and σ_ϵ^2/M is the posterior variance based on true signals.

It is easy to see that the intuitive equilibrium is not the only reporting equilibrium. For instance, for any constants $\{b_i\}^N$ such that $\sum_{i\in N} b_i = 0$, the strategy profile $s_i(\theta_i, t_i) = N\theta_i/M + Nt_i + b_i$ is a reporting equilibrium that yields the identical social surplus and payoffs for all committee members as in the intuitive equilibrium. Our characterization of reporting equilibria in the proof of Proposition 4 leads to the following efficiency property of the intuitive equilibrium.

Proposition 5 *Under the mean decision rule, the social surplus and the expected payoffs of all committee members are greater in the intuitive equilibrium than in any other reporting equilibria.*

Proof: See the Appendix.

Proposition 5 says that the intuitive equilibrium is the most preferred by all committee members and the principal/social planner. The idea behind Proposition 5 is the following. In the intuitive equilibrium every committee member truthfully reveals his signal except for their policy preferences. In any other reporting equilibrium, if one committee member believes that other members will deviate from truthfully revealing their signals, then he will deviate as well. In fact, every committee member will try to "neutralize" other members' expected deviations conditional on his own information. The net effect of such deviations is to add mean zero noise in their reports and hence to the committee decisions. So the final decision will thereby be less informative, resulting in a lower expected utility for the principal as well as for every committee member.

4.2 Non-Commitment Case

We now consider situations in which the principal is a real decision maker who acts on the committee's information. In the cheap talk game between the principal and informed committee members, it is well known that there exist many equilibria, including the babbling equilibrium, in which no information is transmitted from the committee to the principal. For the one agent case and with a different information structure, Crawford and Sobel (1982) show that a fully revealing equilibrium does not exist and in fact very little information can be revealed in equilibrium. We show that in our context, under certain conditions, a substantial amount of information can be transmitted from the committee to the principal and be incorporated in the collective decisions of the society.

Proposition 6 *Suppose $\tau_\theta = 0$. The following strategy profile is an equilibrium: (i) for any committee member i with a policy preference t_i, $s_i^*(\theta_i, t_i) = \theta_i + Nt_i$; (2) for any report profile $\hat{\theta}^N$, the principal chooses a policy of $x = \sum_{i \in N} \hat{\theta}_i / N$.*

Proof: See the Appendix.

Proposition 6 says that with noninformative prior, committee members' reporting strategies in the intuitive equilibrium studied above can still be a part of an equilibrium, wherein the principal simply uses the mean report as her policy. Of course, given the principal's mean decision rule, we know from the preceding section that the committee members' reporting strategies are their best responses. The additional equilibrium requirement in the non-commitment case is that the mean decision rule must be the principal's best response to the committee members' reporting strategies. With noninformative prior, it can be shown that this requirement is satisfied. The basic reason is as follows. From the principal's point of view, the committee members simply report their true signals with some additional noises (Nt_i). Hence a report profile can be thought of a different "true" signal profile with smaller precision. With non-informative prior, the posterior mean of θ conditional on a signal profile is simply the sample mean. Therefore, the principal's best response is to choose a policy equal to the mean report.

The condition of noninformative prior is of course rather special. However, it can be a reasonable approximation for some collective decision-making situations in which the principal does not have good prior knowledge about the state of the world. For decisions that involve complex specialized knowledge, it is quite common for the decision makers to seek advice from a group of experts, e.g., scientific advisory committees, expert panels, or financial analysts covering certain stocks. Because of the principal's vast ignorance about the decision problem relative to the committee members (experts), she can be thought of having noninformative prior and will thereby try to get as much information as possible. Our analysis suggests that in such situations it makes sense for the principal to use the mean report as the decision rule despite the fact that she knows committee members have instilled their own biases in their reports. Due to the lack of prior knowledge, she has to tolerate some added noises in order to have the committee members reveal their information. When committee members have relatively good information (large τ_ϵ) and small biases (large τ_t) and the committee size is relatively small, the committee members' reports contain good information and the principal's policy decision can be close to the first best.

When $\tau_\theta > 0$, the mean decision rule will not be the principal's best response to the committee members' reporting strategies. It can be checked that when the committee members report

$s_i(\theta_i, t_i) = \frac{N\theta_i}{M} + Nt_i$ where $M = N + \frac{\tau_\theta}{\tau_\epsilon}$, the principal's best response is to choose a policy of

$$x = \frac{N + \tau_\theta/\tau_\epsilon}{N + \tau_\theta/\tau_\epsilon + M^2\tau_\theta/\tau_t} \frac{\sum_{i \in N} \hat{\theta}_i}{N}$$

When τ_θ/τ_t is very small, this will be sufficiently close to the mean decision rule. Consequently, given the committee members' reporting strategies $s_i(\theta_i, t_i) = N\theta_i/M + Nt_i$, the mean decision rule will give the principal an expected utility very close to what she could get by using the best response. Therefore, for sufficiently small τ_θ/τ_t, the strategy profile of the intuitive equilibrium in Proposition 4 is an "epsilon equilibrium" in the sense of Radner (1981).

