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Designing Institutions to Aggregate Preferences and Information

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ABSTRACT

I consider the design of policy-making institutions to aggregate preferences and information. A pervasive incentive problem hinders the creation of desirable deliberative institutions; participants that expect to have minority interests have an incentive to misrepresent their information. Moreover, contrary to conventional wisdom, diversity of preferences or information sources amplifies this incentive problem. It is only when all types of participants expect to have the majority interests or no individual's private information can be decisive that full aggregation is possible. The addition of external incentives enables efficient aggregation of preferences and information. The external incentives need only depend on agent actions and, interestingly, the magnitude of these external incentives can be vanishingly small for large groups. These external incentives can be created by augmenting deliberation with concerns about ex-poste monitoring or ex-interum perceptions of competence, the opportunity to trade in information markets, or the opportunity to join clubs with network externalities.

Recent studies of strategic behavior in policy-making institutions with communication and voting are less sanguine about the effectiveness of this form of decision-making than the traditional literature on deliberative democracy (for example Gutmann and Thompson, 1996). A participant believing that she has minority interests has an incentive to misrepresent her private information in order to distort the inferences drawn by others. This paper sharpens this intuition by isolating necessary and sufficient conditions for information aggregation in a class of communication and voting problems with potentially opposed preferences. The news, however, is not all bad for deliberative democrats.

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In the presence of external incentives to be correct, or at least perceived as knowledgeable, about factual questions there are equilibria that fully aggregate preferences and information. Incentives can be created by transfers in the form of external prediction markets[1] or sanctions based on incompetence. The sanctions can be based on either the ex-poste accuracy of agent predictions or the ex-interum likelihood that agent predictions are correct. Limiting results are attained for the natural special case in which participants observe private signals about the state that are conditionally independently and identically distributed. Because the marginal influence of an individual agent's report tends to be small and vanishes very quickly, the magnitude of these external incentives/transfers can vanish as group size gets large. In general, when a natural participation constraint needs to be satisfied the design of institutions involves a tradeoff. External transfers can increase the likelihood that the equilibrium decision is desirable but transfers may impose a cost on the institutional designer. Simple examples demonstrate that the question of whether institutions with transfers are more efficient than communication and voting games without transfers is sometimes answered in the affirmative and sometimes in the negative.

These conclusions offer two insights. First, justifications of effective deliberation that are not based on external incentives are inconsistent with strategic behavior unless participants believe that preferences or information sources are homogeneous. Second, in settings where preferences over policy generate incentive problems, even small concerns about being "correct" can be sufficient to facilitate information transmission and aggregation. Consequently, deliberative performance can be higher in institutions in which accountability is based on expertise about policy relevant facts or decision-makers derive some small value from being perceived as competent.

While deliberative democracy is a central piece of the normative theory literature most scholarship fails to recognize the potential incentive problems. Typically, scholars of deliberation assume that participants share their information. In a few game theoretic papers, however, the value of communication is endogenous and shown to depend on the rules used to aggregate votes and the size of the group. Specifically, Austen-Smith and Feddersen (2003a,b) show that unanimity rule induces less information sharing than majority rule, and Gerardi and Yariv (2003) establish an equivalence between the amount of information aggregation in the sequential equilibrium sets for communication games under all simple rules other than unanimity. Meirowitz (2003) shows that, in models in which private preference types are correlated, equilibria that reach the full information majority rule core policy are more likely to exist for small groups than for large groups; equilibrium performance is not monotone in the number of participants.[2]

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[1] See Wolfers and Zitzewits (2004) and Meirowitz and Tucker (2004) for reviews on information markets. Chen and Plott (2002) and Chen, Fine, and Huberman (2003) provide evidence on information market performance in experiments and corporate applications. In the public policy domain Neumann (2005) and Jordan (2004) discuss the use of information markets to inform medical policy decisions that depend on forecasts about influenza outbreaks.

[2] The literature on the strategic Condorcet Jury Theorem (e.g. Austen-Smith and Banks 1996, Feddersen and Pessendorfer 1998, Witt 1998, Duggan and Martinelli 2001, Meirowitz 2002) has connections with the formal work on deliberation. These papers consider common values problems and no communication. Coughlan (2000) demonstrates that cheap talk communication prior

Generally, in these problems some participants may believe that it is more likely that the information they provide will be used to justify a policy that they like less than some other policy which might be more likely to pass given a different report of their private information. This paper develops a particularly simple model; one that, if anything, stacks the deck against information aggregation by considering groups in which participants may have diametrically opposed state contingent preferences. By characterizing conditions on the primitives that are necessary and sufficient for the existence of equilibria which efficiently aggregate the available information, this paper improves our understanding of how heterogeneity detrimentally affects incentives in aggregation problems. While the mechanism design literature demonstrates that it is possible to implement efficient choice rules with transfers (e.g. d'Aspremont, Cremer, and Gerard-Varet 2003), this literature tends to be silent as to how plausible or intrusive the transfer schemes must be. Even though this paper considers problems which are stacked against deliberative democracy, I find that very small transfers are all that is needed. One interpretation of the external incentives is particularly natural in the context of policy-making; for accountability or ego reasons participants care at least a little about whether their arguments are perceived to be correct.

THE COLLECTIVE CHOICE PROBLEMS

I consider a class of collective choice problems with asymmetric information about preferences and policy-relevant facts. These problems represent the simplest set of models in which participants have private information about the consequences of policy decisions and their own state-contingent preferences.[3] A collective choice problem involves a set of agents $N = \{1, 2, \ldots, n\}$ (n odd) that must make a binary group decision, choosing a policy $p \in \{a, b\}$. Each agent has a binary preference type $\theta_i \in \{-1, 1\}$ and there is an unknown state of the world $x \in \{a, b\}$. Agent i has a Von Neumann-Morgenstern utility function over lotteries. Her Bernoulli (state-contingent) utility function depends on the policy p, the state x, and her type θ_i, and is of the form

$$u_i(p; x, \theta_i) = \theta_i \cdot 1_{\{p=x\}} \tag{1}$$

where $1_{\{p=x)}$ is the indicator function taking value 1 if $p = x$ and 0 otherwise. So type $\theta_1 = 1$ agents want to match x and p while type $\theta_i = -1$ agents want x and p unmatched.[4] Two examples demonstrate that some interesting choice problems have this structure.

to voting can improve the aggregation properties of equilibria in a common values setting, and Kim (2004) considers jury voting when preferences can be diametrically opposed, but without communication. In addition, Lipman and Seppi (1995), Glazer and Rubinstein (2001) and Hafer and Landa (2003) consider models of communication that do not involve cheap talk.

[3] See Meirowitz (2005a) for work on deliberation and bargaining in the spatial model. With larger choice spaces similar incentives surface.

[4] I use the same names for the possible states, x, and policies, p, to make it easy to keep track of the preference types. Type 1 participants want to match the policy and state, while type -1 participants don't want to match.

