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Expert Information and Majority Decisions*

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Abstract

This paper shows experimentally that hearing expert opinions can be a double-edged sword for collective decision making. We present a majoritarian voting game of common interest where committee members receive not only private information, but also expert information that is more accurate than private information and observed by all members. In theory, there are Bayesian Nash equilibria where the committee members' voting strategy incorporates both types of information and access to expert information enhances the efficiency of the majority decision. However, in the laboratory, expert information had excessive influence on the voting behaviour and prevented efficient aggregation of individual information. We find a large efficiency loss due to the *presence* of expert information especially when the committee size is large. Using an incentivized questionnaire, we find that many subjects severely underestimate the efficiency gain from information aggregation and they follow expert information much more frequently than efficiency requires. This suggests that those who understand the efficiency gain from information aggregation and perceive the game correctly might nonetheless be "stuck" in an inefficient outcome.

Keywords: committee decision making, voting experiment, expert information, strategic voting

JEL Classification: C92, D72, D82.

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1 Introduction

When collective decisions are made through voting, typically each voter has not only private information known solely to themselves but also public information observed by all voters. Examples of commonly held information in collective decision making include "expert" opinions solicited by a committee, shared knowledge in a board meeting that has emerged from pre-voting deliberation, and evidence presented to a jury. Such information may well be superior to the private information each individual voter has, and if so, it would be natural to expect that their votes should take the public information into account at least to some extent.

Meanwhile, such public information is rarely perfect, and in particular expert opinions are often alleged to have excessive influence on decision making. For example, in recent years the IMF's advice to the governments of some highly indebted countries have heavily influenced their parliamentary and cabinet decisions for austerity. However, the IMF's expertise has been questioned by specialists in monetary policy, and it has been reported that the IMF itself has admitted that they may have underestimated the impact of their austerity measure in Greece.[1] Financial deregulations in the 1990s seem to have been prompted by endorsements from financial experts at the time, but some politicians reflect that in retrospect they may have followed expert opinions too naively.[2] Indeed, the role of experts in political decisions was one of widely discussed topics in debates on the UK's withdrawal from the EU, where a vast majority of "experts" on political, economic, and social issues warned against leaving the EU.[3] In the legal profession, how information from an "expert witness" should be presented in trials is an important topic, so that the judges and juries can process the information appropriately when making their decisions (Federal Judicial Center, 2011). The recognition that expert opinions can be overly influential in collective decision making is not a recent one. In the Athenian Democracy of Ancient Greece, any citizen could be expelled from the city state for ten years if he was considered to be excessively influential on democratic choice and thus posing a risk for a potential transition to tyranny.[4][5] How would collective decision making through voting be influenced by shared information? If commonly observed expert information is better than the information each voter has, would the presence of such expert information improve the quality of the collective decision? Can expert information have "too much"

[1] "IMF 'to admit mistakes' in handling Greek debt crisis and bailout", *Guardian*, 4 June 2013, `http://www.guardian.co.uk/business/2013/jun/05/imf-admit-mistakes-greek-crisis-austerity`

[2] "Gordon Brown admits 'big mistake' over banking crisis", *BBC News*, 13 March 2013, `http://www.bbc.co.uk/news/business-13032013`

[3] "Who are 'experts' anyway?", *Guardian*, 12 November 2016, `http://www.theguardian.com/science/political-science/2016/nov/12/who-are-experts-anyway`

[4] Several citizens were banned from the Ancient Athenian Democracy for this reason, including Aristides the Just, one of the most well-known Athenian citizens for his intelligence and objectivity (hence the name Just, see "Aristeides" in *Plutarch's Lives*, `http://oll.libertyfund.org/titles/plutarch-plutarchs-lives-dryden-trans-vol-2#lf1014-02_head_016`).

[5] This procedure is called *ostracism*, since the names of the over-influencing experts was written by voters behind pottery shards (*ostraka*) for the ballot (see Kagan, 1961for a detailed description).

influence? If so, why?

This paper addresses these questions experimentally, by introducing a public signal into an otherwise classical Condorcet jury setup with majority rule. The public signal is observed by all voters, and when it has superior accuracy to each voter's private signal, we call it "expert" information. We find that expert information had excessive influence on voting behaviour, which may lead to inefficiency. Moreover, we argue that the excessive influence of expert information stemmed largely from failure to appreciate the efficiency gain from aggregation of private information, which was observed for a majority of the voters. Those who did understand the benefit of information aggregation were nonetheless "stuck" in the inefficient outcome, because as minority voters they had no or very little influence over the majority decisions.[6]

Before reporting on the experiment we first present a majoritarian voting game with expert information and identify two symmetric strategy equilibria of interest, namely i) the symmetric mixed strategy equilibrium where each member randomizes between following the private and expert signals should they disagree; and ii) the "obedient" equilibrium where all committee members and hence the committee decision always follow the expert signal.[7] We note that in the mixed strategy equilibrium, the expert signal is collectively taken into account in such a way that it maximizes the efficiency (accuracy) of the committee decision among all symmetric strategy profiles. The Condorcet jury theorem (CJT) holds a fortiori so that as the size of the committee becomes larger the probability that the decision is correct increases and converges to 1. However, in the obedient equilibrium, private information is not reflected in the committee decision and its efficiency is identical to that of expert information, which may well be lower than the efficiency the committee could achieve in the absence of expert information. In other words, the introduction of expert information might reduce efficiency, depending on which equilibrium is played.

Motivated by the possibility that expert information can enhance or diminish the efficiency of equilibrium committee decisions, we conducted a laboratory experiment to study the effect of expert information on voting behaviour and majority decisions. Of particular interest is whether the subjects can incorporate expert information into their voting behaviour efficiently not least because doing so requires complex statistical and strategic calculations as well as coordination across voters. Specifically, we set the accuracies of the signals in such a way that the expert signal is more accurate than each voter's private signal but less accurate than what the aggregation of the private signals can achieve by informative voting without the expert signal. Such parameter values seem plausible in that the expert opinion should be taken into account but should not be decisive on its

[6] As we will discuss later in Section 2, a public signal can also be thought of as shared information emerged through pre-voting deliberation.

[7] While the voters may ignore their private information completely, they cannot ignore the expert information completely in equilibrium. That is, voting according only to their private signal is never an equilibrium, since if a voter knows that all the others will follow their private signals, he deviates and follows the expert signal.

own. We had seven-person committees and fifteen-person committees, the latter of which entail a larger potential efficiency loss from the obedient outcome because more private information can be wasted by obedient voting in a larger committee.

In the experiment we find that the voters follow the expert signal much more frequently than they should in the efficient mixed strategy equilibrium. Specifically, the majority decisions follow the expert signal most of the time, as is consistent with the obedient equilibrium.

Along with the treatments with both private and expert information, we ran treatments where each voter received a private signal only, in order to compare the observed efficiency of the committee decisions with and without expert information. For seven-person committees the difference in efficiency between the two treatments is insignificant, largely due to some non-equilibrium behaviour (i.e., voting against private information) in the control treatment with private signals only, which reduces the benchmark efficiency. However, despite some inefficient non-equilibrium voting, the fifteen-person committees without expert information perform much better than those with expert information and the difference in efficiency is significant. This suggests that expert information may indeed be harmful for a larger committee.

In order to further investigate the source(s) of over-reliance on public information, we also ran the treatments where i) public information is less accurate than private information; and where ii) public information is presented as a common biased prior rather than an additional piece of information on top of a uniform prior. When the public information is less accurate the subjects follow their private information most of the time, which indicates that the over-reliance on public information is due to its superior accuracy. We also find that when public information that has superior accuracy is presented as a common biased prior and therefore less salient on screen when the subjects make decisions, obedient voting is also less pronounced. However, voting according to the biased prior (against the private signal when they disagreed) is still frequent enough relative to the prediction from the efficient equilibrium that the majority decisions follow the biased prior very often.

Furthermore, using an incentivized questionnaire, we examine subjects' understanding of the power of information aggregation through majority rule in the absence of any strategic concerns.[8] The answers to the questionnaire reveal that more than a majority of the subjects severely underestimate the efficiency gain from information aggregation. Moreover, those who give correct answers vote according to public information more often when the public information and private information disagree. This suggests that, from the viewpoint of a social planner who decides whether to and how to provide a committee with expert information, creating an equilibrium with higher efficiency does

[8] Specifically each subject chose how "the computer will vote" on all voters' behalf, namely whether the computer will vote according to the private signals all voters will receive, (in which case the decision coincides with the majority of the private signals); or the public signal only, (in which case the decision coincides with the public signal).

not necessarily mean it is played.

In their seminal paper Austen-Smith and Banks (1996) first introduced game-theoretic equilibrium analysis to the Condorcet jury with independent private signals. They demonstrated that voting according to the private signal is not generally consistent with equilibrium behaviour. McLennan (1998) and Wit (1998) studied symmetric mixed strategy equilibria in the model of Austen-Smith and Banks (1996) and showed that the CJT holds in equilibrium for majority and super-majority rules (except for unanimity rule). The analysis of the model was further extended by Feddersen and Pesendorfer (1998) for different voting rules.[9] The experimental study on strategic voting was pioneered by Guarnaschelli et al. (2000) who tested the theoretical predictions from Austen-Smith and Banks (1996) and Feddersen and Pesendorfer (1998), and found that the subjects' behaviour was largely consistent with the theory.[10] Focusing on unanimity rule, Ali et al. (2008) found that the findings by Guarnaschelli et al. (2000) are fairly robust to voting protocols such as the number of repetitions and timing of voting (simultaneous or sequential). The present paper focuses on majority rule, but examines the effect of public information on voting behaviour and outcomes.