5 Optimal Committee Size and Implications

Having characterized the intuitive equilibrium and established its efficiency property, we now analyze the information production stage. By Equation 7, if all $N \backslash i$ committee members gather information, member i's expected utility from gathering information is given by

$$E_{\{\theta_i, t_i\}} u_i(\theta_i, t_i) - k = -(N-1)\sigma_t^2 - \sigma_\epsilon^2/M - k$$

If member i does not gather information, the decision rule will be $x_{-i}^* = \sum_{j \neq i} \hat{\theta}_i/(N-1)$ and the reporting strategies of other committee members will be $s_j(\theta_j, t_j) = (N-1)\theta_j/(M-1) + (N-1)t_j$ for all $j \neq i$. In this case member i's expected utility is

$$-E_{\{\theta_{-i}, t_{-i}, t_i\}}\{E_\theta[(x_{-i}^* - \theta - t_i)^2 | \theta_{-i}, t_{-i}, t_i]\} = -\sigma_t^2 - \sigma_\epsilon^2/(M-1) - (N-1)\sigma_t^2$$

Therefore, given that all other committee members gather information, member i will also gather information if

$$\sigma_\epsilon^2/(M-1) - \sigma_\epsilon^2/M + \sigma_t^2 \geq k \tag{8}$$

The right hand side of Equation 8 is simply the cost of becoming informed. The left hand side is the benefit to member i from becoming informed given that all other committee members gather information. If he gathers information, his signal makes the policy more informative, yielding a benefit of $\sigma_\epsilon^2/(M-1) - \sigma_\epsilon^2/M$ to himself. Moreover, once he finds out he has certain policy biases, he can manipulate the policy in his own favor. In a sense, by becoming informed, every member is insured against the uncertainty of his own policy preference, yielding an additional benefit of σ_t^2 (the ex ante variance of his policy preference).

Equation 8 has some interesting implications for participation in committees. When σ_t^2 is large relative to k, then every member has incentives to gather information, despite the fact that information gathering is personally costly. This will tend to be true when the policy has a larger impact on members and ex ante it is difficult to figure out what their preferences will be. In such cases, if committee memberships are not regulated, there will be "too many" volunteers even with uncompensated information costs (k), leading to over-sized committees. This may explain why memberships of committees in the U.S. Congress (especially those "important" ones) are subject to strict regulation.[11]

Having worked out the incentive compatibility conditions for information gathering and reporting, we can now solve for the optimal committee size. From Equation 8, the optimal committee size cannot exceed $\sigma_\epsilon/(k-\sigma_t^2)^{0.5} - \tau_\theta/\tau_\epsilon$ when $k > \sigma_t^2$. From Equation 6, the principal's net expected utility in the intuitive equilibrium with a committee of N member is

[11]Even so, the party leaders in the U.S Congress often find it difficult to resist party members' requests for those committee assignments. Consequently, committees in both the Senate and House have been growing in modern history. Illustration f this is the following statement taken from "Final Report of the Joint Committee on the Organization of Congress":

"Representative Henry Gonzalez, Chairman of the Banking, Finance, and Urban Affairs Committee, made this point in his testimony of April 29:

'Fifty-one members presently serve on what is one of the largest committees in the House. I often describe the Banking Committee as one half of the U.S. Senate plus one. While I recognize the Speaker's prerogative to negotiate committee sizes, I would strongly [recommend] that serious consideration be given to limiting the number of members assigned to various committees and reducing the size of some of the larger committees. My point is illustrated by the fact that five of the committee's subcommittees are too large to utilize our two subcommittee hearing rooms.' "

$$TS = EV - Nc = -\sigma_\epsilon^2/M - N\sigma_t^2 - Nc \tag{9}$$

The solution that maximizes this function is $\sigma_\epsilon/(c+\sigma_t^2)^{0.5} - \tau_\theta/\tau_\epsilon$. Thus, we have the following result:

Proposition 7 *When $c \geq k - 2\sigma_t^2$, the optimal committee size $\bar{N}$ is given by $[\tau_\epsilon(c+\sigma_t^2)]^{-0.5} - \tau_\theta/\tau_\epsilon$. When $c < k - 2\sigma_t^2$, the optimal committee size $\bar{N}$ is given by $[\tau_\epsilon(k-\sigma_t^2)]^{-0.5} - \tau_\theta/\tau_\epsilon$.*

Below we present the implications of the model in several corollaries.

