THE PARADOX OF UNBIASED PUBLIC INFORMATION

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Recent game-theoretic literature on juries proposes many reforms including the abandonment of the unanimity rule. Considering the scope of the proposed change, this paper sets out to do one thing: it tests the critical game-theoretic assumption that jurors vote on the basis of being pivotal. The test is devised such that if the groups do well in aggregating dispersed information, they would support the game-theoretic view of juries; if not, they would oppose the game-theoretic view. Here is how. In theory, as shown in the paper, large enough juries remain relatively unaffected when public signals the jurors observe happen to be misleading because theoretical juries do not erroneously overweight the public signals at the expense of the private signals. In reality, however, each individual may overweight misleading public signals leading real juries to a terrible outcome. It is this potential for direct contradiction between theoretical and experimental juries that makes our experimental test sharper than previous tests: given misleading public signals, rational voting would still produce information aggregation; naïve voting would not. In prior research with no public signals, both rational and naïve voting produced information aggregation. Hence, we present a sharper test. Certain public policy implications of our work pertaining to the media are offered.

I. Introduction:

Markets do quite well in aggregating dispersed information about preferences over private goods (Hayek, 1948), but when markets fail we often resort to firms and governments. Firms and governments must still aggregate private information and they do it with the help of a suitable incentive system or collective decisionmaking. For this paper, we assume there is no incentive problem and focus on collective decisionmaking in the special case when informed individuals share a common goal in the sense that if each had full information, each would choose the true hypothesis.

The first mathematical work in this area appears to be Condorcet's jury theorem (1785). It states that, under certain conditions, a majority of partially informed individuals is more likely to choose the true hypothesis than an average voter. Moreover, the probability that a majority chooses the true hypothesis approaches 1, as the size of the group approaches infinity. In other words, majority-rule aggregates decentralized information. Recently, Austen-Smith and Banks (1996) argued, however, that for information aggregation to occur, the votes must be informative; but informative votes would not be rational unless the aggregation rule happens to be the optimal rule. That is, rational voting may not produce information aggregation. Back in 1995-96, it seemed bad news: rationality could not seem to coexist with majority rule even when voters shared a common goal.

A series of recent papers have since restored optimism in majority-rule decisionmaking by showing that rational voting is not inimical to information aggregation, rather rationality yields better information aggregation than possible under sincere (naïve) voting (Coughlan 2000; Feddersen and Pesendorfer 1998; Ladha 1998; Wit 1998; McLennan 1998; Myerson 1997; Dekel and Piccione, 2000). While this restoration of optimism is good news, it is based only on *theory*. What we want to do is to test this theory experimentally, with a view to its public policy implications. Allow us to explain intuitively our main idea while we introduce our experimental work; the omitted details appear in subsequent sections.

Like previous experimental work (Ladha, Miller and Oppenheimer 1997; McKelvey and Palfrey, 2001), we construct a case in which each of our experimental subjects receives one private signal correlated with the true state, and the subjects together predict the true state by a pre-specified aggregation rule; in this paper we consider majority-rule voting. For a moment, let the model parameters be such that majority-rule is not the optimal aggregation rule. Then rationality demands, as per the theorem provided later, that some individuals vote contrary to their signals. Previous experiments show that some individuals indeed do, and these findings constitute the main evidence in support of rational voting. The problem, however, is that many subjects vote contrary to their signals even when it is not rational to do so; we found this when majority-rule was the optimal rule requiring each subject to vote informatively. In essence, we think that the data are far too noisy, and hence, conclusions of previous studies are ambiguous. It is necessary to develop a sharper experimental test.

Here is our twist: in addition to one private signal per subject, we display two public signals, drawn from the same distribution, so that each participant sees three signals – one private and two public signals. If each subject were to choose the true state *as if* acting in solitude, surely each would decide on the basis of all three signals. But voting as a member of a committee, each must also base her vote on her assessment of what others should have observed under the assumption that she is pivotal (a tie-breaker); the assumption is the cornerstone of rational voting because when a voter is not pivotal, it does not matter how she votes because she cannot change the group decision; her utility, as specified later, is one if the *group* is right, zero if wrong.

What effect would public signals have on the quality of group decision? We need to consider three possibilities: the two public signals are split, both support the true hypothesis, and both are misleading because both support the false hypothesis. When the public signals are not misleading, they improve group performance in *theory* and, we expect, in *practice*, although improvement is only marginal in large groups because large groups are already so accurate that there is not enough space left to improve things. When the public signals are misleading, then in *theory,* large groups continue to be effective; see Theorem 1, but we recommend reading Examples 2 and 3 for it. *In practice*, however, the misleading public signals may sway each voter, including those whose private signals point in the right direction, toward the false hypothesis. Thus, the misleading public signals, which would cause only marginal damage in theory, could do real harm *in practice*. Combining gains from supportive and losses from misleading signals, it follows that public signals can do real harm in *practice*, but not in *theory*.