Battaglini et al. (2010) and Morton and Tyran (2011) report results from experiments where voters are asymmetrically informed, to study how the quality of the private signal affects their decision to abstain, in the spirit of the model of Feddersen and Pesendorfer (1996).[11] The quality of the information each voter has in our framework also varies according to whether the private and expert signals agree, in which case they provide strong information about the state; or they disagree, in which case the uncertainty about the state becomes relatively high. However, we do not allow voters to abstain, and more importantly our primary interest is in the combination of private and public information, which is fundamentally different from private information with different accuracy levels with respect to the effect on the voters' strategic choice, since the public signal represents a perfectly correlated component of the information each voter has.

While we focus on simultaneous move voting games, the inclination to ignore private information in favour of expert information is reminiscent of rational herding in sequential decisions.[12] Hung and Plott (2001) conducted a laboratory experiment on sequential voting with majority rule. They found that some herding indeed occurs, resulting in

[9]For the same information structure as ours, Liu (2016) proposes a voting procedure that leads to an equilibrium where all agents vote according to their private signal, regardless of the quality of the public information/common prior.

[10]See Palfrey (2009) for an overview of the voting experiment literature. There is some recent laboratory evidence of non-strategic sincere voting (Bouton et al. (2016); Bhattacharya et al., 2015) in different setups from ours.

[11]Bhattacharya et al. (2014) study a related experimental setup but with costly voting.

[12]In the early rational herding literature (e.g., Banerjee, 1992; Bikhchandani, Hirshleifer, and Welch, 1992) each player's payoff is assumed to be determined only by his decision but not by others. Dekel and Piccione (2000) and Ali and Kartik (2012) are among the papers that theoretically study sequential voting in collective decision making where payoffs are intrinsically interdependent. Unlike the expert signal in our setup, which is exogenously given to all voters, public information in their models is generated endogenously by the observed choices of earlier voters.

inefficiency compared to informative voting.

Bouton et al. (2016a) report on a voting experiment that involved multiple non-trivial equilibria, although their main focus is on voting rules. In contrast with Bouton et al. (2016b), where a lack of aggregate uncertainty is the main driving force behind voters' coordination on one candidate, in our experiment it is high quality public information that leads to significant reduction in welfare.

The role of public information and its welfare implications have been studied especially in the context of coordination games (e.g. Morris and Shin, 2002; Angeletos and Pavan, 2004 and more recently Loeper et al., 2014). While theoretical models in that literature point to the possibility that more accurate public information may reduce welfare, our simple voting game (as in most other jury models) does not feature strategic complementarities, which means there is no direct payoff from taking the same action since the voters are concerned only with whether the committee decision is right or wrong. Therefore the mechanism through which public information has any effect on players' choice and belief is very different from that in coordination games. Cornand and Heinemann (2014) conducted a laboratory experiment based on the coordination game of Morris and Shin (2002) and found that subjects put *less* weight on public information in their choice, compared to their unique equilibrium prediction. Cognitive biases in processing public and private information for such coordination games have been explored by Trevino (2016).[13] In our experiment, we find that subjects put *more* weight on public information relative to the prediction from the efficient equilibrium, most probably by severely underestimating aggregation of private information. A related type of bounded rationality in voting games was also observed by Esponda and Vespa (2014) who suggest that experimental subjects face obstacles in carrying out simple pivotal calculations, despite feedback, hints, and experience.[14]

The rest of this paper is organized as follows. The next section presents our model, and its equilibria are derived in Section 2. Section 3 presents the experimental design, and Section 4 discusses the results. Section 5 concludes.

2 Equilibrium Predictions

Consider a committee that consists of an odd number of agents $i \in N = \{1, 2, .., n\}$. Each agent simultaneously casts a costless binary vote, denoted by $x_i = \{A, B\}$, for a collective decision $y \in Y = \{A, B\}$. The committee decision is determined by majority rule. The binary state of the world is denoted by $s \in S = \{A, B\}$, where both events are ex ante

[13] Duffy et al. (2016) study subjects' choice in an individual decision making problem between private information and social (public) information, the latter of which is the subjects' past actions given private information in the previous period.

[14] Levy and Razin (2015) develop a voting model where voters underestimate the correlation between their own private signals ("correlation neglect"), and show that this cognitive bias may lead to better information aggregation.

equally likely $\Pr[s = A] = \Pr[s = B] = 1/2$. The members have identical preferences $u_i : Y \times S \to \mathbb{R}$ and the payoffs are normalized to 0 or 1. Specifically we denote the vNM payoff by $u_i(y, s)$ and assume $u_i(A, A) = u_i(B, B) = 1$ and $u_i(A, B) = u_i(B, A) = 0$, $\forall i \in N$. This implies that the agents would like the decision to be matched with the state.

Before voting, each agent receives two signals. One is a private signal about the state $\sigma_i \in K = \{A, B\}$, for which the probability of the signal and the state being matched is given by $\Pr[\sigma_i = A \mid s = A] = \Pr[\sigma_i = B \mid s = B] = p$, where $p \in (1/2, 1]$. We also have $\Pr[\sigma_i = A \mid s = B] = \Pr[\sigma_i = B \mid s = A] = 1 - p$.

In addition to the private signal, all agents in the committee observe a common public signal $\sigma_E \in L = \{A, B\}$. Specifically, we assume $\Pr[\sigma_E = A \mid s = A] = \Pr[\sigma_E = B \mid s = B] = q$ and $\Pr[\sigma_E = A \mid s = B] = \Pr[\sigma_E = B \mid s = A] = 1 - q$, where $q \in (1/2, 1]$. Thus the model has n private signals and one public signal, and they are all assumed to be independently distributed. The agents do not communicate before they vote.[15]

The public signal in our model has natural interpretations. When $q > p$, the public signal can be thought of as expert information presented to the entire committee as in, e.g. congressional hearings. Briefing materials presented to and shared among all committee members would also have the same feature. Alternatively, it may capture shared knowledge as a result of pre-voting deliberation. In that case, the private signal represents any remaining uncommunicated information held by each agent, which is individually inferior to shared information.[16] Note that in the absence of the public signal, there exists an informative voting equilibrium such that $x_i = \sigma_i$ for any i and the Condorcet Jury Theorem holds (Austen-Smith and Banks, 1996), so that as the number of agents becomes larger, the probability that the majority decision matches the state converges to 1.

Let $v_i : K \times L \to [0, 1]$ denote the probability of an agent voting for the state his private signal $\sigma_i \in K = \{A, B\}$ indicates, given the private signal and the public signal $\sigma_E \in L = \{A, B\}$. For example, $v_i(A, B)$ is the probability that agent i votes for A given that his private signal is A and the public signal is B.

In what follows we consider equilibria in which voting behaviour and the outcome depend on the signals the agents observe. Specifically, we focus on how agents vote

[15] The literature on deliberation in voting has studied public information endogenously generated by voters sharing their otherwise private information through pre-voting deliberation (e.g., Coughlan, 2000; Austen-Smith and Feddersen, 2005; and Gerardi and Yariv, 2007). In these models, once a voter reveals his private information credibly, he has no private information. Goeree and Yariv (2011) find in a laboratory experiment that deliberation diminishes differences in voting behaviour across different voting rules. However, Fehrler and Hughes (2015) find that in the presence of reputational issues agents tend to misreport their private signals and therefore enhanced transparency may actually hinder information aggregation.

[16] Suppose that every agent receives two independent signals $\sigma_i^{(1)}$ and $\sigma_i^{(2)}$ with accuracy $p^{(1)}$ and $p^{(2)}$, respectively, but there is no public signal ex ante. Assume also that due to time, cognitive or institutional constraints, only the first piece of information ($\sigma_i^{(1)}$) can be shared through deliberation in the committee before voting. If $\{\sigma_1^{(1)}, \sigma_2^{(1)}, ..., \sigma_n^{(1)}\}$ are revealed to all agents, they collectively determine the accuracy of public information q, while the accuracy of remaining private information for each agent $\{\sigma_1^{(2)}, \sigma_2^{(2)}, ..., \sigma_n^{(2)}\}$ is that of the second signal.

depending on whether their private and public signals agree or disagree, i.e., $v_i(A, A) = v_i(B, B)$ and $v_i(A, B) = v_i(B, A)$ for any i. Since the signals are symmetric, the labelling of the state is assumed irrelevant, in line with the feature that the payoffs depend only on whether the decision matches the state.

2.1 Equilibria

Let us focus our attention to symmetric strategy equilibria, where $v_i(A, A) = v_i(B, B) \equiv \alpha$ and $v_i(B, A) = v_i(A, B) \equiv \beta$ for any i. Note that because of the symmetry of the model with respect to A and B, we can consider the cases of $\sigma_E = A$ and $\sigma_E = B$ as two independent and essentially identical games, where only the labelling differs. We start by observing that expert information cannot be ignored in equilibrium.

Proposition 1. *If $q > p$, every agent voting with probability one for their own private signal is not a Bayesian Nash equilibrium. If $q \leq p$, voting with probability one for their own private signal is a Bayesian Nash equilibrium.*

Proof. See Appendix A. □

The proposition has a straightforward intuition. Suppose that an agent is pivotal and his private signal and the public signal disagree. In that event, the posterior of the agent is such that the votes from the other agents, who vote according to their private signal, are collectively uninformative, since there are equal numbers of the votes for A and B. Given this, the agent compares the two signals when they disagree and chooses to follow the one with higher accuracy. If $q > p$, such voting behaviour breaks the putative equilibrium in which every agent votes according to their private signal.

In contrast, there is an equilibrium where every agent follows the public signal.