Corollary 2 *The optimal committee size $\bar{N}$ is smaller than the first best solution N^*.*

Corollary 2 follows immediately from Propositions 3 and 7. The reason is that committee members do not always report truthfully and hence their reports are not as informative as what they would be if there were no incentives to distort information. As is apparent from comparing N^* and $\bar{N}$, the added noise in the reports has the same effect as having a fixed cost of σ_t^2 in addition to attendance cost c (when $c \geq k - 2\sigma_t^2$). Note also that the outcome (committee size and decision rule) of the intuitive equilibrium is close to the first best solution when the heterogeneity of policy preferences σ_t^2 is small.

Corollary 3 *Policy decisions are more volatile than in the first best solution.*

There are two reasons for Corollary 3. First, for a fixed committee size, the variance of equilibrium policy is greater than that of the first best policy since committee members with policy biases distort their information. In the intuitive equilibrium of Proposition 4, the policy is given by $x = \sum_i \theta_i/M + \sum_i t_i$. Comparing it with the first best policy $x^* = \sum_i \theta_i/M$, we see that while both are unbiased estimates of θ, their posterior variances are different: $\text{Var}(x) = \sigma_\epsilon^2/M + N\sigma_t^2$ and $\text{Var}(x^*) = \sigma_\epsilon^2/M$. Secondly, since the optimal committee size is smaller than in the first best solution, policy decisions in the intuitive equilibrium are less informative than those in the first best solution. With the optimal committee size, the posterior variance of the equilibrium policy is $\sigma_\epsilon^2/\bar{M} + \bar{N}\sigma_t^2$ where $\bar{M} = \bar{N} + \tau_\theta/\tau_\epsilon$; while in the first best solution, the posterior variance of the first best policy is σ_ϵ^2/M^* where $M^* = N^* + \tau_\theta/\tau_\epsilon > \bar{M}$.

The following corollaries present the comparative statics results of the model.

Corollary 4 *The optimal committee size and the total social surplus decrease (at least weakly) in attendance and information costs (c and k). The precision of the prior τ_θ decreases the optimal committee size but increases the total social welfare.*

Corollary 4 is apparent by inspection. The total social welfare, $TS = -\sigma_\epsilon^2/\bar{M} - \bar{N}(\sigma_t^2 + c)$, increases in τ_θ because $\bar{M}$ is independent of τ_θ and $\bar{N}$ is decreasing in τ_θ.

Corollary 5 *The optimal committee size first increases in the precision of signals when it is low and then decreases when it gets above a certain level. The total social surplus always increases in the precision of signals.*

Proof: Let $\gamma = \max\{c + \sigma_t^2, k - \sigma_t^2\}$. Since $\partial\bar{N}/\partial\tau_\epsilon = \tau_\epsilon^{-2}[\tau_\theta - 0.5(\tau_\epsilon/\gamma)^{0.5}]$, we can see that when $\tau_\epsilon \leq 4\gamma\tau_\theta^2$, $\bar{N}$ is increasing in τ_ϵ; when $\tau_\epsilon > 4\gamma\tau_\theta^2$, $\bar{N}$ becomes decreasing in τ_ϵ. Since the total surplus can be written as $TS = -(\gamma/\tau_\epsilon)^{0.5} - \bar{N}\gamma$, we have $\gamma^{-1}\partial TS/\partial\tau_\epsilon = \tau_\epsilon^{-2}[(\tau_\epsilon/\gamma)^{0.5} - \tau_\theta]$. It is non-negative when $\tau_\epsilon > \gamma\tau_\theta^2$, which must hold for $\bar{N} \geq 0$. *Q.E.D.*

As in the first best solution, the optimal committee size is not globally monotonic in the precision of signals. In contrast, the more precise signals are, the greater the social surplus. For a fixed committee size, more precise signals always improve the quality of policy decisions. This effect dominates the committee size effect when signal precision decreases the optimal committee size.

In our model, σ_t^2 represents the heterogeneity of committee preferences. Thus we have the following comparative statics result.

Corollary 6 *When $c + 2\sigma_t^2 \geq k$, the optimal committee size decreases in the heterogeneity of committee members' policy preferences. When $c + 2\sigma_t^2 < k$, the optimal committee size increases in the heterogeneity of committee members' policy preferences.*

When $c + 2\sigma_t^2 \geq k$, added noise in committee members' reports decreases the value of having more signals, so an increase of σ_t^2 decreases the optimal committee size. When $k > c + 2\sigma_t^2$, motivating committee members to gather information is a dominant concern, so an increase of σ_t^2 increases the optimal committee size. Because in the intuitive equilibrium committee members with policy biases can effectively manipulate the policy, becoming informed gives them full insurance against uncertainty about their own policy preferences, which provides additional incentives to gather information. When information cost k is significant so that the committee size is constrained by committee members' tendency to shirk in gathering information, greater or uncertain stakes in committee policies can help mitigate the shirking problem in information production and make a larger committee functional. By Corollary 1, compared to the case in which either information is hard or committee members have no policy biases, the optimal committee size is thereby greater when information is soft and committee members have strong policy biases.