In theory, large enough juries remain relatively unaffected by misleading public signals because *theoretical juries* do not erroneously overweight the public signals at the expense of the private signals. *In practice*, however, each individual may overweight the public signals leading the group to a terrible outcome when the public signals are misleading. It is this potential for direct contradiction between theoretical and experimental groups that makes our experimental test sharper than previous tests. In our experiments, given misleading public signals, rational voting would still produce information aggregation; naïve voting would not. In prior research with no public signals, both rational and naïve voting produced information aggregation. Hence, we have a sharper test.

We focus on group performance: if the groups do well with misleading public signals, they would support the game-theoretic view of juries; if not, they would not. In contrast, previous experiments, with majority rule voting, could not focus on group performance because both strategic and naïve voting led to information aggregation; any expected difference in the magnitude of information aggregation was difficult to decipher based on limited experimental data. Consequently, previous experiments had to focus on individual performance: those who voted contrary to their signals seemed to be doing the strategic thing, but as we noted before it is unclear whether such contrary votes were driven by strategic considerations or errors. It would make for a better test if we can assert with greater confidence that the participants intended, rather than just appeared, to vote strategically. In the experiment we propose, we get closer to learning the participant's intent. If groups are repeatedly swayed by the public signals, then we know that the case for strategic voting is weak. And that is what makes our test superior to previous tests. In our setting, real juries are either with game theory or against it! Examples 2 and 3 make all our assertions crystal clear.

Stated somewhat imprecisely, public signals may start an information cascade if people do not vote on the basis of being pivotal. This information cascade differs from the information cascade in the case of private goods (Bikhchandani et al). The private-good cascade leads people to either good private decisions (good restaurant perhaps) with substantial gains, or bad private decisions with substantial losses. However, a collective-decision cascade, *when it occurs in reality*, leads to (i) a good collective decision, with only *marginal* gain in the accuracy of large groups, or (ii) a bad collective decision, with *substantial* loss in group accuracy. Note however that, *in theory*, there can be no information cascade in the case of a collective decision (Dekel and Piccione, 2000). Thus, if we do indeed find information cascades in practice, then we have a stronger basis to reject the theory on the grounds that it does not represent the voting behavior of real juries.

The implications for policymaking are now obvious. Consider some examples. Should the members of a jury be allowed to question trial lawyers when a question may serve as a public signal for the rest of the jurors? Should only one point of view be expressed on the floor of the House (few public signals), or must we insist on multiple points of view (many public signals)? Perhaps these questions would not be critical for rational voters, but are of utmost relevance otherwise. So let us move to our results and their relevance.

Based on our pilot results, it appears that groups were swayed toward wrong decisions by misleading public signals. That is, individuals did not vote as prescribed by the game-theoretic literature on juries even though by so doing they could have done better. We think that these results will be upheld, with greater conviction, after we have done more experiments especially with larger groups of size 15 or so; down the road Table 1 explains the basis of our conviction.

If our pilot results are upheld, we could use game-theory to prescribe behavior, but we ought to accept people the way they are and formulate policies based on the way they actually behave till the day the merit of rationality in a jury situation dawns upon them.

Moreover, if upheld, we would have identified a social process that leads to group failure, rather than group success: an orator by making public his private, but misleading, information can sway his audience to take a wrong path which they otherwise would not have. The failure is not due to the orator's strategic bias or skullduggery. Quite to the contrary, we assume that the orator receives a random draw. Indeed, the problem is especially likely under such circumstances: each individual follower, knowing that the orator is unbiased, may update her beliefs in a way that incorporates the public information, but does not vote on the basis of being pivotal. The end result is *less effective* group judgments than if the information were publicly unavailable. We interpret this as being analogous to the "groupthink" phenomenon: if the leaders in spotlight focus on the same bits of information and ignore crucial bits of obscure information, bad things happen. Each group member, confident in the group and its decision processes, chooses not to "disrupt" the group with privately held information that seems to contradict an emerging consensus.

Subsequent sections describe the jury game, introduce our experiments, present the experimental results and offer conclusions.