Proposition 2. *There exists a symmetric Bayesian Nash equilibrium where every agent votes with probability one for the public signal. If $q \geq p$ the equilibrium is trembling hand perfect.*

Proof. Consider agent i. If all the other agents vote according to the public signal, he is indifferent to which alternative to vote for, and thus every agent voting for the public signal is an equilibrium. See Appendix A for trembling hand perfection. □

The majority decision in this equilibrium follows the public signal with probability 1, and we call it the *obedient equilibrium.* While the equilibrium is trivial from the strategic perspective and the obedient strategy is weakly dominated, it is "robust" to perturbations if the public signal is more accurate than the private signal. Indeed, if the probability distribution of trembles is the same whether the signals agree or disagree, even if there is a non-degenerate pivot probability, being pivotal by itself is completely uninformative about the state, and thus he would consider the two signals at hand (public and private) only and if they disagree, he follows the public signal for higher accuracy. This also implies that obedient voting in equilibrium does not necessarily require that an agent should never be pivotal.

However, if trembles have different distributions depending on the signal realization, then being pivotal becomes informative about the state. In this case, agents may have incentive to deviate from obedience. We consider this possibility in Section 4 when we discuss experimental results.

Next we show that there exists a mixed strategy equilibrium where both private and public signals are taken into account, if $q > p$ but q is not too high.

Proposition 3. *If $q \in (p, \bar{q}(p,n))$, there exists a unique mixed strategy equilibrium, where*

$$\bar{q}(p,n) = \frac{\left(\frac{p}{1-p}\right)^{\frac{n+1}{2}}}{1 + \left(\frac{p}{1-p}\right)^{\frac{n+1}{2}}}.$$

In the equilibrium, the agents whose private signal coincides with the public signal vote accordingly with probability $\alpha^* = 1$. The agents whose private signal disagrees with the public signal vote according to their private signal with probability

$$\beta^* = \frac{1 - A(p,q,n)}{p - A(p,q,n)(1-p)}, \text{ where } A(p,q,n) = \left(\frac{q}{1-q}\right)^{\frac{2}{n-1}} \left(\frac{1-p}{p}\right)^{\frac{n+1}{n-1}}.$$

Proof. This partially follows from Wit (1998).[17] A direct proof is given in Appendix A. □

Note that in order for the mixed strategy equilibrium to exist, the accuracy of the public signal has to be lower than the threshold $\bar{q}(p,n)$. If this is the case, there are two symmetric equilibria of interest, namely i) the obedient equilibrium where all agents follow the public signal; and ii) the mixed strategy equilibrium in which the agents take into account both signals probabilistically. Meanwhile, if the public signal is sufficiently accurate relative to the private signals ($q \geq \bar{q}(p,n)$), the mixed strategy equilibrium does not exist since it is more efficient for agents to be obedient to the public signal.

Let us consider the efficiency of the mixed strategy equilibrium in relation to that of the obedient equilibrium, and also the informative equilibrium without public information.

Proposition 4. *The mixed strategy equilibrium in Proposition 3 maximizes the efficiency of the majority decision with respect to the symmetric strategy profile $\{\alpha, \beta\}$.*

Proof. This follows from Theorem 1 in Wit (1998). A direct proof is given in Appendix A. □

Since the obedient equilibrium requires $\alpha = 1$ and $\beta = 0$, the mixed strategy equilibrium outperforms the obedient equilibrium. Another direct implication of Proposition 4

[17] Cf. The proof of Lemma 2 in Wit (1998).

is that providing the committee with expert information is beneficial if the agents play the symmetric mixed strategy equilibrium:

Corollary. *The mixed strategy equilibrium identified in Proposition 3 outperforms the informative voting equilibrium in the absence of public information.*

This holds true because informative voting is equivalent to $\alpha = \beta = 1$, and Proposition 4 has just shown that the mixed strategy equilibrium ($\alpha^* = 1$ and $\beta^* \in (0, 1)$) is optimal with respect to the choice of α and β if q is higher than p but not too high.

It is straightforward to see that the informative voting equilibrium without public information can be better or worse than the obedient equilibrium with public information. However, the informative voting equilibrium without public information unambiguously dominates the obedient equilibrium when the committee size is large enough. From the next section onwards, we mostly focus on an interesting case where the public signal is more accurate than the private signal but not too accurate, so that the informative voting equilibrium in the *absence* of public information is more efficient than the obedient equilibrium in the *presence* of public information. This case raises an interesting question whether the provision of expert information enhances or diminishes efficiency when the game is played by human subjects.[18]

3 Experimental Design

So far we have seen that the introduction of expert information ($q > p$) into a committee leads to multiple equilibria of interest. On one hand, we have derived the mixed strategy equilibrium where such expert information is used to enhance efficiency. On the other hand, however, it also leads to the obedient equilibrium, where the outcome always follows the expert signal so that the decision making efficiency may be reduced relative to the informative voting equilibrium in the absence of expert information. Despite the (potentially severe) inefficiency, the obedient equilibrium seems simple to play and requires very little coordination among agents.

In order to examine how people vote in the presence of expert information, we use a controlled laboratory experiment to collect data on voting behaviour when voters are given two types of information, private and public. The experiment was conducted through computers at the Behavioural Laboratory at the University of Edinburgh.[19] We ran six treatments, in order to vary committee size, whether or not the subjects received public

[18]Kawamura and Vlaseros (2016) show that there is also an asymmetric pure strategy equilibrium that outperforms the symmetric mixed strategy equilibrium we saw in Proposition 3. However, in the present paper we focus on the symmetric mixed strategy equilibrium as an efficiency benchmark, because the efficiency gain from playing the asymmetric pure equilibrium is marginal given the parameter values in our experiment, and also because in the laboratory, coordinating on the asymmetric pure equilibrium seems much more demanding than the symmetric mixed equilibrium.

[19]The experiment was programmed using z-Tree (Fischbacher, 2007). See Appendix D for the experimental instructions.

Table 1: Treatments

Treatment	$q > p$	$q < p$	Biased prior	Comm. size	No. of committees	No. of subjects
1	yes	no	no	7	6	$7 \times 2 \times 3 = 42$
2	yes	no	no	15	6	$15 \times 6 = 90$
3	no	no	no	7	6	$7 \times 2 \times 3 = 42$
4	no	no	no	15	3	$15 \times 3 = 45$
5	no	yes	no	15	3	$15 \times 3 = 45$
6	yes	no	yes	15	3	$15 \times 3 = 45$

information, accuracy of public information, and presentation of public information. The variations were introduced across treatments rather than within because, as we will see shortly, we had to let our subjects play over relatively many periods, in order to ensure that the subjects have enough (random) occurrences where the private and public signals disagree. Each treatment involved either private information only or both private and public information, and each session consisted of either two seven-person committees or one fifteen-person committee (see Table1). The committees made simple majority decisions for a binary state, namely which box (blue or yellow) contains a prize randomly placed before the subjects receive their signals. The instructions were neutral with respect to the two types of information: private information was literally referred to as "private information" and public information was referred to as "public information" regardless of its accuracy. After the instructions were given, the subjects were allowed to proceed to the voting game only after they had given correct answers to all short-answer questions about the instructions.[20]

For all treatments, we set the accuracy of each private signal (blue or yellow) at $p = 0.65$. Treatments 1 and 2 in Table 1 had a public signal (also blue or yellow) and a uniform prior, where the accuracy of the public signal was set at $q = 0.7$. We will refer to these treatments as *treatments with expert information*. Treatments 3 and 4 are control treatments without public information, in which the subjects received private signals only and the prior was uniform. Treatment 5 featured a public signal whose accuracy was lower than each private signal, such that $q = 0.6$. We also had a treatment (Treatment 6) where public information with $q = 0.7$ was presented as a common biased prior. The prior in the treatment was described as "the computer places the prize in the blue box 70% of time" and the subjects received private signals independently in each period. We presented the subjects with the accuracy of the signals clearly and explicitly in percentage terms, which was described by referring to a twenty-sided dice in order to facilitate the understanding by the subjects who may not necessarily be familiar with percentage representation of uncertainty.[21]

The parameter values, which involve a small difference between p and q, were chosen

[20]If a subject gave a wrong answer, a detailed explanation was given and the subject was prompted to answer the same question again.

[21]Every subject was given a real twenty-sided dice.

so as to make the potential efficiency loss from the obedient outcome large for $q > p$. This is a deliberate design feature to give the subjects strong incentive to avoid the obedient outcome and (if possible) coordinate on the efficient equilibrium by putting a large weight on the private signals.

Let $P_C(p, n)$ be the probability that the majority decision by an n-person committee without public information matches the state, when the accuracy of the private signal is p and all voters follow it.[22] In the absence of a public signal, always following the private signal is also the most efficient Bayesian Nash equilibrium (Austen-Smith and Banks, 1996). The predicted accuracy of decisions by seven-person committees with private signals only is $P_C(0.65, 7) = 0.8002$ and that by fifteen-person committees is $P_C(0.65, 15) = 0.8868$. Thus the accuracy of the public information $q = 0.7$ is above each private signal but below what the committees can collectively achieve by aggregating their private information. This implies that the obedient equilibrium, in which the accuracy of decisions by committees of any size is $q = 0.7$ as they coincide with the public signal, is less efficient than the informative voting equilibrium without public information. Note that the symmetric mixed equilibrium we saw earlier for committees with expert information achieve higher accuracy than $P_C(\cdot, \cdot)$ (Corollary in Section 2.1), although the margin is small under the parameter values here. Specifically, in the symmetric mixed equilibrium, the predicted accuracy of seven-person committees with expert information is 0.8027; and the predicted accuracy of fifteen-person committees is 0.8878.[23]

As we saw earlier, our equilibrium predictions include obedient voting. This may result from the public signal being focal, either because it has superior accuracy when $q > p$, or because it provides a "sunspot" for subjects to coordinate upon irrespective of the value of q. In the recent voting experiment literature, various forms of systematic non-equilibrium behaviour have been observed (e.g. Esponda and Vespa, 2014; Bhattacharya et al., 2015; Bouton et al., 2016). A natural non-equilibrium prediction for our setup is naive sincere voting, where subjects vote consistently according to the expert signal, simply because it is the more accurate of the two signals. Obedient voting could thus be interpreted as either equilibrium behaviour or non-equilibrium behaviour, and we discuss this issue in Section 4.3.