Corollary 7 *When $c \geq k$, the total social surplus is always decreasing in the heterogeneity of committee members' policy preferences. When $c < k$, the social total surplus initially increases in the heterogeneity of committee members' policy preferences for $2\sigma_t^2 < k - c$, then becomes decreasing for $2\sigma_t^2 \geq k - c$.*

Proof: Since $TS = -\sigma_\epsilon^2/\bar{M} - \bar{N}\gamma$, where $\gamma = \max\{c + \sigma_t^2, k - \sigma_t^2\}$, by the Envelope Theorem, $d(TS)/d\gamma = -\bar{N} < 0$. So the total surplus is always decreasing in γ. The Corollary then follows the definition of γ. *Q.E.D.*

Corollary 7 shows that sometimes committee members' policy biases and distortion of information may improve social welfare. This can happen when the moral hazard problems in information production are so severe that the IC condition for information production is binding. It will tend to occur when information gathering is hard to monitor and is relatively costly for committee members.

We assume that society members are ex ante identical, so the only issue for committee design is the committee size. From the analysis of the model, it is not difficult to obtain some implications for the optimal committee composition when society members are not ex ante identical. Due to space limitations, only a brief informal discussion is provided here. Consider first the case in which society members differ in terms of information gathering abilities. If some members are more adept at gathering information than others, e.g., getting more signals or signals with higher precision, then their information will be given greater weights in the policy decisions. All the current results should follow without substantive modifications. In forming the committee, the principal prefers the most productive members.[12] Now consider the case in which society members differ in their ex ante policy preferences. If some members are likely to have larger biases than others (perhaps due to their having large stakes in the policy decisions), then they will add more noise in their reports. All the analysis and results of the current model should carry through with minor modifications. However, by Corollary 7, the optimal committee composition is not entirely trivial. When $c \geq k$, the principal would like to select members with the smallest biases. However, when moral hazard problems in information production are severe ($c < k$), then the principal needs to select members with biases large enough such that $2\sigma_t^2 \geq k - c$ even though there are other people with smaller biases. For example, in the U.S Congress, members with greater stakes in a legislature committee are more likely to be assigned to that committee (e.g., those from agricultural states seeking assignment to the Agricultural Committee). While it is generally believed that this reflects rent-seeking of the senators and congressmen, our analysis suggests there may be an efficiency argument for it.

[12]For example, being knowledgeable about a committee's legislative affairs is an important requirement for assigning senators and congressmen to that committee. Similarly, investment bankers often serve on finance committees of boards of directors; and people with good knowledge about their profession (and with connections to other departments) are likely to serve on recruiting committees.

6 Related Literature

This paper is related to several lines of research in the existing literature. One is the strategic information transmission ("cheap talk") literature originated from the seminal work of Crawford and Sobel (1982). In their model, a decision maker seeks advise from an agent endowed with useful information ("expertise") whose policy preference differs from that of the decision maker. A strand of this literature extends the basic model of Crawford and Sobel to situations in which different experts have the same information, e.g., Gilligan and Krehbiel (1987, 1989), Austen-Smith (1993), Krishna and Morgan (2000a, b), and Battaglini (2000). Wolinsky (1999) examines situations where experts share the same preferences but observe different signals. Several papers have also studied models in which the principal does not know her expert's preference. In a dynamic setting where the expert wants to build a reputation for unbiasedness, Morris (2000) demonstrates that no information is conveyed in equilibrium. Morgan and Stocken (2001) study a model in which the expert (stock analyst) is biased in one direction with positive probability and show that this uncertainty about the expert's preference may sometimes help information transmission. De Garidel-Thoron and Ottaviani (2000) analyze quite thoroughly a large number of one-principal-one-agent variations of t Crawford and Sobel's basic model. Among other things, they show that when the expert's bias is unknown there exists an equilibrium whose outcome achieves the optimum (i.e., constrained delegation outcome).[13] Strategic information transmission is also a core element of our model, but our setting (committee members having different preferences and different information with normal prior and normal noise) and focus (optimal committee design) are different from the above works.

Our paper is also related to the literature on jury decisions. Strategic voting in jury-type committee decisions has attracted much attention recently (See, Austen-Smith and Banks (1996), Feddersen and Pesendorfer (1997, 1998), Chwe (1999), Li, Rosen and Suen (1999), Persico (2000), Gerardi and Yariv (2002), and others). The common setting in this literature is a jury with

[13]Like Holmstrom (1984) and Dessein (2000), the main focus of de Garidel-Thoron and Ottaviani (2000) is to study delegation as an alternative to strategic information transmission.

differentiated information trying to vote between two choices. Chwe (1999) analyzes the optimal voting rule in a two-signal binary decision setting in the mechanism design approach. Li *et al* (1999) study a two-juror strategic voting model with continuous signals. In terms of research question and approach, our paper is closest to Persico (2000), who studies the optimal jury size and voting rule with information production. Gerardi and Yariv (2002) consider communication in committee decisions and study the mechanism design problem that focuses on the tradeoff between information acquisition and information aggregation. The main difference between our paper and the jury decisions literature is that we consider situations with a continuous policy space and are not concerned about voting mechanisms.