II. The jury game

Imagine a committee of n individuals, denoted by the set N = {1,...,n}. The committee must distinguish between the null hypothesis A and the alternate hypothesis B. Sometimes we will think of A as being the hypothesis that a defendant is innocent. Later A and B will represent colors of our experimental marbles. Each individual has the same prior probability $\pi = P(A) < 1$ that the true hypothesis is A.

Each individual observes a private signal $s_i \in \{\alpha,\beta\}$ pertaining to the true hypothesis as per the following distributions: $q_\alpha = P(s=\alpha|A) \in (.5,1]$; and $q_\beta = P(s=\beta|B) \in (.5,1]$. The signals are independent conditional on the state. After observing the private signal, each juror selects an action from the set {**a**,**b**} to maximize her expected utility, where **a** (resp. **b**) is to accept hypothesis A (resp. B). Let each juror's utility from various action-hypothesis combinations be as follows: u(**a**,A) = 1 = u(**b**,B), and u(**a**,B) = 0 = u(**b**,A). Suppressing the i subscript, let v(*s*) be the individual's action after observing signal *s*. Then, v(α)= **a** if and only if E[u(**a**,.| α) > E[u(**b**,.| β) that is, if and only if P(A|α) > P(B|β), and by Bayes' rule, if and only if $\frac{P(\alpha|B)}{P(\alpha|A)} = \frac{1-q_\beta}{q_\alpha} < \frac{\pi}{1-\pi}$.

Similarly, $v(\beta) = b$ if and only if $\frac{\pi}{1-\pi} < \frac{q_\beta}{1-q_\alpha}$.

<u>Definition</u>. An action v is <u>informative</u> if the individual chooses action **a** upon observing signal α, and action **b** upon observing signal β.

A decision-maker, *acting in solitude*, would act informatively if and only if P(A|α) > P(B|α) and P(B| β) > P(A|β); that is, if and only if

$$\frac{1-q_\beta}{q_\alpha} < \frac{\pi}{1-\pi} < \frac{q_\beta}{1-q_\alpha}. \qquad (1)$$

If $\pi = .5$, then (1) would hold for all $q_\alpha > .5$ and $q_\beta > .5$ leading to an informative action. Figure 1 shows the complete picture. Let $x = \frac{\pi}{1-\pi}$ and let the horizontal line be the x-axis. Then, if $x \le (1-q_\beta)/q_\alpha$, choose b irrespective of the observed signal; if $x \ge q_\beta/(1-q_\alpha)$, choose a irrespective of the observed signal; and if x lies in the middle, choose informatively. Obviously, for a sufficiently high (resp. low) $\pi = P(A)$, a decision-maker would always choose **a** (resp. **b**), and be correct with probability π (resp. 1-π). If she chose informatively, she would be correct with probability $p = P(s=\alpha|A)\ P(A) + P(s=\beta|B)\ P(B) = q_\alpha \pi + q_\beta (1-\pi)$. Note that the votes would be dependent unless $\pi = 0$ or 1, or $q_\alpha = q_\beta$. For example, P (i and j vote correctly) = $P(sig_i=\alpha, sig_j=\alpha \mid A)\ P(A) + P(sig_i=\beta, sig_j=\beta \mid B)\ P(B) = q_\alpha^2 \pi + q_\beta^2 (1-\pi) \neq p^2$ unless $\pi = 0$ or 1, or $q_\alpha = q_\beta$.

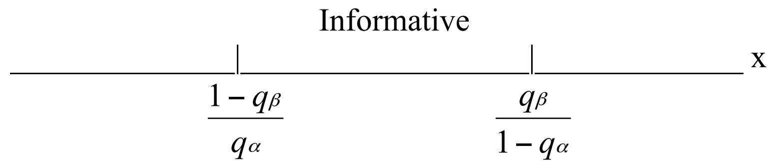

Figure 1: Individual action in solitude

Suppose the jury decides by the m-rule: adopt A if A gets m votes, adopt B if B gets n-m+1 votes. For a simple majority rule, $m = (n+1)/2$. Each individual votes to maximize her expected utility conditioned on whatever she knows at the time of voting. Clearly, each knows her signal. Moreover, in a committee setting, each pretends to be pivotal and knows the distribution of others' signals compatible with a tie. A voting profile of the committee is a map $v: \{\alpha,\beta\}^n \rightarrow \{\mathbf{a},\mathbf{b}\}$ defined by $v(s) = (v_1(s_1), ..., v_n(s_n))$.

Definition. A voting strategy is rule reforming if the individual votes either a or b independent of her signal.