Example 1: The spatial model with a noisy alternatives to the status quo. Suppose participants have symmetric single-peaked preferences on the real line; type $\theta_i = -1$ participants have ideal point -1 and type $\theta_i = 1$ participants have ideal point 1. Let policy a correspond to the status quo which results in the outcome 0 with certainty and let policy b result in an alternative policy which involves some uncertainty. If $x = a$ then the outcome that results from policy b is $-\frac{1}{4}$ and if $x = b$ then the outcome that results from policy b is $\frac{1}{4}$. In this case if $x = a$ then type $\theta_i = -1$ participants prefer policy b and if $x = b$ then type $\theta_i = -1$ participants prefer policy a. If $x = a$ then type $\theta_i = 1$ participants prefer policy a and if $x = b$ then type $\theta_i = 1$ participants prefer policy b.

Example 2: Fishkin's deliberative poll with saboteurs. Consider a party primary with two viable candidates. Let p denote the identity of the party nominee for the general election, while x is the identity of the party nominee that general election voters are more likely to prefer to the incumbent. In this setting $\theta_i = 1$ is a preference type that wants to unseat the incumbent while $\theta_i = -1$ is a preference type that wants to see the incumbent retained. The possibility of both preference types participating is a risk in a caucus or deliberative poll without a strong screening technology.

In order to complete the description of the choice problem, I must characterize the informational environment. The common prior probability distribution over the unknown state is given by $\Pr(x = a) = \pi \geq \frac{1}{2}$. To capture situations in which agents are uncertain about the preferences of the other members of the deliberative body, I assume that only agent i knows her type and that there is common knowledge about the random process that generates the profile $\theta = (\theta_1, \ldots, \theta_n)$.

I am agnostic about the process generating θ except for the symmetry assumption that the θ_i's are identically (but not necessarily independently) distributed. For $t \in \{-1, 1\}$, let η_t^+ denote the probability that at least $\frac{n+1}{2}$ of the $N\backslash\{i\}$ participants have type $\theta_j = t$ conditional on $\theta_i = t$. Let η_t^- denote the probability that at least $\frac{n+1}{2}$ of the $N\backslash\{i\}$ participants have type $\theta_j = -t$ conditional on $\theta_i = t$. With almost no loss of generality we assume that $\eta_1^+ > \eta_{-1}^+$ and $\eta_{-1}^- > \eta_1^-$, to capture the case where $\theta_i = 1$ is more likely than $\theta_i = -1$. For the remainder of the analysis, the probabilities $(\eta_1^+, \eta_{-1}^+, \eta_1^-, \eta_{-1}^-)$ are sufficient summaries of the joint distribution of θ. A few concrete examples help to clarify; these examples are discussed throughout the remainder of the paper.

Technical Example 1: Independent types. A convenient probability model to keep in mind involves θ_i's being drawn from the binomial distribution with $pr(\theta_i = 1) = z \in (\frac{1}{2}, 1]$. In this example $\eta_t^+ > \eta_t^-$ for $t \in \{-1, 1\}$ when $z > \frac{1}{2}$.

Technical Example 2: Correlated types. A probability model with correlated types involves a mixture model in which with probability $1 - c$ the types are generated as in the binomial example and with probability c nature randomizes between giving all participants $\theta_i = 1$ with probability z and all types $\theta_i = -1$ with probability $1 - z$. Meirowitz (2005b) shows that $\eta_t^+ > \eta_t^-$ for $t \in \{-1, 1\}$ if $c \geq \frac{1}{2}$ or $z = \frac{1}{2}$. If $c < \frac{1}{2}$ and n is sufficiently big then $\eta_{-1}^+ < \eta_{-1}^-$.

To capture the case of private information about the state, assume that agents do not observe x, but instead each agent receives an informative private signal $s_i \in \{a, b\}$ about x. A profile of n private signals, s, is then a vector in $\{a, b\}^n$. Let $\mu(s)$ denote the posterior probability that $x = a$ conditional on the realization of private signals, s. To capture the case of informative private signals but maintain a fair amount of flexibility a weak assumption is made.

Definition 1 *The information environment satisfies* ***weak monotonicity*** *if* $\mu(s') \geq \mu(s)$ *for any two profiles s and s′ which differ only in that one coordinate of s which has the value b has the value a in s′.*

The common modeling convention is to assume that conditional on x these signals are independent and identically distributed, with $\Pr(s_i = x) = g > \frac{1}{2}$. This example satisfies the weak monotonicity condition and is explicitly considered in a subsequent section of the paper.

The above describes a lottery over the space $\Omega := \{a, b\} \times \{-1, 1\}^n \times \{a, b\}^n$. The first $n + 1$ dimensions represent payoff-relevant information and the last n dimensions represent the imperfect signals that agents learn. In this setting each agent's type is a double $\phi_i = (\theta_i, s_i) \in \Phi = \{-1, 1\} \times \{a, b\}$. I sometimes use the notation $\phi = (\phi_1, \ldots, \phi_n)$ and $\Phi^n = \times_{i=1}^n \Phi$. It is convenient to let s_{-i}, θ_{-i} and ϕ_{-i} denote the appropriate vectors of values for $N \backslash \{i\}$. Also, let s_{-ij}, θ_{-ij} and ϕ_{-ij} denote the appropriate vectors for $N \backslash \{i, j\}$.

Definition 2 *An* ***admissible information environment*** *is a joint probability distribution* $\nu(x, s, \theta)$ *on* $\{a, b\} \times \Phi^n$ *in which (i) weak monotonicity is satisfied; (ii) the vectors* θ *and s are independent of each other and; (iii)* $\mu(s') < \frac{1}{2} < \mu(s)$ *for some vectors s and s′.*

Finally, for some of the results I assume that utility is transferable, in the sense that participants have separable preferences over policy and a transferable resource,

$$U_i(p, x, t_i, \theta_i) = u_i(p; x, \theta_i) + t_i. \tag{2}$$

A choice function assigns a probability of selecting policy $p = a$ for every profile $\phi \in \Phi^n$. Given this collective choice problem, the natural benchmark is the first best or efficient policy that an aggregate welfare-maximizing planner would select

$$p^+(\phi) = \begin{cases} 1 \text{ if } \left\{\mu(s) > \frac{1}{2} \text{ and } |i : \theta_i = 1| \geq \frac{n+1}{2}\right\} \text{ or} \\ \quad \left\{\mu(s) < \frac{1}{2} \text{ and } |i : \theta_i = -1| \geq \frac{n+1}{2}\right\} \\ 0 \text{ if } \left\{\mu(s) < \frac{1}{2} \text{ and } |i : \theta_i = 1| \geq \frac{n+1}{2}\right\} \text{ or} \\ \quad \left\{\mu(s) > \frac{1}{2} \text{ and } |i : \theta_i = -1| \geq \frac{n+1}{2}\right\} \\ \frac{1}{2} \text{ if } \left\{\mu(s) = \frac{1}{2}\right\}. \end{cases} \tag{3}$$

The benchmark, $p^+(\cdot)$, also corresponds to the full information majority rule (FIMR) outcome and any equilibrium to a game that selects according to this rule satisfies what Feddersen and Pesendorfer (1997) term full information equivalence.