7 Conclusion

In this paper we develop a simple model of committee size based on costly participation and the informational role of committees in collective decision making. We characterize the most efficient equilibrium under the mean decision rule and explore conditions under which the mean decision rule is also the principal's equilibrium strategy. We then derive the optimal committee size and discuss some of the implications of the main result. Among other things, the optimal committee size and the total social surplus can sometimes increase rather than decrease in the heterogeneity of committee policy preferences.

The simple model developed in this paper is only a small step towards understanding the incentives and information problems in committee decisions. It can be extended in many directions. Starting from the obvious, we have focused on the normal distribution case, but the analysis can be extended to other distributions, especially those conjugate distribution families whose posterior distributions can be easily computed. Like most existing literature, we have assumed that all players have quadratic utility functions (loss functions from policy decisions). It is desirable to investigate how robust our results are to more general specification of utility functions such as general polynomial functions. More importantly, it would be interesting to solve for the optimal mechanism in the commitment case and the most informative equilibrium in the non-commitment case with any given priors. All these have to be left for future research.

8 Appendix

Proof of Proposition 2: The first best solution requires a committee size of N^* and the optimal decision rule $x^* = \bar{\mu}$: the posterior mean. For case (i), the question is whether committee members have the right incentives to gather information. For any member $i \in N^*$, given all other members will collect information, his expected utility if he also collects information will be

$$\begin{aligned} Eu_i - k &= -E_{\{\theta^{N^*}, t_i\}}\{E_\theta[(\bar{\mu} - \theta - t_i)^2 | \theta^{N^*}, t_i]\} - k \\ &= -\sigma_t^2 - \bar{\sigma}_{N^*}^2 - k \end{aligned}$$

If i does not collect information, the remaining $N^* - 1$ members report their signals; and the decision rule will be the posterior mean of the $N^* - 1$ signals. In this case, it is easy to see that member i's expected utility is $-\bar{\sigma}_{N^*-1}^2 - \sigma_t^2$, where $\bar{\sigma}_{N^*-1}^2$ is the posterior variance with $N^* - 1$ signals. Hence, given that all other members gather information, member i also collects information if

$$\bar{\sigma}_{N^*-1}^2 - \bar{\sigma}_{N^*}^2 \geq k$$

By the definition of N^* (Equation 5), the above inequality holds when $c \geq k$. Therefore, it is an equilibrium for every member in N^* to exert effort in collecting information.

For case (ii), it is easy to see that reporting truthfully is an equilibrium given the optimal decision rule. Since for all i, $t_i = 0$, committee member i's expected utility coincides with that of the principal. So, if all other committee members report truthfully, committee member i will also report truthfully under the optimal decision rule. The argument of case (i) implies that the incentive compatibility condition for information production is satisfied. *Q.E.D.*

Proof of Proposition 4: We want to show that when the decision rule is fixed at $x = (\sum_{i\in N}\hat{\theta}_i)/N$, committee members' reporting strategies $s_i^*(\theta_i,t_i) = N\theta_i/M + Nt_i$ are best responses to each other.

Consider informed member i's best response to any reporting strategies by other members $s_{-i}(\theta_{-i},t_{-i})$. Let $\bar{x}$ be the true "adjusted" sample mean: $\bar{x} = (\sum_{i\in N}\theta_i)/M$, which is also the posterior mean condition on the true signal profile θ^N: $\bar{x} = E_\theta[\theta|\theta^N]$. When $t_i = 0$, i's reporting strategy $s_i^*(\theta_i,0)$ maximizes

$$\begin{aligned}
u_i(\theta_i,0)(s_i,s_{-i}) &= -E_{\{\theta,\theta_{-i},t_{-i}\}}[(\frac{\sum_{j\neq i}\hat{\theta}_j}{N} + \frac{s_i(\theta_i,0)}{N} - \theta)^2|\theta_i] \\
&= -E_{\{\theta_{-i},t_{-i}\}}\{E_\theta[(\frac{\sum_{j\neq i}\hat{\theta}_j}{N} + \frac{s_i(\theta_i,0)}{N} - \bar{x} + \bar{x} - \theta)^2|\theta_i,\theta_{-i},t_{-i}]\} \\
&= -E_{\{\theta_{-i},t_{-i}\}}[(\frac{\sum_{j\neq i}\hat{\theta}_j}{N} + \frac{s_i(\theta_i,0)}{N} - \bar{x})^2|\theta_i] - E_{\{\theta_{-i}\}}\{E_\theta[(\bar{x}-\theta)^2|\theta_i,\theta_{-i}]\} \\
&= -E_{\{\theta_{-i},t_{-i}\}}[(\frac{\sum_{j\neq i}\hat{\theta}_j}{N} + \frac{s_i(\theta_i,0)}{N} - \bar{x})^2|\theta_i] - \frac{\sigma_\epsilon^2}{M} \qquad (10)
\end{aligned}$$