The definition is intuitive: suppose a jury of five is required to choose A or B by majority rule. If a juror votes “a” independent of her signal, then only two out of the remaining four must vote “a” for the jury to choose A, whereas three out of the remaining four must vote b for the jury to choose B. The juror voting “a” independent of her signal has changed the rule: she has made it easier for the jury to choose A (two out of four, instead of three out of five), and harder to choose B (three out of four, instead of three out of five). The idea of rule reforming is important because it enables the jury to adopt the constrained optimal rule when the mandated aggregation rule is not the optimal rule. We should emphasize here that jurors vote as rule reformers not because they want to throw away their private information, but because they would make even greater contribution to the jury by reforming the rule; since they have only one vote, they cannot do both things. Let us explain our ideas by way of examples that also contain our experimental parameters.

We should emphasize here that while our Examples 2 and 3 are built on the basis of a pure-strategy strong Nash equilibrium contained in Theorem 1 that follows, we could have developed these examples on the basis of a symmetric mixed-strategy equilibrium (Feddersen and Pesendorfer, 1998). Here is why. At both pure- and mixed-strategy Nash equilibria, rational voting yields information aggregation. Our experimental design is such that if jurors do not vote rationally, there would be no information aggregation. Thus, our experiments are a general test of all types of equilibria at which there is information aggregation.

Example 1.

Suppose a jury of five must use majority rule to choose A or B. As before, let the utilities be: u(**a**,A) = 1 = u(**b**,B), and u(**a**,B) = 0 = u(**b**,A). Suppose $q_\alpha = 0.7$ and $q_\beta = 0.7$, so that either hypothesis, when true, emits its corresponding signal with probability 0.7. Suppose the prior probability π = P(A) is 0.5. Then, by the symmetry of the problem, it is easy to see that majority rule is the optimal rule: all voters would vote informatively and there would be information aggregation. The first two rounds of our experiment are based on these parameters. The results help us make an assessment of the fraction of people who vote contrary to their signals when, as rational voters, they should not. Note that for the given parameters, P(a majority is correct) = P(a majority votes a|A) P(A) + P(a majority votes b|B) P(B) = $2*\{10*.7^3*.3^2 + 5*.7^4*.3 + .7^5\} * .5$ = 0.837, by a simple application of the Binomial distribution. For a jury of size eleven, a majority would be correct with probability 0.92.

Example 2.

Suppose now that two public signals are drawn from the same distribution from which the private signals are drawn. Suppose that both turn out to be (α, α); the analogous case of (β, β) is omitted. Then, by Bayes' rule, each juror would conclude that P(A|α, α) = 0.845, and would make it her (updated) prior probability before observing her private signal. *In theory*, that is the only effect of public signals: they lead to a revision of the prior probability. So let us now return to rule reforming, a topic we were discussing just before we introduced Example 1.

Let us maintain all parameter values of Example 1, except π. Set $\pi = 0.845$ as would be the case after each participant observed public signals (α, α). Since π of 0.845 is considerably greater than its value of 0.5 in Example 1, it would seem, and rightly so, that fewer $\alpha' s$ should suffice to choose A. So it might well suit the jury if

a. two (which turns out to be the optimum number) out of five jurors vote "a" independent of their signals, and
b. the remaining three jurors vote informatively.

Clearly, when two jurors vote "a" as rule reformers, the group choice would be B only if the remaining three jurors vote b. Indeed, it is the case (not shown here) that when n = 3, $\pi = 0.845$, $q_\alpha = 0.7$ and $q_\beta = 0.7$, the (unconstrained) optimal rule is m = 1, that is, choose B if and only if all three jurors choose b. Moreover, when the three jurors vote informatively, the probability the jury is correct would be 0.875 = P(at least one α among three informative jurors|A) P(A) + P(β,β,β|B) P(B) = $(1 - 0.3^3) * 0.845 + 0.7^3 *.155$. Compare this with the case when there are no public signals. From example 1, we know that probability to be 0.837. Thus, the group does better after observing (α, α). Similarly, the group would do better after observing (β,β). Finally, when the public signals are split, P(A|α,β) = 0.5 implying no gain from observing (α,β). Combining all three cases, it follows that the group would do better after observing public signals, at least in *theory*. That is the point of Example 2.

Example 3.

Actually it is a continuation of Example 2, but we call it Example 3 to refer to it later. Suppose everything is as in Example 2, and that public signals (α, α) were observed which led the participants to $\pi = 0.845$. Consider two cases: the true state is A, and the true state is B.