In this setting a natural communication and voting model involves a communication period, where participants simultaneously submit messages, and a voting period, where after hearing the messages participants simultaneously cast ballots. It is easy to see, by way of the revelation principle (Myerson 1982), that assuming that the message space is just $\{a, b\}$ does not limit generality. Similarly, a ballot is simply a choice from the set $\{a, b\}$. Thus, in period 1 participants make simultaneous message announcements $m_i \in \{a, b\}$ and in period 2 they cast ballots $v_i \in \{a, b\}$. The final policy is given by simple majority rule. Let m and v, both elements of $\{a, b\}^n$, denote profiles of messages and votes. Let m_{-i} and m_{-ij} denote the profile of messages from the participants $N \backslash \{i\}$ and $N \backslash \{i, j\}$ respectively. Given a message strategy, let $\mu(m_{-i}, s_i)$ denote the posterior probability that $x = a$ given the messages and private signal s_i. The natural equilibrium concept is perfect Bayesian equilibrium in weakly undominated voting strategies. This concept requires that for each $i \in N$, given the public profile of messages, m_{-i}, and private signal, s_i, participant i selects the alternative which is more desirable given a belief about x that is consistent with Bayes' rule and the equilibrium message strategies. In addition, the message strategies must be best responses given the voting strategies. The remainder of the paper investigates when there are perfect Bayesian equilibria in weakly undominated voting strategies (called **equilibria**) which make the policy selection $p^+(\phi)$ for each profile of states ϕ that occurs with positive probability. If this property is satisfied we say the equilibrium **implements** $p^+(\cdot)$.

WITHOUT EXTERNAL INCENTIVES

When participants care only about policy, they are willing to reveal their private information s_i if they expect the final policy to be responsive to this information in the right direction (at least weakly). This positive responsiveness depends on two features of the model: the extent to which participants believe that they are in the majority (comparisons of η_t^+ and η_t^-) and the extent to which private information about x is redundant. The first feature, the belief that one is in the majority can be defined simply.

Definition 3 *The information environment satisfies* ***preference optimism*** *if* $\eta_1^+ \geq \eta_1^-$ *and* $\eta_{-1}^+ \geq \eta_{-1}^-$.

The first result demonstrates that, even in settings where preferences can be strongly opposed, uncertainty about preferences can induce incentives for information transmission.

Proposition 1 *Any admissible environment satisfying preference optimism possesses an equilibrium which implements* $p^+(\cdot)$.

Proof: The proof is constructive. I show that the following is an equilibrium: each participant announces $m_i(s_i) = s_i$, given the message profile m each agent forms a posterior that corresponds to $\mu(s_i, m_{-i})$ for every (s_i, m_{-i}) that occurs with positive probability, and each participant votes for the policy he/she prefers given this belief (sincere voting). Clearly, sincere voting satisfies weak dominance given the posteriors. By construction, the beliefs $\mu(s_i, m_{-i})$ are consistent with Bayes' rule given truthful message strategies. It remains to verify that there is no incentive for a unilateral deviation from truthful messages. By weak monotonicity for each j, $\mu(s_j, m_{-ij}, a) \geq \mu(s_j, m_{-ij}, b)$. Because this strategy profile yields the policy that is optimal for i given s with probability $\eta^+_{\theta_i}$ the assumption that $\eta^+_{\theta_i} \geq \eta^-_{\theta_i}$ implies that a truthful message yields a weakly higher expected utility than a deviation. ■

Note that if the private preference types, θ, were publicly known and not all the same, then any participant with the minority type would be unwilling to share her private information. Thus, the above result demonstrates that uncertainty about preferences makes fruitful deliberation somewhat easier to support. This result is contrary to the conventional wisdom as it shows that aggregation can be easier in problems with uncertainty about preferences than in similar problems in which preferences are known.

One strong way for information to be redundant is given by a strengthening of Postlewaite and Schmeidler's (1986) condition of nonexclusivity. See also Palfrey and Srivastava (1989) for use of nonexclusivity in implementation. One such concept is called strong nonexclusivity. In the mechanism design literature Duggan (1997) presents results using this condition. In the signaling games literature Baron and Meirowitz (2004) present results using this condition. With binary signals satisfying weak monotonicity the condition can be defined as follows.

Definition 4 *The information environment satisfies **strong nonexclusivity** if for all $i \in N$ there are two distinct $j, k \in N\backslash\{i\}$ s.t.* $\Pr(s_i = s_j = s_k) = 1$.

This condition is sufficient for implementation of $p^+(\cdot)$.

Proposition 2 *Any admissible environment satisfying strong nonexclusivity possesses an equilibrium which implements $p^+(\cdot)$.*

Proof: The proof is constructive. By strong nonexclusivity for each $i \in N$ there exists a set $N_i \subset N$ s.t. $\Pr(s_i = s_j \forall j \in N_i)$ and N_i contains three participants (including i). For each $i \in N$, and thus each N_i, define the following function $\varrho^i : \{a, b\}^3 \to \{a, b\}$

$$\varrho^i(m) = \begin{cases} m_i \text{ if for } i, j, k \in N_i, m_j = m_i = m_k \\ b \text{ if for } t, j, k \in N_i, m_t = a \text{ and } m_j = m_k = b \\ a \text{ if for } t, j, k \in N_i, m_t = b \text{ and } m_j = m_k = a \end{cases} \tag{4}$$

Now define the mapping, $\varrho_{-i}(m_{-i}) \; : \; \{a, b\}^{n-1} \; \to \; \{a, b\}^{n=1}$ that translates m_{-i} into $(\varrho^1(m), \ldots, \varrho^{i-1}(m), \varrho^{i+1}(m) \ldots, \varrho^n(m))$ by taking the composition of all the functions $\varrho^j(m)$ for $j \in N\backslash\{i\}$. I now show that the following is an equilibrium: Each participant announces $m_i(s_i) = s_i$, given the message profile, m, each agent forms the posterior belief

$\mu(s_i, \varrho_{-i}(m))$ and each agent votes for the policy he or she likes best given this belief. It is clear that on the path the equilibrium policy corresponds to $p^+(\phi)$ for every ϕ that occurs with positive probability. By strong nonexclusivity for any m no unilateral deviation in m_i affects $\varrho^i(m)$ and thus a unilateral deviation by i does not affect the posterior of any participant in $N \backslash \{i\}$. Thus the message strategies are best responses. ■

While either of the above conditions is sufficient, it is not the case that satisfaction of one of these conditions is necessary for implementation of $p^+(\cdot)$. To see this suppose that there are nine participants and the information environment satisfied the following condition: for every realization of the random variable ϕ it is the case that s is a permutation of either $(a, a, a, b, b, b, a, a, a)$ or $(a, a, a, a, a, a, a, a, a)$ or $(b, b, b, a, a, a, b, b, b)$ or $(b, b, b, b, b, b, b, b, b)$. Further assume that each agent's private information is equally informative, in the sense that the number of agents observing each of the two possible signals is a sufficient statistic. In this case any unilateral deviation results in a profile of messages in which one type of message occurs $k + 1$ times (where k is divisible by 3) and the other type of message occurs $k - 1$ times. Consider beliefs that assume that when $k + 1$ messages are for a, the actual profile has k messages for a. In this context these beliefs induce voting strategies that create incentives for truthful revelation. While this information environment does not satisfy strong nonexclusivity, because it is not possible to infer which agents observed which signals following a unilateral deviation, a weaker condition is satisfied.