where the last equality follows from the fact that the posterior variance is $(\tau_\theta + N\tau_\epsilon)^{-1} = (\tau_\epsilon M)^{-1} = \sigma_\epsilon^2/M$. Similarly, for $t_i \neq 0$, $s_i^*(\theta_i,t_i)$ maximizes

$$u_i(\theta_i,t_i)(s_i,s_{-i}) = -E_{\{\theta_{-i},t_{-i}\}}[(\frac{\sum_{j\neq i}\hat{\theta}_j}{N} + \frac{s_i(\theta_i,t_i)}{N} - \bar{x} - t_i)^2|\theta_i,t_i] - \frac{\sigma_\epsilon^2}{M}$$

Then it must be the case that $s_i^*(\theta_i,t_i) = s_i^*(\theta_i,0) + Nt_i$ is i's best reporting strategy for $t_i \neq 0$. If not, then $\tilde{s}_i(\theta_i,0) = s_i^*(\theta_i,t_i) - Nt_i$ would yield a higher value for $u_i(\theta_i,0)(s_i,s_{-i}^*)$ than $s_i^*(\theta_i,0)$.

Since in equilibrium $s_i^*(\theta_i,t_i) = s_i^*(\theta_i,0) + Nt_i$ for every i and t_i, Equation 10 becomes

$$\begin{aligned}
u_i(\theta_i,0)(s_i,s_{-i}) &= -E_{\{\theta_{-i},t_{-i}\}}[(\frac{\sum_{j\neq i}(s_j^*(\theta_j,0)+Nt_j)}{N} + \frac{s_i(\theta_i,0)}{N} - \bar{x})^2|\theta_i] - \frac{\sigma_\epsilon^2}{M} \\
&= -E_{\{\theta_{-i},t_{-i}\}}[(\sum_{j\neq i}t_j + \sum_{j\neq i}\frac{s_j(\theta_j,0)-N\theta_j/M}{N} + \frac{s_i(\theta_i,0)-N\theta_i/M}{N})^2|\theta_i] - \frac{\sigma_\epsilon^2}{M} \\
&= -E_{t_{-i}}(\sum_{j\neq i}t_j)^2 - E_{\theta_{-i}}[(\sum_{j\neq i}\frac{s_j(\theta_j,0)-N\theta_j/M}{N} + \frac{s_i(\theta_i,0)-N\theta_i/M}{N})^2|\theta_i] - \frac{\sigma_\epsilon^2}{M}
\end{aligned}$$

The last equality follows from the facts that (i) t_{-i} are independent with θ_i and θ_{-i}, and (ii) $E_{t_{-i}} \sum_{j \neq i} t_j = 0$.

Since t_i's are independent, $E_{t_{-i}} (\sum_{j \neq i} t_j)^2 = \sum_{j \neq i} E(t_j^2) = (N-1)\sigma_t^2$. Let $\Delta(\theta_i) = E_{\theta_{-i}}[\sum_{j \neq i}(s_j(\theta_j, 0) - N\theta_j/M)|\theta_i] = \sum_{j \neq i} E_{\theta_j}[(s_j(\theta_j, 0) - N\theta_j/M)|\theta_i]$. Then we have

$$\begin{aligned} u_i(\theta_i, 0)(s_i, s_{-i}) &= -\frac{1}{N^2} E_{\theta_{-i}}[(\sum_{j \neq i}(s_j(\theta_j, 0) - N\theta_j/M) - \Delta(\theta_i))^2|\theta_i] \\ &\quad -\frac{1}{N^2}[s_i(\theta_i, 0) - N\theta_i/M + \Delta(\theta_i)]^2 - (N-1)\sigma_t^2 - \sigma_\epsilon^2/M \qquad (11) \end{aligned}$$

Since only the second term on the right hand side of Equation 11 is affected by $s_i(\theta_i, 0)$, member i's best response function when $t_i = 0$ is

$$s_i(\theta_i, 0) = N\theta_i/M - \Delta(\theta_i) = N\theta_i/M - \sum_{j \neq i} E_{\theta_j}[(s_j(\theta_j, 0) - N\theta_j/M)|\theta_i] \qquad (12)$$

Any $\{s_i^*(\theta_i, 0)\}_{i \in N}$ that satisfies Equation 12 gives rise to a reporting equilibrium with $s_i^*(\theta_i, t_i) = s^*(\theta_i, 0) + Nt_i$ for $t_i \neq 0$. Clearly $s_i^*(\theta_i, 0) = N\theta_i/M$ for all $i \in N$ constitutes a solution to Equation 12. Therefore, $s_i^*(\theta_i, t_i) = N\theta_i/M + Nt_i$ for all i and t_i are an equilibrium under the mean decision rule $x = \sum_{i \in N} \hat{\theta}_i/N$.