When the true state is A, then the *theoretical* probability of choosing A at equilibrium = P(the jury selects A given two jurors, acting as rule reformers, vote "a" independent of their signals) = P(there is at least one α among three informative jurors) = = 1 – P(β,β,β|A) = 1 - 0.3^3 = 0.973. When the true state is B, then the *theoretical* probability of choosing B at equilibrium = P(the jury selects B given two jurors vote "a" independent of their) = P(all three informative jurors observe β) = P(β,β,β|B) = 0.7^3 = 0.343.

Naïve voting

Now suppose all five jurors vote naively, that is, each juror votes *as if* acting in solitude. Since each juror observes exactly one private signal, let us compute her posterior probability for state A. With π = 0.845, P(A|α) = P(α|A) π/{P(α|A) π + P(α|B) (1 - π)} = .7*.845/{.7*.845 + .3*.155} = 0.927, and P(A|β) = .3*.845/{.3*.845 + .7*.155} = 0.7003. It follows that each naïve juror would vote for the more likely state A whether she observes α or β. Thus, when the true state is A, the jury would be correct with probability 1; but when the true state is B, the jury would be wrong with probability 1.

An alternative and more fruitful way of stating the content of the preceding paragraph is the following. Each juror starts with π = .5, and observes two public signals (α, α). She votes A because, no matter what she observes as her private signal, a majority of three signals points to A. Each individual would have a 78.4% chance of being correct, with a sample of three signals: siding with a majority of the three signals improves individual accuracy. Consequently, the jury would be right when the true state is A, and wrong when the true state is B. Thus, misleading public signals cause havoc when jurors do not vote on the basis of being pivotal.

To summarize the key points of the above examples, we present Table 1. It assumes q_α = P(α|A) = 0.7, and q_β = P(α|B) = 0.7. Columns 3-7 assume that two public signals (α, α) have been observed resulting in π = 0.845. Columns 2-5, pertaining to Examples 1-3, provide theoretical probabilities at equilibrium; columns 3-5, pertaining to Examples 2 and 3, assume that two jurors vote "a" independent of their signals. Columns 6 and 7 are for naïve voting: the probabilities are based on the assumption that each juror votes *as if* acting in solitude.

TABLE 1

1	2	3	4	5	6	7
Jury Size	P(Majority is correct) as per Example 1 No public signal (π = 0.5)	P(Majority is correct) as per Example 2 (π = 0.845)	P(Majority votes A|A) as per Example 3 (π = 0.845)	P(Majority votes B|B) as per Example 3 (π = 0.845)	P(Majority votes A|A) as per Naïve Voting (π = 0.845)	P(Majority votes B|B) as per Naïve Voting (π = 0.845)
5	.837	.875	.973	.343	1	0
11	.922	.937	.974	.73	1	0
15	.95	.959	.982	.835	1	0
21	.973	.978	.989	.916	1	0

The row for n = 5 is explained in the text. But let us reiterate some key points stated in the introduction. Rationality leads to information aggregation: each equilibrium probability of group accuracy (column 2 without any public signal, and column 3 with public signals) is greater than the probability of individual accuracy 0.7. When the public signals are supportive of the true state A (column 4), rational jurors attain the true state with probability .973 (for n = 5) or greater, and naïve jurors do so with probability 1 (column 6); naive juries do not appear to offer much gain over theoretical juries. When the public signals are misleading, the effect on rational jurors depends on the size of the jury. In small juries, the effect is severe; in large juries, the effect is marginal (column 5): note how P(Majority votes B after having observed misleading public signals | true state = B) shoots up from .343 (for n =5) to .73 (for n = 11), and then to .916 (for n = 21). Just as we said, it is not easy to mislead a large jury comprising rational jurors! But, then look at the disaster in the last column. When the two public signals are misleading, and when all jurors vote as if acting in solitude, then they attain the true state with probability 0. It is this feature of our experimental design that led us to conclude that we have a sharp test. If the real jurors were naïve, they would almost always mess things up. If the real jurors were rational, they would seldom mess things up, especially in groups of size15 or so. Our pilots were run for n = 5 and seem to support the idea that real juries vote naively. We would soon run additional experiments on larger juries to draw upon the strength of our test.

Before we state the theorem, let us capture the moral of Example 1. It says that once the optimal number of rule reformers, say r^*, has done its thing, the reformed rule is the constrained optimal rule for the remaining jury of size $n - r^*$ leading to aggregation of dispersed information. It turns out, as the following theorem states, that the probability of jury accuracy is maximized when r^* jurors vote as rule reformers.