Definition 5 *The information environment is* ***locally flat*** *if for any two profiles s and s' that both occur with positive probability and which differ in exactly one coordinate (one participant's private signal)* $\max\{\mu(s), \mu(s')\} \leq \frac{1}{2}$ *or* $\min\{\mu(s), \mu(s')\} \geq \frac{1}{2}$.

Locally flat environments have the property that a unilateral deviation from truthful messages is either detectable or does not move anyone's posterior enough to change policy preferences. If it is possible to construct consistent beliefs which induce preferences over policy that are not affected by a unilateral deviation then local flatness is satisfied. Thus, a necessary condition for implementation of $p^+(\cdot)$ can be stated.

Proposition 3 *If there exists an equilibrium that implements $p^+(\cdot)$ then either preference optimism or local flatness or both are satisfied.*

Proof: Assume that neither condition is satisfied but that there is an equilibrium that implements $p^+(\cdot)$. Let $p(m)$ denote the probability that the policy $x = a$ is chosen following message profile m when players use equilibrium voting strategies. Because preference optimism is not satisfied, $\eta^+_{-1} < \eta^-_{-1}$ and $p(a, m_{-i}) \geq p(b, m_{-i})$ if $\mu(a, m_{-ij}, s_j) \geq \mu(b, m_{-ij}, s_j)$ for each i, j. Because $p^+(\cdot)$ is implemented by the equilibrium, $p(m) = p(m')$ if either $\max\{\mu(s), \mu(s')\} \leq \frac{1}{2}$ or $\min\{\mu(s), \mu(s')\} \geq \frac{1}{2}$. Thus, for a participant with type $\theta_i = -1$ to prefer being truthful it must be the case that for every (m_{-ij}, s_j), $\mu(a, m_{-ij}, s_j) \leq \mu(b, m_{-ij}, s_j)$ or both posteriors are either above $\frac{1}{2}$ or below $\frac{1}{2}$. But by weak monotonicity Bayes' rule implies that for any pairs (a, m_{-ij}, s_j)

and (b, m_{-ij}, s_j) that occur with positive probability $\mu(a, m_{-ij}, s_j) \geq \mu(b, m_{-ij}, s_j)$. Thus, it must be the case that one of the profiles is not possible (and Bayes' rule does not pin down the posterior) or $\frac{1}{2} \notin (\mu(b, m_{-ij}, s_j), \mu(a, m_{-ij}, s_j))$. This contradicts the assumption that local flatness is violated. ■

To see that local flatness is not sufficient return to the nine-agent example but assume that player 1's private signal is much more informative than the other private signals. In this case, following the profile (a, a, a, a, a, b, b), it is clear that at least one participant has lied. This is true because it is not possible for exactly two (not divisible by 3) participants to observe b. The presumption, however, that exactly one player has lied does not pin down which of the players is the liar. This determination can be important when the signal qualities differ (as in the case where 1's signal is very informative).

WITH TRANSFERS

In the remainder of the paper I consider settings in which preference optimism and local flatness are not satisfied. For simplicity I make the somewhat standard assumption that the private signals are conditionally independent with $g > \frac{1}{2}$ denoting the probability that $s_i = x$ (regardless of whether x is a or b).

State-contingent Transfers

Suppose that it is possible to construct mechanisms or institutions that distribute transfers based on both agent messages about s_i and the actual realized state, x. In this setting it is not difficult to see that some very simple institutions implement the first-best outcome. Specifically, consider a two-stage game in which participants are first asked to announce their private signal by submitting a message $m_i \in \{a, b\}$ and then participants observe the public messages, m, and vote. The departure point for this analysis is that, in addition to the expected payoff from policy, participants receive transfers given by the scheme $t_i(m_i, x)$. For each i this transfer function specifies a payment based on i's report m_i and the actual state, x.

Proposition 4 *There exist values $v_a^+, v_a^-, v_b^+, v_b^-$ (characterized by the conditions IC-i and IC-ii stated below) for which the two-stage game described above with transfers,*

$$t_i(m_i, x) = \begin{cases} v_a^+ \text{ if } m_i = a = x \\ v_a^- \text{ if } m_i = a \neq x \\ v_b^+ \text{ if } m_i = b = x \\ v_b^- \text{ if } m_i = b \neq x, \end{cases} \tag{5}$$

has an equilibrium which implements $p^+(\cdot)$.

Proof: Consider the defined game. In any PBE with weakly undominated voting in which participants send truthful messages, each agent votes for the policy it likes best given the beliefs $\mu(m_{-i}, s_i)$. Thus, following truthful messages policy corresponds to $p^+(\cdot)$. Given such a truthful strategy profile, the best deviation for i involves lying about both s_i and then voting for the policy it prefers given (m_{-i}, s_i). The remainder of the proof thus characterizes values of $v_a^+, v_a^-, v_b^+, v_b^-$ that make this type of deviation unattractive. I first show that the binding incentive compatibility conditions apply for $\theta_i = -1$ types and then derive the values $v_a^+, v_a^-, v_b^+, v_b^-$ to induce truthfulness by $\theta_i = -1$ types. Let λ_a denote the probability that the profile s_{-i} is such that s_i is pivotal in affecting the policy decision given that $x = a$. This is the probability that exactly α of the $n-1$ other signals are supportive of a conditional on $x = a$, when α solves

$$\begin{aligned}\frac{\pi g^{\alpha+1}(1-g)^{n-\alpha-1}}{\pi g^{\alpha+1}(1-g)^{n-\alpha-1} + (1-\pi)(1-g)^{\alpha+1} g^{n-\alpha-1}} > \frac{1}{2} \\ > \frac{\pi g^{\alpha}(1-g)^{n-\alpha}}{\pi g^{\alpha}(1-g)^{n-\alpha} + (1-\pi)(1-g)^{\alpha} g^{n-\alpha}}.\end{aligned} \tag{6}$$