In this equilibrium, $x = \sum_{i \in N} \hat{\theta}_i/N = \sum_{i \in N} s_i(\theta_i, 0)/N + \sum_{i \in N} t_i = \sum_{i \in N} \theta_i/M + \sum_{i \in N} t_i$. So conditional on a true signal profile θ^N, the expected social surplus is

$$E_\theta[V|\theta^N] = -E_\theta[(x - \theta)^2|\theta^N] = -N\sigma_t^2 - \sigma_\epsilon^2/M$$

Since this is independent of the signal profile θ^N, it is also the ex ante expected social surplus before the realization of signals. Since $s_i^*(\theta_i, t_i) = s^*(\theta_i, 0) + Nt_i$, it must be that $u_i(\theta_i, t_i)(s_i^*, s_{-i}^*) = u_i(\theta_i, 0)(s_i^*, s_{-i}^*)$ for all i and all t_i. From Equation 11, we have

$$u_i(\theta_i, t_i) = -(N-1)\sigma_t^2 - \sigma_\epsilon^2/M$$

This proves the proposition. *Q.E.D.*

Proof of Proposition 5: Let $\{s_i(\theta_i, t_i)\}$ be any reporting equilibrium. Let $\delta_i(\theta_i) = s_i(\theta_i, 0) - N\theta_i/M$. Since Equation 12 must hold, then $\delta_i(\theta_i) = -\Delta(\theta_i) = -\sum_{j\neq i} E_{\theta_j}[(s_j(\theta_j, 0) - N\theta_j/M)|\theta_i] = -\sum_{j\neq i} E_{\theta_j}[\delta_j(\theta_j)|\theta_i]$. Therefore, for any θ_i, $\sum_{j\in N} E_{\theta_j}[\delta_j(\theta_j)|\theta_i] = 0$.

Under the mean decision rule, we have $x = \frac{\sum_{i\in N}\hat{\theta}_i}{N} = \frac{\sum_{i\in N} s_i(\theta_i,0)}{N} + \sum_{i\in N} t_i = \frac{\sum_{i\in N}\theta_i}{M} + \frac{\sum_{i\in N}\delta_i(\theta_i)}{N} + \sum_{i\in N} t_i$. Conditional on a true signal profile θ^N, the expected social surplus is

$$
\begin{aligned}
E[V|\theta^N] &= -E_\theta[(x-\theta)^2|\theta^N] \\
&= -E_\theta[(\frac{\sum_{i\in N}\theta_i}{M} + \frac{\sum_{i\in N}\delta_i(\theta_i)}{N} - \theta)^2|\theta^N] - N\sigma_t^2 \\
&= -\frac{(\sum_{i\in N}\delta_i(\theta_i))^2}{N^2} - N\sigma_t^2 - \sigma_\epsilon^2/M
\end{aligned}
$$

Since the first term is non-negative and will remain non-negative after taking the expectation over θ^N, this is less than $E[V]$ in the intuitive equilibrium.

For the committee members' expected payoffs, Equation 11 now becomes

$$
u_i(\theta_i, t_i) = -\frac{1}{N^2} E_{\theta_{-i}}[(\sum_{j\neq i}\delta_j(\theta_j) - \sum_{j\neq i} E[\delta_j(\theta_j)|\theta_i])^2|\theta_i] - (N-1)\sigma_t^2 - \sigma_\epsilon^2/M
$$

Since the first term is non-negative, this is clearly less than $u_i(\theta_i, t_i)$ in the intuitive equilibrium. *Q.E.D.*

Proof of Proposition 6: By Proposition 4, the reporting strategies of the committee members are clearly optimal under the principal's decision rule. We only need to show that given committee members' reporting strategies, the principal's optimal policy is indeed $x = \sum_{i\in N}\hat{\theta}_i/N$.

Given committee members' reporting strategies and a report profile $\hat{\theta}^N$, the principal gets a sample of N signals about θ: $\hat{\theta}_i = \theta_i + Nt_i = \theta + \epsilon_i + Nt_i$. Let $\lambda_i = \epsilon_i + Nt_i$, then $\{\lambda_i\}$ are i.i.d normal random variables with mean zero and variance $\sigma_\lambda^2 = \sigma_\epsilon^2 + N^2\sigma_t^2$, or precision $\tau_\lambda = \frac{\tau_\epsilon\tau_t}{N^2\tau_\epsilon + \tau_t}$. By the standard Bayesian updating rule, the posterior mean of θ given $\hat{\theta}^N$ is

$$
E[\theta|\hat{\theta}^N] = \frac{N\tau_\lambda}{\tau_\theta + N\tau_\lambda}\frac{\sum_i\hat{\theta}_i}{N}
$$

Clearly the principal's best response to the committee members' reporting strategies is to choose a decision equal to this posterior mean of θ. When $\tau_\theta = 0$, this reduces to $\sum_i \hat{\theta}_i/N$. Therefore, the proposed strategy profiles indeed constitute an equilibrium. *Q.E.D.*

References

[1] Austen-Smith, David, 1993, Interested Experts and Policy Advice: Multiple Referrals under Open Rule", *Games and Economic Behavior*, 5:3-43.