Theorem 1. Suppose a committee of n members would adopt hypothesis A if and only if it gets m votes. Before voting, each member receives a private signal from {□,ß} such that $q_{\square} = P(\square|A) > .5$ and $q_{\hat{}} = P(\hat{}|B) > .5$. Each has prior probability π that the true hypothesis is A. Assume that π is not so extreme that all have to vote A or all have to vote B. Then there exists a unique integer r^* such that the voting profile, at which r^* members vote as rule reformers and the rest vote informatively, would constitute a pure-strategy strong Nash equilibrium at which the probability that a jury arrives at the correct decision is maximized.

Theorem 1 states that when r^* members vote as rule reformers and $n - r^*$ members vote informatively, it would produce a strong Nash equilibrium at which the jury accuracy is maximized. Note that π can incorporate public signals; we assume that the public signals are not so many that π takes an extreme value. Given $\pi = .845$ (Table 1), $r^* = 2$ for all n; r^* does not vary with n because $q_{\square} = q_{\hat{}}$. Given $\pi > .5$, it would be a strong Nash for two jurors to vote A independent of their signals, and the rest to vote informatively. Column 3 of Table 1 offers the maximum probability that a majority is correct.

Note that strong Nash implies that no coalition of jurors can make itself better off by defecting from equilibrium. Hence, the coordination problem may be solved by pre-play communication among jurors as to who would vote informatively. Any agreement the jurors reach would be self-enforcing because of the strong Nash property.

III. Experimental Design

The following experiments were designed to test whether or not simple majority rule decision-making could aggregate group decisions effectively. In the setting we design, strategic voting should facilitate effective group decisions, even when considering the sometimes misleading impact of shared public signals.

The basic design was to give groups of five students an opportunity to make money by correctly predicting the color of a hidden marble. Each individual was given a private signal correlated with the true color (we also refer to it as the true state), and asked to predict the true state both individually and as a member of the five-person group. Each individual was given the opportunity to make money based on the accuracy of his or her individual prediction; they were also given an opportunity to vote—distinct from their individual prediction—knowing that the aggregated votes in their group would determine whether they received a second payoff. These can be regarded as baseline experiments revealing individual and group judgmental accuracies, how individuals signal to the group, and the resulting accuracy of groups with minimal opportunity for information exchange.

In the final period, an element of "public" dialogue was introduced. In addition to receiving a private signal, every individual in the group received the same two public signals. Here, the questions again revolved around the accuracy of individual judgments, individual choices regarding voting, and the resulting accuracy of group judgments.

Ninety-five MBA students were given the opportunity to make money based on the accuracy of their individual and group predictions. Most of the subjects were not only evening MBA students, they were also employed in professional or managerial positions.

Students were divided into 19 five-person groups; the composition of the groups was unknown to the students, and shifted after the end of each period. The students made their judgmental decisions for all periods, results were collated, and they received their payments later in the evening.

Students were read a set of instructions as shown in the appendix. They were told that, for each group and for each period, there was a hidden marble drawn from an urn with 50 amber and 50 black marbles. In each period, each student was to make two decisions. The first decision was their individual prediction—black or amber; they would receive $1 if and only if their individual prediction was correct. The second decision was a vote that would be compiled with the four other votes of the anonymous members of their group. Each member of the group would receive an additional $1 if and only if the majority of the group was correct in its prediction.

In each round, each student would receive a signal—information available only to him or her. The signal varied in informativeness across periods. In Round One, for example, if the hidden marble was amber, each person had a 70% chance of receiving a amber signal. If the hidden marble were black, each person had a 70% chance of receiving a black signal. Each subject had a decision sheet for each period, which reproduced this information, and each had the opportunity to make his/her two decisions.

The parameters were identical in Round Two. In both of these cases, receiving a amber (or black) signal should be sufficient to create a belief that the hidden marble was amber (or black). That is, the probability that the hidden marble is amber, given a amber signal, is 70%. Each person has a 70% probability of being correct, and each group should be able to make the right prediction by majority rule exactly 83.6% of the time.

Table 2
EXPERIMENTAL DESIGN

Period	P(α|A)*	P(β|B)**	Theoretical probability of a correct vote by an individual acting in solitude***
1	.7	.7	.7
2	.7	.7	.7
FINAL	.7	.7	.784

*p(α|A) is the probability of an *amber* signal given that the hidden marble is AMBER.
**p(β|B) is the probability of a *black* signal given that the hidden marble is BLACK.
***Assuming everyone votes their true Bayesian beliefs.
In the Final Round, every voter in a group observes two public signals, with p(α|A) = p(β|B) = .7, as well as one private signal.