Note that from the theoretical viewpoint, the subjects in the treatments with both types of information would have had a non-trivial decision to make only when their private and public signals disagree. Otherwise (when the two signals agree), they should vote according to these signals in any of the three equilibria we are concerned with. Since for $q = 0.7$ the probability of receiving disagreeing signals is only 0.44 ($= 0.7 \times 0.35 + 0.3 \times 0.65$), the voting game was run for sixty periods to make sure each subject has enough occurrences of disagreement. In every treatment the sixty periods of the

[22] As is well known, $P_C(p, n) \equiv \sum_{k=\frac{n+1}{2}}^{n} \binom{n}{k} p^k (1-p)^{n-k}$.

[23] If $q = 0.6$ as in treatment 6, the public signal is ignored in equilibrium so that the accuracy of the majority decision coincides with $P_C(0.65, 15) = 0.8868$.

Table 2: Voting behaviour and outcome with expert information

		7-person committees		15-person committees	
	periods	w/ expert	efficient eqm.	w/ expert	efficient eqm.
vote for private signal under disagreement	overall	0.3501	0.9381	0.3089	0.9745
	1-20	0.3511		0.2750	
	21-40	0.3571		0.3163	
	41-60	0.3421		0.3338	
vote for signals in agreement	overall	0.9488	1	0.9642	1
	1-20	0.9547		0.9625	
	21-40	0.9571		0.9689	
	41-60	0.9350		0.9612	
majority decision coincided with expert signal		0.9778	0.6654	1	0.6731

respective voting game were preceded by another ten periods of the voting game without public information, in order to increase the complexity of information in stages for the subjects in the public information treatments.[24] We do not use the data from the first ten periods of the treatments without public signals, but it does not alter our results qualitatively.

After all subjects in a session cast their vote for each period, they were presented with a feedback screen, which showed the true state, vote counts (how many voted for blue and yellow respectively) of the committee they belong to, and payoff for the period.[25] The committee membership was fixed throughout each session.[26] This is primarily to encourage, together with the feedback information, coordination towards the efficient equilibrium.

4 Experimental Results

In this section we present our experimental results. We first discuss the individual level data to consider the change and heterogeneity of the subjects' voting behaviour in the treatments with expert information ($q > p$). We examine the majority decisions in those treatments and contrast them to the equilibrium predictions we discussed in Section 2 and other predictions based on bounded rationality. We then compare the efficiency of the committee decisions in the treatments with expert information and that in the treatments without expert information. Finally, we examine sources of inefficient obedient voting

[24]The subjects in the private information treatments played the same game for seventy periods but they were given a short break after the first ten periods, in order to make the main part (sixty periods) of all treatments closer.

[25]The feedback screen did not include the signals of the other agents or who voted for each colour. This is to capture the idea of private information and anonymous voting, and also to avoid information overload.

[26]In the treatments for two seven-person committees, the membership was randomly assigned at the beginning of each session.

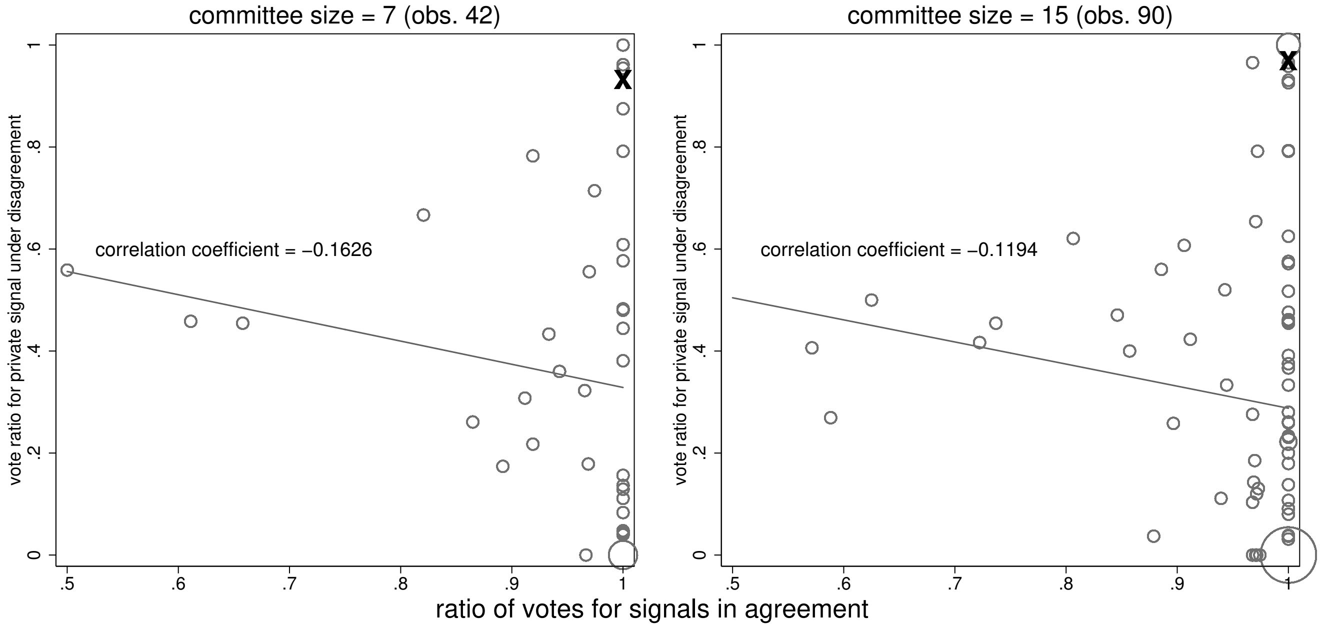

Figure 1: Voting behaviour with signals in agreement and disagreement (**x** indicates the symmetric mixed equilibrium strategy for each committee size)

observed for many subjects.

4.1 Voter choices with expert information

Let us first examine voting behaviour in the game with expert information. In Table 2 we can see immediately that, when the private and public signals disagree, the subjects vote against their private signals much more often than they should in the efficient (symmetric mixed) equilibrium.

As the informational advantage of the expert information over private information is not large (70% versus 65%), in the efficient equilibrium we saw in Proposition 3 the agents should vote according to the private signal most of the time when the signals disagree (93.8% in the seven-person and 97.5% in the fifteen-person committees, respectively).

In the laboratory, by contrast, when the two signals disagree the subjects vote against their private signal in favour of the expert signal for a majority of the time, in both the seven-person and fifteen-person committees. The frequency of following their private signal is only 35.1% in the seven-person committees and 30.9% in the fifteen-person committees. This, together with the high frequency of voting according to agreeing signals which is close to 100%, we find a significant overall tendency to follow expert information both individually and collectively. Moreover, Table 2 indicates that the observed voting behaviour changes very little over the 60 periods. Over-reliance on the expert signal under disagreement persisted and there is no obvious sign of move towards the efficient equilibrium.

Before discussing the influence of expert information on the voting outcome, let us look at the heterogeneity of voting behaviour. Figure 1 plots each subject's average voting behaviour according to how often they vote for the signals in agreement (horizontal axes), and how often they voted for the private signal under disagreement (vertical axes). The top right corner corresponds to the strategy of only using the private signal, whereas the bottom right corresponds to the strategy of only using the public signal. The size of each circle represents the number of subjects whose average voting behaviour is the same. The symmetric mixed equilibrium strategy we saw earlier in Table 2 is represented by **x** for each committee size. We observe several subjects whose voting behaviour can be seen as largely consistent with that in the equilibrium. [27]

Now let us focus on the vertical axes in Figure 1. When the two signals disagree, the highest fraction of the subjects vote against the private signal always or almost always, as indicated by the concentration of circles on the bottom half of the squares. At the other extreme, there are a small number of subjects who consistently follow private information, around the top of the vertical axis particularly on the right hand side. There is significant subject heterogeneity in voting behaviour, and the low overall frequency of following the private signal as documented in Table 2 is largely driven by the "extreme followers". Meanwhile, if we focus on the horizontal axes, most circles are at or near 1, which implies that we do not observe comparable heterogeneity when their signals agree. Most subjects vote according to signals in agreement most of the time, and interestingly, across the subjects we find no systematic association between their voting behaviour when the signals agree and when they disagree. In what follows we focus primarily on voting behaviour when the signals disagree.

Let us now look at the majority decisions in relation to the presence of the public signal. A striking feature we observe in the last row of Table 2 is that in both expert treatments, the decisions follow the expert information most of the time (97.8% for the seven-person committees and 100% for the fifteen-person committees), while the predictions for the efficient mixed equilibrium are only around 67%. Since the committee decisions mostly follow the expert signal, their efficiency is almost (in the case of fifteen person committees, exactly) identical to that of the expert signal.

4.2 Efficiency comparison

If we assume that the decisions in the expert treatments always follow the expert signal and those in the treatments without expert information play the informative voting equilibrium, in expectation we should observe the efficiency loss of $P_C(0.65, 7) - 0.7 = 0.1002$ (14.3% reduction) for the seven-person committees and $P_C(0.65, 15) - 0.7 = 0.1868$ (26.7%

[27] The large circles at the right bottom corners in Figure 1 represent 6 (out of 42) subjects in the seven-person committees and 23 (out of 90) subjects in the fifteen-person committees who always followed the public signal. The circle at the right top corner for the fifteen-person committees represents 4 subjects who always voted for the private signal. Any other circles represent a single subject.

reduction) for the fifteen-person committees, due to the *presence* of expert information.