[2] Austen-Smith, David and Jeffrey Banks, 1996, Information Aggregation, Rationality, and the Condorcet Jury Theorem, *American Political Science Review*, 90:34-45.

[3] Battaglini, Marco, 2002, Multiple Referrals and Multidimensional Cheap Talk, *Econometrica* , 70:1379-1401.

[4] Campbell, Colin, 1999, Large Electorates and Decisive Minorities, *Journal of Political Economy*, 107:1199-1217.

[5] Chwe, Michael, 1999, Minority Voting Rights Can Maximize Majority Welfare, *American Political Science Review*, 93:85-97.

[6] Coughlan, Peter J., 2000, In Defense of Unanimous Jury Verdicts: Mistrials, Communication, and Strategic Voting, *American Political Science Review*, 94:375-393.

[7] Crawford, Vincent and Joel Sobel, 1982, Strategic Information Transmission, *Econometrica*, 50:1431-1451.

[8] de Garidel-Thoron, Thomas and Marco Ottaviani, 2000, The Economics of Advice, working paper.

[9] De Sinopoli, Francesco and Giovanna Iannantuoni, 2000, A Spatial Voting Model Where Proportional Rule Leads to Two-Party Equilibria, CORE Discussion Paper 2000/37.

[10] Dessein, Wouter, 2000, Authority and Communication in Organization, working paper, University of Chicago.

[11] Doraszelski, Ulrich, Dino Gerardi and Francesco Squintani, 1999, Deliberations with Double-Sided Information, working paper, Northwestern University.

[12] Feddersen, Timothy and Wolfgang Pesendorfer, 1997, Voting Behavior and Information Aggregation in Elections with Private Information, *Econometrica*, 65:1029-58.

[13] Feddersen, Timothy and Wolfgang Pesendorfer, 1998, Convicting the Innocent: The Inferiority of Unanimous Jury Verdicts under Strategic Voting, *American Political Science Review*, 92:23-35.

[14] Gerardi, Dino and Leeat Yariv, 2002, Putting Your Ballot Where Your Mouth Is—An Analysis of Collective Choice with Communication, mimeo.

[15] Gibbons, Robert, 1988, Learning in Equilibrium Models of Arbitration, *American Economic Review*, 78:896-912.

[16] Gilligan, Thomas and Keith Krehbiel, 1987, Collective Decision-Making and Standing Committees: An Informational Rationale for Restrictive Amendment Procedures, *Journal of Law, Economics, and Organization*, 3:287-335.

[17] Gilligan, Thomas and Keith Krehbiel, 1989, Asymmetric Information and Legislative Rules with a Heterogeneous Committee, *American Journal of Political Science*, 33:459-490.

[18] Holmstrom, Bengt, 1984, On the Theory of Delegation, in *Bayesian Models in Economic Theory*, ed. Marcel Boyer and Richard Kihlstrom. New York: North-Holland.

[19] Joint Committee on the Organization of Congress, "Final Report of the Joint Committee on the Organization of Congress", December 1993.

[20] Krishna, Vijay and John Morgan, 2000, A Model of Expertise, *Quarterly Journal of Economics*, forthcoming.

[21] Krishna, Vijay and John Morgan, 2000, Asymmetric Information and Legistlative Rules: Some Amendments, working paper.

[22] Li, Hao, Sherwin Rosen and Wing Suen, 1999, Conflict and Common Interests in Committees, working paper.

[23] Milgrom, Paul and John Roberts, 1986, Relying on the Information of Interested Parties, *Rand Journal of Economics*, 17:18-32.

[24] Morgan, John and Phillip Stocken, 2001, An Analysis of Stock Recommendations, working paper.

[25] Morris, Stephen, 2000, Political Correctness, forthcoming, *Journal of Political Economy*

[26] Osborne, Martin, Jeffrey Rosenthal, and Matthew Turner, 2000, Meetings with Costly Participation, *American Economic Review*, 90:927-943.

[27] Persico, Nicola, 2000, Consensus and The Accuracy of Signals: Optimal Committee Design With Endogenous Information, forthcoming, *Review of Economic Studies*.

[28] Radner, Roy, 1981, Monotoring Cooperative Agreements in a Repeated Principal-Agent Relationship, *Econometrica*, 49:1127-48.

[29] Radner, Roy and Joseph Stiglitz, 1984, A Nonconcavity in the Value of Information, in *Bayesian Models in Economic Theory*, ed. Marcel Boyer and Richard Kihlstrom. New York: North-Holland.

[30] Wolinsky, Asher, 1999, Eliciting Information from Multiple Experts, forthcoming, *Games and Economic Behavior*.