The Final Period provided signals like the first two periods. However, each individual saw two public signals as well as their own private signal. The two public signals were each exactly as informative as either individual signal.

Thus, in the final period, each individual had *more* information on which to base his or her individual judgment. Two or more signals (out of three) should result in a judgment that the hidden marble is AMBER. Each individual should now have a 78.4% chance of being correct, because if the hidden marble is AMBER, there is a $.7^3$ = 34.3% chance that all three signals will be amber, and $3*(.7^2*.3)$ = 44.1% chance that two of the three signals will be amber.

However, *the question is whether rational individuals will choose to vote in such a way as to take full advantage of the extra information in the public signals.* The public signals may be thought of as inducing a shared modification in everyone's prior, whenever the public signals are both amber or both black. But it is this change in beliefs that creates an incentive for strategic voting. If everyone sees the same two amber public signals, then everyone should have the same heightened belief (prior to the private signal), that the hidden marble is AMBER. (In particular, P(AMBER) = π is now .845.) It is no longer a Nash equilibrium for everyone to vote informatively. In fact, it is a Nash equilibrium, after two public signals have changed pi from .5 to .845, for *two* people in a group of five to vote amber as rule reformers, ignoring their private signals, and three to vote informatively.

The three voters who vote informatively are voting strategically in that, if they are pivotal, then the two other informative voters must be seeing private signals opposite those of the two public signals—in which case it is best for them to vote their signals. The same is true for the two rule-reformers; if either one is pivotal, it means that two of the three informative voters have seen a signal that is opposite that of the public signals and the third informative voter has seen a marble of the color of the public signals. Consequently, the total information available to a rule reformer, is that three out of five marbles (the two public signals and one of the private signals going to an informative voter) are all of the same color—and it is therefore consistent for the rule-reformer to vote with the public signals. In equilibrium, each individual is voting in a way that is consistent with the information conditional on being pivotal. The bottom line is that the group is best served by this combination of informative and non-informative voting.

As long as the voters are able to coordinate on one of these equilibrium outcomes, the group should be able to make *better decisions* than if they either all vote informatively, or all vote on the basis of public signals. If they all vote their private signals, then they ignore the information in the two public signals. If they all vote as Bayesian voters, then they will all ignore the information in their private signals, whenever the two public signals are identical. It is only by coordinating on an equilibrium in which some voters vote their private signals and some ignore their private signals in favor of the public signal that the group is able to do as well as it can; and this outcome is an equilibrium.

This provides a very interesting test of strategic voting. If voters coordinate on the equilibrium level of strategic voting, then the group should be able to improve on *either* informative voting or on voting their naïve Bayesian beliefs.

If, on the other hand, individuals vote sincerely, on the basis of public signals, then the group should be significantly constrained in their judgmental accuracies—whenever the public signals are misleading, the group will not be able to benefit from the information that is in their private signals.

IV. EXPERIMENTAL RESULTS: INDIVIDUAL JUDGMENT

Overall, the experiments with public signals in the final period did *not* reveal the improved group decision-making that should follow from strategic considerations. Rather, they were consistent with the hypothesis that individuals voted naively, given the combination of public and private signals they saw. This meant that *when the public signals were identical,* the group members over-weighted the information in their public signals and under-utilized the information in their private signals, resulting in systematically inferior results.

When the two public signals were mixed, they in effect canceled each other. The Bayesian response was to vote with the private signal. Although a majority did so, it was only 24 out of 33, rather than 100%, indicating a relatively high rate of non-Bayesian updating. *We regard this as an indicator of the "base rate" of judgmental error, not to be confused with consciously strategic voting.*

When the two public signals agreed, but disagreed with the private signal, subjects voted with the public signals 26 out of 30 times. This proportion of voters who voted with their public signals is far different from the equilibrium level of 40%.

Majority Rule Synergies: Rounds 1 and 2

The ability of even small, five-person groups to improve on individual decision-making was clearly noticeable in periods 1 and 2. In period 1, majority rule transformed individual judgmental accuracies or about 63% into majority rule group accuracies of 84%. In period 2, majority rule transformed individual judgmental accuracies of 64% into majority rule accuracy of 93%. The accuracy of the groups, therefore, was close to the theoretical accuracy of 83.4%, predicted by a Condorcet jury theorem, despite the number of individual judgmental errors. The important thing for this paper is that 15 to 25% of the voters in rounds one and two, respectively, voted against their private signals, which was in this case an error. If we find people voting contrary to their signals in a situation that calls for strategic voting, then it ought to be in greater proportions than this to be convincing evidence of strategic voting.