Table 3: Voting behaviour in committees without expert information

	periods	7-person comm. w/o expert (2520 obs.)	eqm.	15-person comm. no w/o expert (2700 obs.)	eqm.
vote for private signal	overall	0.8472	1	0.9141	1
	1-30	0.8505		0.9111	
	31-60	0.8437		0.9170	

In the laboratory, the subjects in the control treatments without expert information vote largely according to the equilibrium prediction of informative voting (Table 3). We observe some deviation from the equilibrium strategy, as commonly observed in the literature on voting experiments for such a benchmark case. Note that, from each subject's perspective, one private signal is less informative of the true state than a pair of private and public signals in agreement. We have seen in Table 2 that the proportion of votes for the agreeing signals is about 95% in both seven-person and fifteen-person committees, which is higher than the proportion of votes for the private signal when expert information is absent. This is consistent with, for example, a finding by Morton and Tyran (2011) that the subjects are more likely to follow their private signal when it is more accurate.

Table 4: Majority decisions and observed efficiency

	7-person comm. (360 obs. each) w/o expert	7-person comm. (360 obs. each) w/ expert	15-person comm. (180 & 360 obs.) w/o expert	15-person comm. (180 & 360 obs.) w/ expert
Observed efficiency	0.7000	0.7389	0.8278	0.7000
Realized efficiency of expert signal	n/a	0.7222	n/a	0.7000
Efficiency if subjects had voted for realized private signals	0.7972	0.8195	0.8778	0.8833

Since informative voting achieves the highest efficiency in the voting game without expert information, any deviation from the equilibrium strategy leads to efficiency loss. The first row on Table 4 records the observed (ex post) efficiency in the four treatments (Treatments 1-4). We can see that the efficiency of the decisions by the seven-person committees without expert information is merely 70.0%, while if every member voted according to the private signal following the equilibrium strategy, given the actual signal realizations in the treatment, they could have achieved 79.7%. Meanwhile the seven-person committees with expert information achieve 73.9%, even though they could have achieved higher efficiency (82.0%) had they always voted according to the private signal.[28] The precise comparison of efficiency between committees with and without expert

[28]Note that every agent voting according to the private signal is not an equilibrium in the presence of expert information (Proposition 1). Here we record the hypothetical efficiencies for both seven-person and fifteen-person committees in order to represent the quality of the realized private signals in each treatment.

information is difficult due to different signal realizations in each treatment. As shown in Table 5 a simple random effects model where each session is treated as an individual in the panel indicates that for the seven-person committees the effect of expert information on efficiency is not statistically significant.

Table 5: Random effects probit: dependent variable = 1 if committee decision matches the state and 0 otherwise

Independent variable	7-person comm.	15-person comm.
Expert information	0.1658	-0.4210***
	(0.2614)	(0.1303)
Constant	0.8783***	0.9454***
	(0.1826)	(0.1103)
Observations	360	540
Log likelihood	-212.3833	-302.6018

Note: Standard errors in parentheses.
*** significant at 1% level

The last two columns of Table 4 give us a somewhat clearer picture. In the fifteen-person committees without expert information, since the agents do not deviate much from the equilibrium strategy of informative voting, the efficiency loss compared to the hypothetical informative voting is small (82.8% vs. 87.8%). In the fifteen-person committees with expert information, since all decisions follow the expert information, the efficiency is exactly the same as that of the expert signals, which is 70.0%. Here the negative effect of expert information on efficiency is large (82.8% $\rightarrow$ 70.0%) and indeed Table 5 indicates that the effect is statistically significant.

4.3 Why was expert information so influential?

As we have seen earlier, the committee decisions follow the expert signal most of the time (97.8% for seven-person committees and 100% for fifteen-person committees) as in the obedient equilibrium, where the decision follows the expert signal with probability 1. In the efficient equilibrium we saw, this rate ranges from 67% to 72% for both seven-person and fifteen-person committees. What leads the subjects to such a clearly inefficient outcome?

To examine this question, let us first see whether obedience to the expert signal in the data is consistent with the individual best response, given the subjects' voting behaviour. Figure 2 illustrates this, with the assumption that the other agents play symmetric strategies. In the figure, the horizontal axes represent α, the probability that the agents vote according to the signals when they agree; and the vertical axes represent β, the probability that the agents vote according to the private signal when the signals disagree. The shaded areas indicate the ranges of α and β such that, with regard to the model in Section 2, an agent's best response given that the other agents adopt α and β is to vote according to the

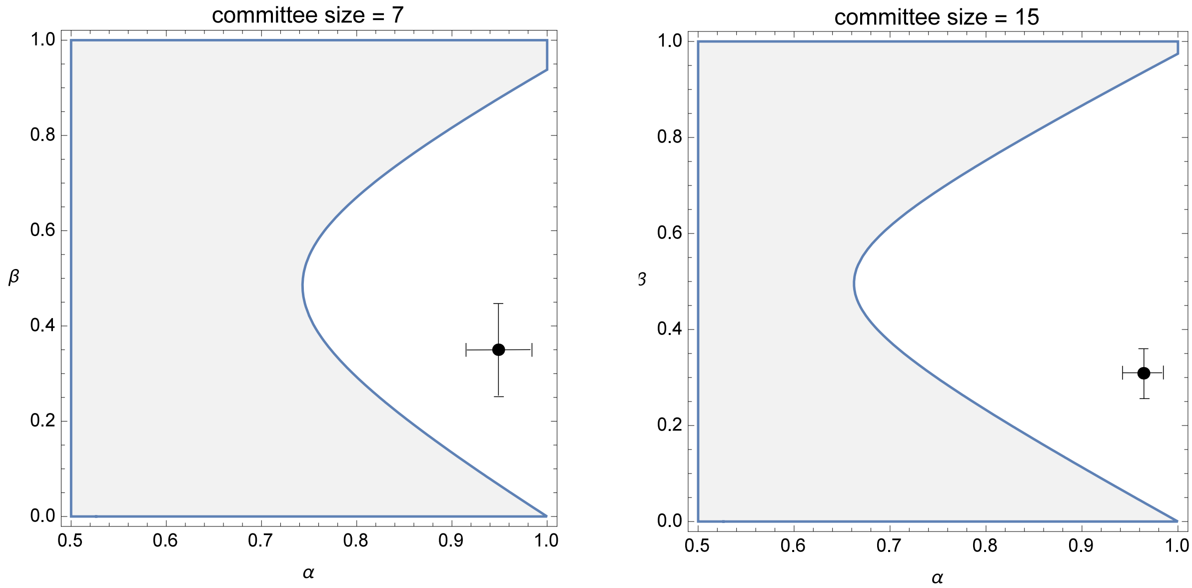

Figure 2: Data (mean frequencies for each committee size represented by a dot with 95% confidence intervals) and individual best response under disagreement given the other voters' behaviour (shaded: follow the expert signal, unshaded: follow the private signal)

expert signal. Conversely, on the unshaded areas the best response is to vote according to the private signal.[29] The dots are from the overall frequencies in Table 2 and they clearly indicate that in both seven- and fifteen-person committees the individual best response given the data is to vote according to the private signal when the signals disagree.[30] The prevalence of obedient voting in the data therefore strongly suggests that many subjects fail to best respond, if we assume that the data represents symmetric strategies and the subjects could infer α and β.[31]

In what follows we report on additional treatments to gain further insights into the over-reliance on the public signal and many subjects' failure to individually best respond, focusing on fifteen-person committees.[32] Specifically, in one of the treatments (Treatment 5) the expert information was presented as a biased prior to suppress the salience of the information. In the other (Treatment 6), the expert signal was replaced by a public signal whose accuracy is lower than the accuracy of each private signal ($q < p$), in order to see whether the reliance is attributed to i) the presence of a public signal to coordinate upon, in which case its accuracy does not necessarily matter, or ii) the superior accuracy of the expert signal. Furthermore, both of the additional treatments and three sessions/groups for fifteen-person committees with expert information (Treatment 2) involved an incen-

[29]See Appendix A for the derivation of Figure 2. Arbitrary α and β of the other agents can be seen as trembles relative to the obedient equilibrium ($\alpha = 1$ and $\beta = 0$), where errors occur with different probabilities depending on whether the signals agree or disagree.

[30]The confidence intervals are larger for the seven-person committees mostly due to the smaller sample size (42 for seven-person and 90 for fifteen-person committees).

[31]We will discuss these assumptions later.

[32]We discuss other non-equilibrium explanations for the observed over-reliance in Appendix B.

Table 6: OLS estimates for 15-person committees: dependent variable = frequency of votes for private signal under disagreement

Independent variable				
Treatment 5: Expert info as prior	0.2897***	0.2820***	0.3471***	
	(0.0608)	(0.0743)	(0.0839)	
Treatment 6: $q < p$	0.5102***	0.5291***	0.5752***	
	(0.0546)	(0.0635)	(0.0723)	
Correct understanding of		0.1473**	0.2505**	0.2151***
information aggregation		(0.0621)	(0.1225)	(0.0637)
Treatment 5 × Correct understanding			-0.1744	
			(0.1630)	
Treatment 6 × Correct understanding			-0.1407	
			(0.1390)	
Frequency of voting for	-0.2071	-0.0849	-0.1182	-0.0398
signals in agreement	(0.1893)	(0.2409)	(0.2483)	(0.2457)
No. of periods with disagreement	0.0064	0.0066	0.0053	-0.0019
	(0.0061)	(0.0072)	(0.0073)	(0.0072)
Constant	0.3320	0.1587	0.1908	0.1547
	(0.2214)	(0.2750)	(0.2822)	(0.2650)
Session dummies	No	No	No	Yes
Observations	180	135	135	135
Adjusted R-squared	0.3193	0.3239	0.3223	0.3728

Robust (unclustered) standard errors in parentheses. Treatment 2 (expert) is the base treatment.
Correct understanding = 1 if a subject answers both questions correctly and otherwise 0.
The number of periods with disagreement varied (18-39) across subjects. The first model includes observations from three sessions of Treatment 2 without the questionnaire.
*** significant at 1% level; ** significant at 5% level; * significant at 10% level

tivized questionnaire, in order to assess each subject's basic understanding of information aggregation. This allows us to consider the possibility that some subjects vote without even thinking about the other subjects' private information or votes.