By the assumption that for some vectors s and s', $\mu(s') < \frac{1}{2} < \mu(s)$ such a value α exists, and because $g, \pi \geq \frac{1}{2}$ the inequality $\alpha \leq \frac{n-1}{2}$ is satisfied. Similarly, let λ_b denote the probability that the profile s_{-i} is such that s_i is pivotal given that $x = b$. Formally,

$$\begin{aligned}\lambda_a &= \binom{n-1}{\alpha} g^{\alpha}(1-g)^{n-1-\alpha} \\ \lambda_b &= \binom{n-1}{\alpha} (1-g)^{\alpha} g^{n-1-\alpha}.\end{aligned} \tag{7}$$

Because $\alpha \leq \frac{n-1}{2}$ and $g \geq \frac{1}{2}$ the inequality $\lambda_a < \lambda_b$ is satisfied. If $\theta_i = -1$ the incentive compatibility condition for truthfully reporting (given the conjectured behavior by $N \backslash \{i\}$), as opposed to lying about both s_i and then voting optimally, is

$$\begin{aligned}&\pi g(\lambda_a \eta_{-1}^+ + v_a^+) + (1-\pi)(1-g)(\lambda_b \eta_{-1}^- + v_a^-) \geq \\ &\pi g(\lambda_a \eta_{-1}^- + v_b^-) + (1-\pi)(1-g)(\lambda_b^+ \eta_{-1}^+ + v_b^+)\end{aligned} \tag{IC1}$$

when $s_i = a$. Similarly the incentive compatibility condition for truthfully reporting when $s_i = b$ is

$$\begin{aligned}&\pi(1-g)(\lambda_a \eta_{-1}^- + v_b^-) + (1-\pi)g(\lambda_b \eta_{-1}^+ + v_b^+) \geq \\ &\pi(1-g)(\lambda_a p \eta_{-1}^+ + v_a^+) + (1-\pi)g(\lambda_b \eta_{-1}^- + v_a^-).\end{aligned} \tag{IC2}$$

The incentive compatibility condition for a $\theta_i = 1$ type that observes $s_i = a$ is

$$\begin{aligned}&\pi g(\lambda_a \eta_1^+ + v_a^+) + (1-\pi)(1-g)(\lambda_b \eta_1^- + v_a^-) \geq \\ &\pi g(\lambda_a \eta_1^- + v_b^-) + (1-\pi)(1-g)(\lambda_b^+ \eta_1^+ + v_b^+).\end{aligned} \tag{IC3}$$

The incentive compatibility condition for a $\theta_i = 1$ type that observes $s_i = b$ is

$$\begin{aligned}&\pi(1-g)(\lambda_a \eta_1^- + v_b^-) + (1-\pi)g(\lambda_b \eta_1^+ + v_b^+) \geq \\ &\pi(1-g)(\lambda_a p \eta_1^+ + v_a^+) + (1-\pi)g(\lambda_b \eta_1^- + v_a^-).\end{aligned} \tag{IC4}$$

It remains to show that there is a pair of values $v_a^+, v_a^-, v_b^+, v_b^-$ satisfying this system. A constraint reduction is helpful. Because $\pi g > (1-\pi)(1-g)$, and $\eta_{-1}^+ < \eta_1^+$, $\eta_{-1}^- > \eta_1^-$ if Condition IC1 is satisfied then Condition IC3 is (with strict inequality). Note that Conditions IC2 and IC4 can be rewritten as

$$(\eta_{-1}^+ - \eta_{-1}^-)((1-\pi)g\lambda_b - \pi(1-g)\lambda_a) \geq \pi(1-g)(v_a^+ - v_b^-) + (1-\pi)g(v_a^- - v_b^+) \tag{8}$$
$$(\eta_1^+ - \eta_1^-)((1-\pi)g\lambda_b - \pi(1-g)\lambda_a) \geq \pi(1-g)(v_a^+ - v_b^-) + (1-\pi)g(v_a^- - v_b^+). \tag{9}$$

Because $(\eta_1^+ - \eta_1^-) > (\eta_{-1}^+ - \eta_{-1}^-)$, Inequality 8 is more restrictive if $(1-\pi)g\lambda_b > \pi(1-g)\lambda_a$ and Inequality 9 is more restrictive if $(1-\pi)g\lambda_b, < \pi(1-g)\lambda_a$. Assuming that the second inequality holds and substituting for λ_a, λ_b and multiplying by a constant yields

$$\frac{(1-\pi)(1-g)^\alpha g^{n-\alpha}}{\pi g^\alpha(1-g)^{n-\alpha} + (1-\pi)(1-g)^\alpha g^{n-\alpha}} < \frac{\pi g^\alpha(1-g)^{n-\alpha}}{\pi g^\alpha(1-g)^{n-\alpha} + (1-\pi)(1-g)^\alpha g^{n-\alpha}}. \tag{10}$$

But the left-hand side is just the difference between 1 and the right-hand side. By Inequality 6, α makes the right-hand side less than $\frac{1}{2}$, implying that in fact the second inequality cannot hold. Thus, the first inequality holds and Condition IC2 binds. The relevant constraints can be restated as

$$(\eta_{-1}^+ - \eta_{-1}^-)(\pi g\lambda_a - (1-\pi)(1-g)\lambda_b) \geq \pi g(v_b^- - v_a^+) + (1-\pi)(1-g)(v_b^+ - v_a^-) \tag{IC-i}$$
$$(\eta_{-1}^+ - \eta_{-1}^-)((1-\pi)g\lambda_b - \pi(1-g)\lambda_a) \geq \pi(1-g)(v_a^+ - v_b^-) + (1-\pi)g(v_a^- - v_b^+). \tag{IC-ii}$$

Finally, to show that it is possible to simultaneously satisfy these conditions note that the system of equations is satisfied with equality if

$$\begin{aligned} v_a^+ - v_b^- &= v_a := \lambda_a\left[\eta_{-1}^- - \eta_{-1}^+\right] \\ v_b^+ - v_a^- &= v_b := \lambda_b\left[\eta_{-1}^- - \eta_{-1}^+\right]. \end{aligned} \tag{11}$$

This completes the proof. ■

A reasonable requirement is that each participant prefer participation in the institution – helping to select policy and receiving the transfers – to non-participation. Given that each agent's signal is possibly informative and all messages are made public prior to voting, a swing voter's curse (Feddersen and Pesendorfer 1996) cannot surface in this type of equilibrium. Namely, each participant would rather send an optimal message than be excluded from the game on policy grounds. Accordingly, if the transfers are constrained to be non-negative in both states, each agent prefers participation. Participation holds the promise of possibly influencing policy and possibly earning transfers.

Setting $v_a^- = v_b^- = 0$ satisfies this requirement. A second question is natural. How large must the transfers given by Equations 11 be? If $x = a$ and the group size is n then the expected transfer to any participant is $Et_a^n = \left[\eta_{-1}^- - \eta_{-1}^+\right] g\lambda_a$.