GROUP JUDGMENT WITH PUBLIC SIGNALS: FINAL ROUND

The accuracy of group judgments in the Final Round 3 (63.2%) was no greater than the overall individual accuracy (64.2%). Again, the informativeness of individual signals was the same as it had been in periods 1 and 2, while everyone had the additional benefit of two public signals. Nevertheless, the number of groups who *failed* to predict the hidden marble went from three groups in periods 1 and 2 to seven groups in the Final period.

With one exception, *all* of the twelve groups, that had either two correct or mixed public signals, made a correct judgment. In only one case of mixed public signals did the group incorrectly call the hidden marble. With mixed public signals, the private signal should have been decisive for rational, Bayesian decision-makers—and four of the private signals accurately indicated the true color of the hidden marble—Black. However, two out of the four voters receiving a black signal voted “Amber” anyway, causing the group to make an incorrect call. In this case, then, the group failure stemmed directly from individual error.

In the other six cases, Table 3, the public signals themselves seem to have been responsible for the errors. In each of these cases, the public signals were misleading. In these six groups, a total of 18 voters received private signals that conflicted with the public signals (and were therefore correct). Seventeen out of the 18 voters in this situation did in fact vote with the public signals.

TABLE 3

GROUP VOTING BEHAVIOR WHEN PUBLIC SIGNALS ARE MISLEADING

	Hidden Marble	Public Signals	Private signals	Majority vote	Voted with public sig. over private
Group 1	B	w,w	b,b,b,w,w	W (4-1)	2/3
Group 7	B	w,w	b,b,w,w,w	W(5-0)	2/2
Group 8	W	b,b	b,b,w,w,w	B(5-0)	3/3
Group 11	W	b,b	w,w,w,w,b	B(5-0)	4/4
Group 14	W	b,b	b,b,b,w,w	B(5-0)	2/2
Group 18	B	w,w	b,b,b,b,w	W(5-0)	4/4

However, if all the members of these groups had ignored their public signals and instead used their votes to make available the information in their private signals, then four of these groups would have been correct. In Groups 1, 8, 11 and 18, the information in the private signals was theoretically sufficient to overcome the miscues in the public signals. In these cases, the public signals caused people to have errors that brought the group to failure.

This can be construed as a failure of coordination. In a five-person group, there are 10 Nash equilibria in which exactly two voters vote with the public signals when they are the same, and the rest vote informatively. In Group 11, for example, in four out of those 10 Nash equilibria, all three of the informative voters would have voted "Amber", resulting in a correction of the misleading public signals. With no opportunity to solve the coordination problem, then virtually none of the voters provided the information incorporated in their private signals, resulting in an inescapable failure of the group to correct for misleading public signals.

If this is simply due to a coordination failure, then an experiment in which subjects are given an opportunity to coordinate (which our strong Nash equilibrium would allow), should see a lot more strategic voting in the presence of public signals. It is our sense that an opportunity to coordinate will not make the difference.

For example consider a group with N = 21. Given our parameters, the appropriate number of rule reformers in the presence of two public signals is still two; the rest should all vote their private signals, leading in theory to highly effective information aggregation based on the large number of private signals—even with misleading public signals. We believe that groups will continue to make wrong decisions in the presence of misleading public signals. Our plan is to conduct experimental research that will test these conclusions.

V. Conclusion

The potential for group judgmental synergies with majority rule can be seen not only in theory, but in the results of rounds 1 and 2. In these cases, individuals tended to vote in such a way that the information available only to themselves was incorporated into vote totals (with a significant degree of error).

This result supports the tendency of organizations to rely on larger proportions of their employees for input into key decisions. On the other hand, in the Final period, positive synergies were not realized. In this case, the existence of two identical public signals was likely to swamp the information present in the private signals. By voting with the public signals, individuals guaranteed that *their groups would be incorrect at least as often as the public signals were incorrect*.

While this small number of tests is merely suggestive, it is worth repeating that the voting patterns with misleading public signals does not suggest strategic voting, nor is it consistent with equilibrium behavior. Groups that could have coordinated on the appropriate degree of strategic voting would have designated voters to vote with the revised priors induced by the public signals—but the rest of the voters would then have voted their private signals. Experiments by Guarnaschelli et al. (2000) provide some evidence that voters engage in such rule-reforming behavior, even without an opportunity for coordination, in the case of unanimity rule. However, in our experiments, there was very little evidence of any systematic inclination toward the kind of strategic thinking that would have resulted in better judgments for the groups. Individuals in groups that had identical public signals tended to ignore the information in their private signals, although that was not equilibrium behavior.

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