4.3.1 Salience of expert information

As noted earlier, one possible reason for obedience to the public signal is that it was overwhelmingly salient as it appeared on every decision making screen, even though our instructions were neutral and we never used the word "expert" or any labelling that hints at superiority except the accuracy itself. Also, the combination of a uniform prior and a public signal may have looked more complex to subjects than biased prior with no additional public information, although these are theoretically equivalent. In Treatment 5 we presented expert information as a common biased prior, such that the prize is placed in the blue box with 70% probability for all periods. In order to further reduce the salience of the information, how the prize is allocated at the beginning of each period was explained only once before the voting game started, and only the private information with 65% accuracy was on the screen in each period.

Table 7: Voting behaviour in 15-person committees

	periods	$q > p$ as prior	$q < p$	$q > p$ as expert
vote for private signal	overall	0.6035	0.8162	0.3089
under disagreement	1-30	0.5931	0.8122	0.2961
	31-60	0.6120	0.8204	0.3219
vote for signals	overall	0.9282	0.9796	0.9642
in agreement	1-30	0.9216	0.9845	0.9662
	31-60	0.9358	0.9744	0.9622
vote for private signal (unconditional)	overall	0.7893	0.9041	0.6781
majority decision coincided with expert signal		0.9222	0.7389	1

In Table 6 we find that the subjects in the treatment are significantly more likely to vote according to the private signal when the signals disagreed, compared to the treatment with a uniform prior and expert information.[33] In Table 7 we see that when expert information is presented as a biased prior, the subjects follow the private signal 60% of the time under disagreement, which is almost exactly in between 31% we saw earlier in Table 2 for the treatment with a uniform prior with expert information, and the equilibrium prediction of 97%. Meanwhile, the last row of Table 7 indicates that the majority decisions are much more clearly leaning towards the prior: they follow the biased prior 92% of the time while in the efficient equilibrium it should be 67%. Clearly, framing expert information as a common biased prior mitigates obedience, although it still has a much larger influence on the voting behaviour and majority decisions than in the efficient equilibrium.

4.3.2 Accuracy of public information

Another possible reason for obedience is that the presence of *public* information, which can in principle be either more or less accurate than private information, rather than *expert* information, leads the subjects to coordinate upon the inefficient obedient equilibrium. To examine this possibility, in Treatment 6 the accuracy of the public signal was set at $q = 0.6$ while we kept the accuracy of the private signal ($p = 0.65$) as in the other treatments. In order to achieve efficiency, the subjects should completely ignore the public information and vote according to their private information only, which is also the efficient equilibrium as in the game without public information.

Both Table 6 and Table 7 show that the voting behaviour change significantly from that in the treatment with expert information and the subjects follow the public signal with $q < p$ much less frequently. More importantly, the voting behaviour in the treatment is very close to that in the treatment without public information we saw in Table 3. In particular, the unconditional frequency of following the private signal is 90.4% in the

[33] We obtain qualitatively very similar results from random effects probit models. See Appendix C for details.

treatment with $q < p$ and 91.4% in the treatment without public information. The excessive obedience seems to be caused by the superior accuracy ($q > p$), not by the mere presence of public information.

4.3.3 Under-appreciation of information aggregation

The results from the two additional treatments so far reveal that neither the salience of expert information nor the presence of public information to coordinate upon can adequately explain the obedient voting and outcome. This leads us to explore yet another possibility that obedient subjects are unable to take into account information aggregation of private signals and vote as if they were facing a single-person (rather than group) decision problem.

Table 8: Proportion of subjects choosing correct answer (15-person committees)

		treatment (45 obs. each)		
		$q > p$	$q > p$ as prior	$q < p$
	both correct	0.3333	0.4444	0.2222
answers	correct for $q > p$	0.4000	0.5330	0.2444
	correct for $q < p$	0.8222	0.8667	0.8667

Since it is difficult to directly observe how subjects perceive the voting game, we focus on their basic recognition of information aggregation in voting. Specifically, we used an incentivized questionnaire at the end of sessions, which was presented as a straightforward extension of the voting game with public information (or the biased prior), where each subject chooses "how the computer votes" on all voters' behalf.[34] In particular, we let the subjects choose between i) decision that follows the public signal only ("the computer casts all votes according to public information only"), in which case the accuracy of the unanimous decision is q; and ii) majority decision based on votes according to all 15 private signals with accuracy $p = 0.65$, where the corresponding accuracy of the majority decision is $P_C(0.65, 15) = 0.8868$. We asked two questions for $q = 0.7$ and $q = 0.6$ respectively, so that for both questions the choice that maximizes the subjects' expected payoff is to let the computer vote according to all private signals. Since the subjects answered the questionnaire after they played the voting game, they might have learnt from the observations from feedback information during the voting game. Therefore, the answers from the treatment with $q < p$ may better indicate pre-learning answers to the question with $q > p$, and vice versa.[35]

[34]The questionnaire was administered in three sessions/groups of each treatment for fifteen-person committees. The other three (out of six) sessions of the treatment with expert information (Treatment 2) did not have the questionnaire.

[35]Administering the questionnaire after the game was played, rather than before has the important advantage that the subjects would have understood the questions better, as the questions were phrased in accordance with the game they had played. One natural concern is that the answers might have been

A striking finding from Table 8 is that many subjects severely underestimate the benefit of the aggregation of private information relative to public information, especially for the question with $q > p$. Overall, a majority of the subjects prefer a decision based on the public signal alone to a decision based on all private signals, at least for one of the questions. This suggests the prevalence of severe underestimation of information aggregation. While the efficient equilibrium can achieve higher efficiency than voting according to the private signals only, the relative efficiency gain is marginal. Therefore it is likely that the subjects who let the computer vote according to the public signal only perceive the other subjects' private signals and votes in the game as irrelevant. Such subjects would mostly focus on the *individual* comparison between their private signal and the public signal. These subjects can be thought of as non-strategic, *sincere* voters who take the voting choice as an individual decision problem.

Table 9: Voting behaviour in 15-person committees with $q > p$

		answers to questionnaire	
	periods	both correct (15/45)	otherwise (30/45)
vote for private signal	overall	0.4593	0.2124
under disagreement	1-30	0.4624	0.1947
	31-60	0.4564	0.2298
vote for signals	overall	0.9846	0.9712
in agreement	1-30	0.9811	0.9771
	31-60	0.9882	0.9652

The subjects' voting behaviour in the presence of expert information is indeed consistent with this view. Table 6 we saw earlier confirms that those who answer both questions correctly are significantly more likely to vote for the private signal when the signals disagree.[36] Interestingly, the interaction terms with the treatment dummies are not statistically significant, suggesting that the effect of the understanding of information aggregation on voting behaviour does not vary according to the nature of public information. Table 9 splits the voting behaviour according to whether the subjects understand information aggregation. Indeed those who fail to understand its benefit vote for the private signal much less frequently (only 21%) than the public signal signal when the signals disagree. In contrast, the average voting behaviour of those who answer both questions correctly is close to 50:50. Also, in Table 9 we do not observe any clear sign that the subjects who give a wrong answer in the questionnaire are ignorant and pay less attention to the screen or choices they make. The frequencies of voting for the signals in agreement

largely driven by how the subjects played the game, rather than how they perceived the questions as single-person decision problems. However, this would not be problematic in our case, since the questions were purely on how the computer would vote, and thus unlike the voting game, they did not involve anything to do with decisions by the other subjects.

[36] The dummy variable ("Correct understanding of information aggregation") is 1 if a subject answered both questions correctly and 0 otherwise.

are very close between those who give the correct answers (98.5%) and those who do not (97.1%).

Table 10: Prediction on other committee members' answers to questionnaire

	prediction on preference of majority	
own preference (obs. 135, pooled)	aggr. of private info ($q = 0.7$)	aggr. of private info ($q = 0.6$)
aggr. of private info ($q = 0.7$ & 0.6)	0.2889	0.9778
public information	0.0667	0.9333

How did the subjects perceive other subjects' understanding of information aggregation? We also asked subjects how a majority of the committee members would answer the questions. We can see in Table 10 that only about a third (29%) of those who gave the correct answers (i.e. preferred the aggregation of private information to public information) believe that a majority would also prefer aggregating private signals when $q = 0.7$. This indicates that those who recognize the benefit of information aggregation are well aware that many others fail to understand it.

Our findings regarding the appreciation of information aggregation and overall majority decisions, namely that i) a majority of the subjects severely underestimate the effect of information aggregation of private signals; and ii) all majority decisions follow the public signal in the fifteen-person committees with expert information, suggest that the subjects who recognize the benefit of information aggregation may nonetheless be unable to change the inefficient outcome.

Our earlier discussion for Figure 2 on individual best response assumes symmetric strategies and the subjects knowing empirical α and β, which implies they must be aware of the strictly positive pivot probability. However, given that all majority decisions followed the expert signal in the fifteen-person committees, some subjects might believe that a majority of the committee members would always follow the expert signal (whatever the reason behind obedience is) and thus they could have no influence on the outcome as they would never be pivotal. Subjects with such a belief face indifference, and voting for the expert signal under disagreement does not contradict their payoff maximization.