It is clear that this term goes to 0 as $n \to \infty$. Moreover, by conditional independence the expected sum of transfers conditional on $x = a$ is $E(\sum t_a^n) = n\left[\eta_{-1}^- - \eta_{-1}^+\right] g\lambda_a$. Because both $\left[\eta_{-1}^- - \eta_{-1}^+\right]$ and g are bounded by 1 and λ_a tends to 0 faster than $\frac{1}{n}$ it must be the case that $nEt_a^n \to 0$. A similar argument establishes the conclusion for the $x = b$ conditional sum.[5]

Corollary 1 *The participation constraint is satisfied if $v_a^- = v_b^- = 0$, $v_a^+ = v_a$ and $v_b^+ = v_b$. Moreover, as $n \to \infty$ the expected sum of transfers, $E(\sum t^n) = \pi E(\sum t_a^n) + (1-\pi)E(\sum t_b^n)$, converges to* 0.

An alternative interpretation is that of probabilistic monitoring and sanctioning. Suppose that participants play the transfer-free communication and voting game with one modification. When the state is $x = a$ a third party sanctions participants that announce $m_i = b$ with probability q_a and when the state is $x = b$ a third party sanctions participants that announce $m_i = a$ with probability q_b. Let c_a denote the cost of being sanctioned when $x = a$ and c_b denote the cost of being sanctioned when $x = b$. These sanctions may pertain to reelection or career concerns. In this context Proposition 4 has the following corollary.

Corollary 2 *With ex-poste monitoring, if $q_b c_b = v_a$ and $q_a c_a = v_b$ there is an equilibrium which implements $p^+(\cdot)$. As $n \to \infty$, the values $q_a c_a$ and $q_b c_b$ converge to* 0.[6]

It is not surprising that ex-poste monitoring can create the appropriate incentives. The novelty of Corollary 2 is that for large groups the magnitude of the sanction or monitoring probability can be quite small; as group size tends to infinity incentives can be created even when these magnitudes vanish.

Message-contingent Transfers

One shortcoming of the transfer schedules described above is that they depend on the state, x. This may be problematic if the time difference between policy-making and observation of x is large. Alternatively, it is not always reasonable to assume that x is ever observed. In settings like Example 1: above, the state x can correspond to a shock that is observed only if a particular policy is chosen. I now construct an institution in which the transfers do not depend on x. In these games, instead of betting on x, participants bet on the other participants' bets.

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5 If the participation constraint does not need to be satisfied it is possible to modify the mechanism and satisfy expected budget balance.

6 The participation constraint will be satisfied if a small modification is made. Suppose the third party gives all participants a reward of $\max\{q_a c_a, q_b c_b\}$ regardless of what happens in the deliberative process (say a salary) and then sanctions in the manner described in Corollary 2.

Proposition 5 *There exists a value ξ s.t. the communication and voting game that distributes transfers*

$$t_i'(m^s) = \begin{cases} \frac{v_a}{\xi} \text{ if } m_i = a \text{ and } \#\{j : m_j^s = a\} \geq \frac{n+1}{2} \\ \frac{v_b}{\xi} \text{ if } m_i = b \text{ and } \#\{j : m_j^s = b\} \geq \frac{n+1}{2} \\ 0 \text{ otherwise} \end{cases} \tag{12}$$

has an equilibrium which implements $p^+(\cdot)$.

Proof: Suppose again that policy is given by $p^+(\cdot)$, but this time the transfers are given by Equation 12. Let

$$\begin{aligned} \xi_c &= \sum_{j=\frac{n+1}{2}}^{n-1} \binom{n-1}{j} g^j (1-g)^{n-1-j} \\ \xi_f &= \sum_{j=k\frac{n+1}{2}}^{n-1} \binom{n-1}{j} (1-g)^j g^{n-1-j} \end{aligned} \tag{13}$$

denote the probability that at least $\frac{n+1}{2}$ of the remaining $n-1$ participants have received correct and incorrect private signals respectively. Because $g > \frac{1}{2}$ the inequality $\xi_c - \xi_f > 0$ holds. Following the approach used above, I consider the incentive of a type $\theta_i = -1$ agent that has observed $s_i = a$ to reveal s_i and vote optimally instead of lying about s_i and voting optimally. The incentive compatibility condition is

$$\begin{aligned} &\pi g \left(\lambda_a \eta_{-1}^+ + u_a \xi_c\right) + (1-\pi)(1-g)(\lambda_b(1-\eta_{-1}^+) + u\xi_f) \geq \\ &\pi g(\lambda_a(1-\eta_{-1}^+) + u\xi_f) + (1-\pi)(1-g)(\lambda_b \eta_{-1}^+ + +u_b \xi_c). \end{aligned} \tag{IC-i$'$}$$

Similarly the incentive compatibility condition for truthfully reporting when $s_i = b$ is

$$\begin{aligned} &\pi(1-g)(\lambda_a(1-\eta_{-1}^+) + u_b \xi_f) + (1-\pi)g(\lambda_b \eta_{-1}^+ + u_b \xi_c) \geq \\ &\pi(1-g)(\lambda_a \eta_{-1}^+ + u_a \xi_c) + (1-\pi)g(\lambda_b(1-\eta_{-1}^+) + u_a \xi_f). \end{aligned} \tag{IC-ii$'$}$$

Repeating arguments that appear in the proof of Proposition 4 demonstrates that these are the binding incentive compatibility constraints. A sufficient condition for incentive compatibility is

$$\begin{aligned} u_a \xi_c - u_a \xi_f &= v_a \\ u_b \xi_c - u_b \xi_f &= v_b. \end{aligned} \tag{14}$$

Accordingly, for $\xi = \xi_c - \xi_f$ the claim is established. ∎

As before, the participation constraint is satisfied, and the net transfer volume diminishes as n gets large. Alternatively, if the participation constraint does not need to be satisfied, expected budget balance can be satisfied. One interpretation of the game in

Proposition 5 is that participants choose which of two clubs/groups to join. One group has the charter "we believe state a is true" and the other has the charter, "we believe state b is true". The club that turns out to be bigger receives a rent that it distributes to members. Participants then observe the size of their club prior to voting.

As in the previous section an alternative interpretation, based on monitoring and sanctioning, is possible; this time, however, it is ex-interum monitoring. Suppose that when m_i is the opposite of the majority of the other announcements a participant suffers disutility for voicing a seemingly unlikely argument. Let ς_a and ς_b denote the costs of announcing a and b respectively when the majority of other participants disagree. The following is a corollary of Proposition 5.

Corollary 3 *With ex-interum monitoring if* $\varsigma_a = \frac{v_b}{\xi}$ *and* $\varsigma_b = \frac{v_a}{\xi}$ *there is an equilibrium which implements* $p^+(\cdot)$. *As* $n \to \infty$ *the terms* ς_a *and* ς_b *converge to* 0.[7]

The convergence result follows from the fact that $\xi_c - \xi_f$ converges to 1 while v_a and v_b converge to 0. In the games of this section equilibrium multiplicity is striking; there are also pooling equilibria in which all participants send the same message regardless of their private signal, s_i.