Furthermore, needless to say, the understanding of information aggregation is only a basic necessary condition to coordinate rationally for efficiency. The subjects would have to perform pivotal calculations and hypothetical thinking, which are found to be difficult even in a simpler setup (Esponda and Vespa, 2014). This, together with the superior accuracy of the expert signal, may also partly explain a significant proportion of votes for the expert signal under disagreement even among the subjects who answer the questions correctly.

5 Conclusions

This paper has studied the effects of a public signal on voting behaviour in committees of common interest. We have reported on the laboratory experiment we conducted to see how human subjects react to expert information. In particular we set the parameter values in such a way that the efficiency of the obedient equilibria is lower than what the agents could have achieved in the informative voting equilibrium without expert information. We find that the subjects follow expert information so frequently that most of the time the committee decisions are the same as what the expert signal indicates. This is in sharp contrast to the predictions from the efficient equilibrium, where only a small number of agents should (in expectation) follow the expert signal and as a result the committee decision and expert signal may not necessarily coincide.

We have then contrasted the results to those from the control treatments where the subjects receive private signals only. We find that the efficiency without expert information is significantly higher than the efficiency with expert information for fifteen-person committees. That is, the provision of otherwise efficiency enhancing expert information actually reduces efficiency in the laboratory.

The result of the incentivized questionnaire reveals that more than a majority of the subjects severely under-appreciate the efficiency gain from information aggregation and they very frequently follow expert information. They can be considered as non-strategic voters, because given their (mis)understanding of information aggregation, they would vote for the public signal regardless of the other subjects' voting strategies. This suggests that even those who do recognize the benefit of information aggregation and understand the game correctly may be "stuck" in an inefficient outcome, as they are a minority. Our findings have potentially important implications for how expert opinions should be presented and processed in collective decision making. Voters may be prone to manipulation by "experts", and the consequence of excessive reliance on expert information may be particularly severe for large committees or referendums, where the potential benefit of information aggregation is likely to be high.

6 Appendix A

6.1 Proposition 1

Proof. Consider agent i's strategy in the putative equilibrium where all the other agents follow their private signal. He computes the difference in the expected payoff between voting for A and B, conditional on his private and public signals, in the event where he is pivotal. Let $Piv(v_{-i})$ be the probability that agent i is pivotal, given all the other agents' strategies. The payoff difference is given by

$$\begin{aligned} w(\sigma_i, \sigma_E) &\equiv E[u_i(A,s) - u_i(B,s)|Piv(v_{-i}), \sigma_i, \sigma_E]\Pr[Piv(v_{-i}), \sigma_i, \sigma_E] \\ &= \frac{1}{2}\Pr[\sigma_E|s=A]\Pr[\sigma_i|s=A]\Pr[Piv(v_{-i})|s=A] \\ &- \frac{1}{2}\Pr[\sigma_E|s=B]\Pr[\sigma_i|s=B]\Pr[Piv(v_{-i})|s=B], \end{aligned} \tag{1}$$

where the equality follows from the independence of the signals. Without loss of generality, let us assume $\sigma_i = B$ and $\sigma_E = A$. From (1) we have

$$\begin{aligned} w(B,A) &= \frac{1}{2}\left(q(1-p)\frac{(n-1)!}{\left[\left(\frac{n-1}{2}\right)!\right]^2}p^{\frac{n-1}{2}}(1-p)^{\frac{n-1}{2}}\right) \\ &- \frac{1}{2}\left((1-q)p\frac{(n-1)!}{\left[\left(\frac{n-1}{2}\right)!\right]^2}p^{\frac{n-1}{2}}(1-p)^{\frac{n-1}{2}}\right) \\ &= \frac{1}{2}(q-p)\frac{(n-1)!}{\left[\left(\frac{n-1}{2}\right)!\right]^2}p^{\frac{n-1}{2}}(1-p)^{\frac{n-1}{2}} > 0. \end{aligned}$$

The inequality holds since $q > p$. This implies that agent i votes for A despite her private signal B. Thus every agent voting according to the private signal is not a Bayesian Nash equilibrium. □

6.2 Proposition 2

Proof. In the symmetric obedient equilibrium we have $(\alpha, \beta) = (1, 0)$ for any agent. Let each agent's totally mixed strategy such that $(\alpha, \beta) = (1/2, 1/2)$ with probability ϵ and $(\alpha, \beta) = (1, 0)$ with probability $1-\epsilon$. In order for an agent to be pivotal, it has to be that $\frac{n-1}{2}$ out of $n-1$ vote against the public signal.

Let l be the number of agents who follow $(\alpha, \beta) = (1/2, 1/2)$. Given $l \geq \frac{n-1}{2}$, the probability of being pivotal conditional on l is

$$\binom{l}{\frac{n}{2}}\left(\frac{\epsilon}{2}\right)^l\binom{n-1}{l}(1-\epsilon)^{n-1-l},$$

where $\binom{l}{\frac{n}{2}}\left(\frac{\epsilon}{2}\right)^l$ is the probability that l agents play $(\alpha, \beta) = (1/2, 1/2)$ and $\binom{n-1}{l}(1-\epsilon)^{n-1-l}$ is the probability that $\frac{n-1}{2}$ of them vote against the public signal. The probability of being pivotal is then given by

$$\sum_{i=\frac{n-1}{2}}^{n-1} \binom{l}{\frac{n}{2}} \left(\frac{\epsilon}{2}\right)^l \binom{n-1}{l}(1-\epsilon)^{n-1-l},$$

which clearly does not depend on signal realizations. This implies that a pivotal event is uninformative about the signals, and the agent prefers to vote according to the public signal if $q \geq p$. □

6.3 Proposition 3

Before deriving the equilibrium, it is useful to note that the mixed strategy equilibrium takes a "hybrid" form, where mixing occurs only when the private and public signals disagree.

Lemma 1. *Suppose there exists a symmetric Bayesian Nash equilibrium in mixed strategies. In such an equilibrium, any agent whose private signal coincides with the public signal votes according to the signals with probability* 1*.*

Proof. Without loss of generality, let us assume $\sigma_E = A$ to prove the lemma.

Define

$$F(A) \equiv \Pr[Piv(v_{-i})|s = A] = \sum_{k=0}^{n-1} \sum_{j=0}^{\min\left(k, \frac{n-1}{2}\right)} \binom{n-1}{k} p^k (1-p)^{n-1-k} \times \binom{k}{j} \alpha^j (1-\alpha)^{k-j} \binom{n-1-k}{\frac{n-1}{2} - j} (1-\beta)^{\frac{n-1}{2}-j} \beta^{\frac{n-1}{2}-k+j} \quad (2)$$

and

$$F(B) \equiv \Pr[Piv(v_{-i})|s = B] = \sum_{k=0}^{n-1} \sum_{j=0}^{\min\left(k, \frac{n-1}{2}\right)} \binom{n-1}{k} p^k (1-p)^{n-1-k} \times \binom{k}{j} \beta^j (1-\beta)^{k-j} \binom{n-1-k}{\frac{n-1}{2} - j} (1-\alpha)^{\frac{n-1}{2}-j} \alpha^{\frac{n-1}{2}-k+j}.. \quad (3)$$

Using $F(A)$ and $F(B)$, we rewrite

$$w(A, A) = \frac{1}{2} [qpF(A) - (1-q)(1-p)F(B)] \quad (4)$$

$$w(B, A) = \frac{1}{2} [q(1-p)F(A) - (1-q)pF(B)]. \quad (5)$$

Note that (4) and (5) incorporate each agent's Bayesian updating on the state and the private signals other agents may have received, conditional on his own signal and the public signal.

In order to have fully mixing equilibrium, namely $\alpha^* \in (0,1)$ and $\beta^* \in (0,1)$, we must have $w(A,A) = 0$ and $w(B,A) = 0$ simultaneously for indifference. In what follows, we show that $w(A,A) > 0$ for any α and β, which implies in equilibrium we must have $\alpha^* = 1$ and if mixing occurs it must be only for β, that is, when the private and public signals disagree. Specifically, we show that $F(A) > F(B)$, which readily implies $w(A,A) > 0$ from (4).

From (4) and (5) we have $F(A) - F(B) > 0$ if

$$\begin{aligned}\alpha^j(1-\alpha)^{k-j}(1-\beta)^{\frac{n-1}{2}-j}\beta^{\frac{n-1}{2}-k+j} &> \beta^j(1-\beta)^{k-j}(1-\alpha)^{\frac{n-1}{2}-j}\alpha^{\frac{n-1}{2}-k+j}\\ &\Leftrightarrow \beta(1-\beta) > \alpha(1-\alpha)\\ &\Leftrightarrow (\alpha+\beta-1)(\alpha-\beta) > 0. \qquad (6)\end{aligned}$$

To see that (6) holds we will show that in equilibrium $\alpha^* + \beta^* - 1 > 0$ and $\alpha^* - \beta^* > 0$.

Let us first observe that $\alpha^* + \beta^* - 1 > 0$. The difference in the difference in payoffs between voting for A and B is given by

$$w(A,A) - w(B,A) = \frac{q(2p-1)}{2}F(A) + \frac{(1-q)(2p-1)}{2}F(B) > 0, \qquad (7)$$

since both terms in the right hand side are positive since $p, q > 1/2$. Thus, given $\sigma_E = A$, the equilibrium probability of voting for A when $\sigma_i = A$ must be strictly greater than that of voting for A when $\sigma_i = B$, which implies[37]

$$\alpha^* + \beta^* - 1 > 0. \qquad (8)$$

Second, let us show that $\alpha^* > \beta^*$. We assume instead that $\alpha^* \leq \beta^*$ in equilibrium and derives a contradiction. There is no hybrid equilibrium such that $\alpha^* \in (0,1)$ and $\beta^* = 1$, because from (6) and (8), $\alpha^* \leq \beta^*$ implies $F(A) \leq F(B)$ and we may have a fully mixed equilibrium, in which case $w(A,A) = w(B,A) = 0$. From (4) we have

$$w(A,A) = 0 \Rightarrow \frac{F(A)}{F(B)} = \frac{(1-q)(1-p)}{qp}, \qquad (9)$$

and from (5)

$$w(B,A) = 0 \Rightarrow \frac{F(A)}{F(B)} = \frac{(1-q)p}{q(1-p)}. \qquad (10)$$

We can see that (9) and (10) hold simultaneously if and only if $p = 1/2$, which is a

[37] See Lemma 1 in Wit (1998) for a similar argument.

contradiction, since $p \in (1/2, 1]$. Thus we conclude that $\alpha^* > \beta^*$ in any mixed strategy equilibrium equilibrium.