WELFARE COMPARISONS

The previous two sections demonstrate that, in designing institutions, transfers can facilitate information aggregation. The corollaries demonstrate that the analysis with transfers can inform institutional design when transfers are not possible; with even very small sanctions (either for being wrong or just perceived as likely to be wrong) the relevant external incentives can be induced by monitoring the communication of participants. In some settings, however, this type of monitoring is not feasible and direct transfers are necessary. A natural question surfaces because these transfers cannot simultaneously satisfy the participation conditions and balance the budget. Are the efficiency gains from information aggregation sufficient to offset the cost to the institution designer of making transfers.[8] A very general treatment of this question would appeal to the mechanism design approach and compare the best direct mechanisms with and without transfers. Chwe (1999), for example, moves beyond voting settings and considers optimal mechanisms without transfers. While Chwe's analysis cannot be applied to the current environments, because it does not allow participants with types $\theta_i = 1$ and $\theta_i = -1$ to coexist in the same society, the intuition can be extended. This approach involves institutions in which participants report their private information ϕ_i to a mediator. The mediator then selects policy according to the mapping $p^+(\phi)$ unless at least one of the

7 As in the case of Corollary 2, it is easy to modify the game to satisfy the participation constraint (say by adding a salary).

8 Note that if only aggregate welfare matters then the transfers are costless. Transfers represent debits to the institutional designer and credits to the participants.

following conditions is satisfied: (i) the number of participants with type $\theta_i = 1$ is $\frac{n-1}{2}$, $\frac{n+1}{2}$ or $\frac{n+2}{2}$; (iii) the report of s is such that there is some $i \in N$ such that the profile s' that results from i switching her report of s_i satisfies $\mu(s') < \frac{1}{2} < \mu(s)$ or $\mu(s) < \frac{1}{2} < \mu(s')$. If one of these conditions is satisfied then the mediator selects policy by a different (and possibly random) function. These functions are selected to satisfy the relevant incentive compatibility conditions.

One shortcoming of these optimal mechanisms is that they tend to be rather peculiar and often require mediation or severe limitations on what type of communication is allowed. Rather than develop these optimal mechanisms, I maintain the focus on institutions with unmediated communication and free voting under majority rule. This section, then, compares equilibria to the communication game without external incentives to the truthful equilibria of the game characterized by Proposition 4 with $v_a^- = v_b^- = 0$. One complication is that the games possesses multiple equilibria. For instance, a pooling equilibrium with uninformative communication exists in the game without external incentives. In addition, there may be many asymmetric equilibria in mixed and pure strategies. The analysis focuses on a particularly simple equilibrium selection. In both the games with and without external incentives, I focus on the class of symmetric pure strategy equilibria and study the properties of the equilibria that maximize the probability that the chosen policy is optimal for a majority of the participants. Meirowitz (2003) presents an analysis of the communication and voting game without transfers, and this section draws on results derived there.

To be more precise, equilibrium probabilities of selecting the policy that is optimal for a majority are computed and then the difference between these probabilities is compared to the expected sum of transfers, $E(\sum t^n) = \pi E(\sum t_a^n) + (1-\pi)E(\sum t_b^n)$, from the game with transfers. To simplify the calculations I focus on the class of environments described in Technical Example 1: and assume that the private signals, s_i are conditionally independent. In other words I assume that (i) the types θ_i are drawn from Bernoulli trials with $\Pr(\theta_i = 1) = z > \frac{1}{2}$; (ii) the states a and b are equally likely; and (iii) the private signals are identically distributed and conditionally independent with $\Pr(s_i = x) = g$. This class of settings does not satisfy local flatness nor preference optimism, and a particular informational environment in this class is characterized by just two parameters, z and g.

For simplicity, assume that there are $n = 3$ participants. In this case the probability that $p^+(\cdot)$ selects the socially efficient policy is just $1 - (1-g)^3 - 3(1-g)^2 g$, which simplifies to $3g^2 - 2g^3$. In this case the expected sum of transfers is given by

$$\begin{aligned} ET &= 3\left[\eta_{-1}^- - \eta_{-1}^+\right] 2g(1-g) \\ &= 6\,[2z-1]\,g(1-g). \end{aligned} \tag{15}$$

Conversely, in the game without transfers as long as z is large enough there is a symmetric pure strategy equilibrium in which $m_i(s_i, \theta_i)$ is equal to s_i if $\theta_i = 1$ and $m_i(s_i, \theta_i)$ is equal to $\{a, b\}\backslash\{s_i\}$ if $\theta_i = -1$. That is participants with $\theta_i = 1$, are truthful about s_i and participants with $\theta_i = -1$ lie. In this equilibrium the public messages are informative (because $z > \frac{1}{2}$ implies that it is more likely that a randomly chosen participant has type $\theta_i = 1$, and is honest), but less efficient than if messages were truthful. Following these messages voters use the available public and private information and vote optimally. The corresponding probability that the policy which is best for a majority is chosen is given by $3q^2 - 2q^3$ where

$$q = zg + (1 - z)(1 - g) \tag{16}$$

is a measure of the equilibrium signal quality. Whether the institution with transfers is better than the institution without transfers can be determined by comparing the gain in the probability of choosing correctly, $G = \left[3g^2 - 2g^3\right] - \left[3q^2 - 2q^3\right]$, with the loss associated with the expected sum of transfers, $ET = 6\,[2z - 1]\,g(1 - g)$.

This difference is given by

$$D = \left[3g^2 - 2g^3\right] - \left[3(zg + (1 - z)(1 - g))^2 - 2(zg + (1 - z)(1 - g))^3\right] \\ -6\,[2z - 1]\,g(1 - g). \tag{17}$$

Figure 1 plots values of D as a function of the parameters g and z. The figure demonstrates that the difference, D, is increasing in g and decreasing in z. The figure also demonstrates that for some parameterizations of z and g the difference is positive, and

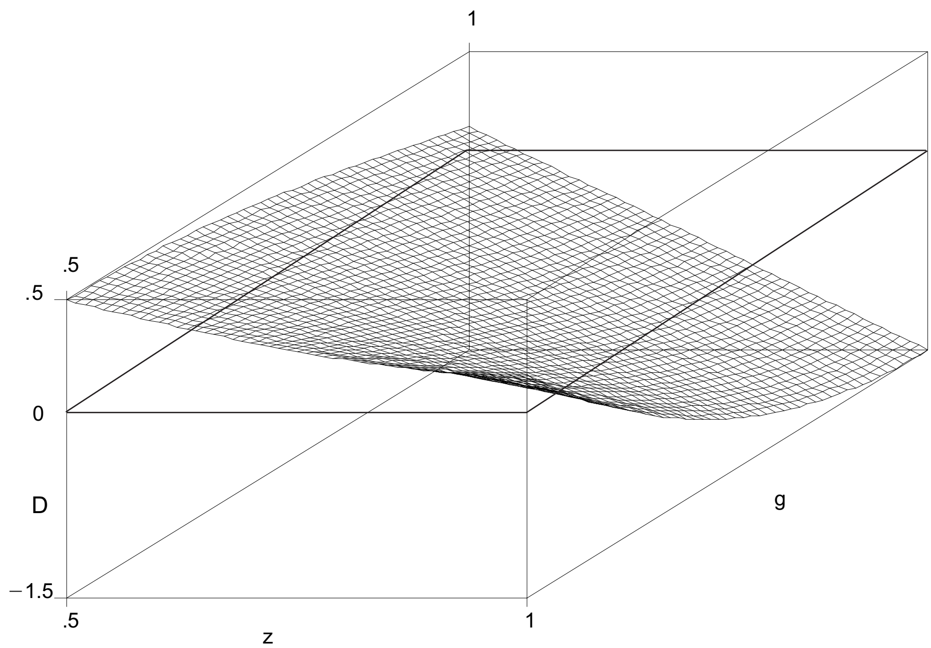

Figure 1. Welfare gain from transfers.

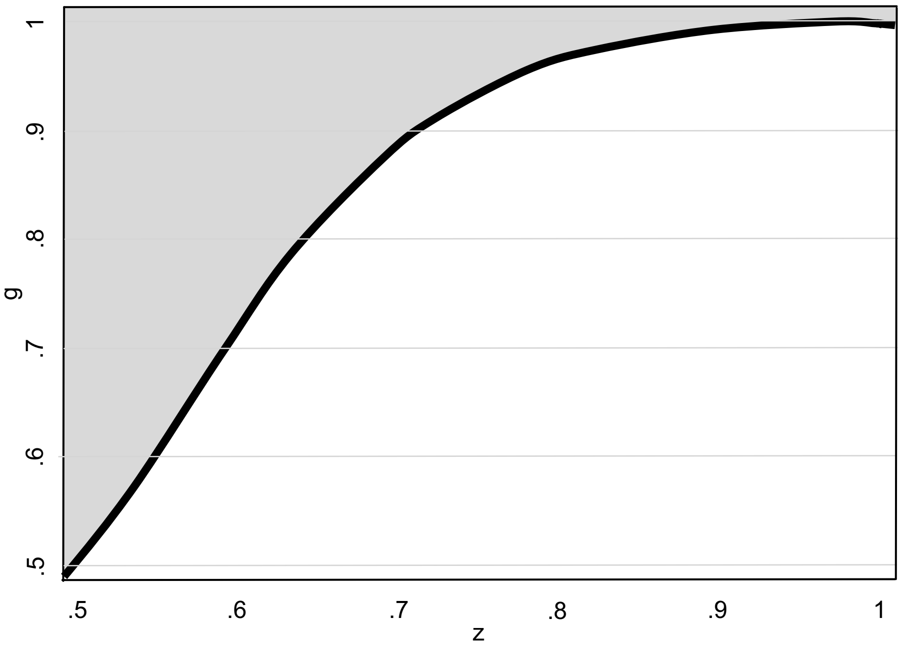

Figure 2. When are transfers efficient? Shaded regions indicate positive values of D.

thus the institution with transfers is more attractive. For other parameterizations the difference is negative, and thus the institution without transfers is more attractive.

Figure 2 clarifies how the graph of $(D(g, z), g, z)$ crosses the plane where $D = 0$. Specifically the figure shows which parameterizations result in positive (negative) values of D.

In larger groups the calculations become far more tedious, but a similar conclusion can be drawn. For some problems the use of external incentives is efficient and for others the drain on resources may not be justified.

Aside from this section and a few motivating examples this paper has remained agnostic as to the fine details of the informational environment. In many settings the gain in the probability of choosing the majority preferred policy converges to 0 and the expected sum of transfers also converges to 0. In this case analysis of the rate of convergence is necessary. In the special case of the settings described in Technical Example 2, more can be said. In these informational environments nature first determines whether the types θ are Bernoulli trials with $\Pr(\theta_1 = 1) = z$ and $\Pr(\theta_1 = 0) = 1 - z$ as above or whether the types are identical with $\Pr(\theta_i = 1\, \forall i \in N) = z$ and $\Pr(\theta_i = 0\, \forall i \in N) = 1 - z$. The types are generated by the Bernoulli process with probability $1 - c$ and with probability c all participants receive the same type. When $c \geq \frac{1}{2}$ preference optimism is satisfied regardless of n and transfers are not needed. When $c < \frac{1}{2}$ and $z \neq \frac{1}{2}$ preference optimism is not satisfied for sufficiently large groups. Meirowitz (2003) considers the communication and voting game without transfers and analyzes the asymptotics of the best pure strategy symmetric equilibrium in these settings. Proposition 5 of that paper establishes that for the best symmetric pure strategy equilibria the probability of selecting the majority preferred policy is eventually bounded away from one if

$$\frac{\pi q}{\pi q + (1-\pi)(1-q)} < 1 - c(1-z). \tag{18}$$

Recall that $q = zg + (1-z)(1-g)$. This means that in these settings the gain is eventually strictly positive. This fact and Corollary 1 imply that in these settings for sufficiently large groups it is better to design institutions with transfers than to allow communication and voting without transfers.

DISCUSSION

Despite the presence of incentives for deception in settings involving communication and voting, the news from strategic models is not all bad. If the institutions can distribute transfers to individuals then it is possible to create incentives for participants to share their private information even when preference alignment is unlikely. The transfers need not be very large. Asking participants to forecast each other's forecasts can be as informative as asking them to forecast the state. The structure of institutions that work well is amenable to some simple decentralizations. Examples include the sale of state-contingent securities at fixed prices, trading of state-contingent and risk-free securities at market-determined prices [9], or the creation of clubs (or parties) that distribute member subsidies according to membership. Alternatively, the analysis justifies the design of institutions in which arguments about facts are made public and participants are given reasons to care about perceptions of their competence.

These findings offer guidance about what is needed for a justification of efficient information-sharing in deliberative settings by strategic participants. Expectations of full preference and information aggregation require strong assumptions about commonality of interests, information structures in which no information is privately possessed, or the presence of externally motivated incentives. While the reply of a dedicated deliberative democrat may be that participants in ideal deliberation value truthfulness, and are thus opposed to lying, the analysis sheds light on when aggregation may not work well and how institutions can be amended to improve aggregation in the presence of participants that are less noble than the ideal of deliberative democrats and akin to James Madison's expectation, "... more disposed to vex and oppress each other than to cooperate for their common good" (*Federalist* 10, pp. 131–2).

[9] Meirowitz (2005b) builds on Proposition 4 to develop a model in which participants trade both a risk-free and risky security. Equilibrium prices aggregate the private information.

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