Combining $\alpha^* > \beta^*$ and (8), we can see that (6) holds. Thus we have $F(A) - F(B) > 0$ and $w(A, A) > 0$, which implies any mixed strategy equilibrium has to have a hybrid form, such that $\alpha^* = 1$. □

Lemma 1 is not surprising, because when both signals coincide they would jointly be very informative about the actual state. The non-trivial part of the lemma is that this intuition holds regardless of the mixing probability when the signals disagree. Thanks to the lemma we can focus on mixing when the private and public signals disagree.

Proof of Proposition 3. From Lemma 1 any mixed strategy equilibrium involves $v_i(A, A) = v_i(B, B) = 1$ and $v_i(A, B) = v_i(B, A) = \beta \in (0, 1)$ for any $i \in N$. When the state and the public signal match, the probability of each individual voting correctly for the state is given by

$$r_a \equiv p + (1-p)(1-\beta), \tag{11}$$

and when the state and the public signal disagree, the probability of each individual voting correctly is

$$r_b \equiv (1-p) \times 0 + p\beta = p\beta. \tag{12}$$

To have $\beta^* \in (0, 1)$, we need any agent to be indifference when the two signals disagree:

$$w(B, A) = q(1-p)\binom{n-1}{\frac{n-1}{2}} r_a^{\frac{n-1}{2}} (1-r_a)^{\frac{n-1}{2}} - (1-q)p\binom{n-1}{\frac{n-1}{2}} r_b^{\frac{n-1}{2}} (1-r_b)^{\frac{n-1}{2}} = 0 \tag{13}$$

$$\Rightarrow \frac{1-p\beta}{1-\beta(1-p)} = \left(\frac{q}{1-q}\right)^{\frac{2}{n-1}} \left(\frac{1-p}{p}\right)^{\frac{n+1}{n-1}} \tag{14}$$

$$\Rightarrow \beta^* = \frac{1-A(p,q,n)}{p - A(p,q,n)(1-p)}, \tag{15}$$

such that $A(p, q, n) = \left(\frac{q}{1-q}\right)^{\frac{2}{n-1}} \left(\frac{1-p}{p}\right)^{\frac{n+1}{n-1}}$. Thus when $\beta^* \in (0, 1)$ we obtain a mixed strategy equilibrium of the hybrid form ($\alpha^* = 1$).

Finally, solving $\beta^* = 0$ for q, we see that $\beta^* \in (0, 1)$ if and only if $q \in \left(p, \frac{\left(\frac{p}{1-p}\right)^{\frac{n+1}{2}}}{1+\left(\frac{p}{1-p}\right)^{\frac{n+1}{2}}}\right)$. The uniqueness follows from the fact that the left hand side of (14) is strictly decreasing in β. □

6.4 Proposition 4

Proof. In what follows we will find $\alpha = v_i(A, A) = v_i(B, B)$ and $\beta = v_i(B, A) = v_i(A, B)$ that maximize the probability of the majority outcome matching the correct state. Conditional on the state $s = A$ and $\sigma_E = A$, let the ex ante probability of each agent voting for A be, from (11), $r_a \equiv p\alpha + (1-p)(1-\beta)$. Also from (12), conditional on the state $s = A$ and $\sigma_E = B$, let the probability of each agent voting for A be $r_b \equiv p\beta + (1-p)(1-\alpha)$. Using r_a and r_b, the ex ante probability $P(\alpha, \beta)$ that the majority decision matches the state can be written as

$$
\begin{aligned}
P(\alpha,\beta) =& \Pr[M=s|s] = \Pr[M=A|s=A]P[A] + \Pr[M=B|s=B]P[B] \\
=& \Pr[M=A|s=A]\frac{1}{2} + \Pr[M=B|s=B]\frac{1}{2} = \Pr[M=A|s=A] \\
=& \Pr[\sigma_E=A|s=A]\Pr[M=A,\sigma_E=A|s=A] \\
&+ \Pr[\sigma_E=B|s=A]\Pr[M=A,\sigma_E=B|s=A] \\
=& q\sum_{k=\frac{n+1}{2}}^{n}\binom{n}{k}r_A^k(1-r_A)^{n-k} + (1-q)\sum_{k=\frac{n+1}{2}}^{n}\binom{n}{k}r_B^k(1-r_B)^{n-k}. \qquad (16)
\end{aligned}
$$

Note that for

$$g(x) \equiv \sum_{k=\frac{n+1}{2}}^{n}\binom{n}{k}x^k(1-x)^{n-k}$$

we have

$$\frac{dg(x)}{dx} = n\binom{n-1}{\frac{n-1}{2}}\left(x(1-x)\right)^{\frac{n-1}{2}}.$$

Partially differentiating (16) with respect to α and β, we obtain

$$
\begin{aligned}
\frac{\partial P(\alpha,\beta)}{\partial\alpha} =& npq\binom{n-1}{\frac{n-1}{2}}\left(r_a(1-r_a)\right)^{\frac{n-1}{2}} \\
&- n(1-p)(1-q)\binom{n-1}{\frac{n-1}{2}}\left(r_b(1-r_b)\right)^{\frac{n-1}{2}} \qquad (17)
\end{aligned}
$$

and

$$
\begin{aligned}
\frac{\partial P(\alpha,\beta)}{\partial\beta} =& -(1-p)nq\binom{n-1}{\frac{n-1}{2}}\left(r_a(1-r_a)\right)^{\frac{n-1}{2}} \\
&+ pn(1-q)\binom{n-1}{\frac{n-1}{2}}\left(r_b(1-r_b)\right)^{\frac{n-1}{2}}. \qquad (18)
\end{aligned}
$$

From (18), taking the first order condition with respect β we have

$$\frac{\partial P(\alpha,\beta)}{\partial\beta} = 0 \Leftrightarrow \left(\frac{r_b(1-r_b)}{r_a(1-r_a)}\right)^{\frac{n-1}{2}} = \frac{q(1-p)}{(1-q)p}. \qquad (19)$$

If (19) holds, then the derivative with respect to α, (17), is strictly positive for any $\alpha \in [0,1]$ since

$$\begin{aligned}\frac{\partial P(\alpha,\beta)}{\partial \alpha} > 0 \Leftrightarrow \frac{qp}{(1-q)(1-p)} &> \left(\frac{r_b(1-r_b)}{r_a(1-r_a)}\right)^{\frac{n-1}{2}} \\ \Leftrightarrow \frac{qp}{(1-q)(1-p)} &> \frac{q(1-p)}{(1-q)p} \\ \Leftrightarrow p > \frac{1}{2}.\end{aligned}$$

Therefore we have a unique corner solution for α, namely $\alpha = 1$, which coincides with the equilibrium α^* in the hybrid mixed strategy identified in Proposition 3. Note that the first order condition (18) and the indifference condition for the mixed strategy equilibrium (13) also coincide. Thus $\beta = \beta^*$ satisfies the first order condition.

It remains to show that the second order condition for the maximization with respect to β is satisfied. Since $P(\alpha,\beta)$ is a polynomial it suffices to show that

$$\begin{aligned}\frac{\partial^2 P(\alpha,\beta)}{\partial \beta^2} < 0 \Rightarrow -(1-p)nq\binom{n-1}{\frac{n-1}{2}}\left(r_a(1-r_a)\right)^{\frac{n-3}{2}}\left(1-p-2\beta(1-p)^2\right) \\ < pn(1-q)\binom{n-1}{\frac{n-1}{2}}\left(r_b(1-r_b)\right)^{\frac{n-3}{2}}\left(p-2\beta p^2\right). \qquad (20)\end{aligned}$$

At $\beta = \beta^*$, (20) reduces to

$$(1-p\beta)(1-2(1-p)\beta) > (1-2p\beta)(1-(1-p)\beta),$$

which holds since $p > \frac{1}{2}$. Since $P(\alpha,\beta)$ is a continuously differentiable function on a closed interval, the local maximum at $\{\alpha,\beta\} = \{1,\beta^*\}$ is also the global maximum. □

6.5 Figure 2

Let agents with agreeing signals vote for the common signal with probability $1-\varepsilon$ and for the other signal with probability ε and agents with disagreeing signals vote for the public signal with probability $1-\delta$ and for their private signal with probability δ .

From the indifference and optimality conditions above, by setting

$$r_a \equiv pa + (1-p)(1-\beta), \qquad (21)$$

and

$$r_b \equiv p\beta + (1-p)(1-a), \qquad (22)$$

we can set $a = 1-\varepsilon$ and $\beta = \delta$. Thus, using equations 19 and 20 we can derive thresholds for the asymmetric trembling probabilities for which $\frac{\partial P(\alpha,\beta)}{\partial \beta} < 0$ and indicate when the symmetric equilibrium fails to be trembling hand perfect. As an example, setting $n = 15$, $\varepsilon = 0.95$, $\delta = 0.35$, $p = 0.65$ and $q = 0.70$, we observe that $\frac{\partial P(\alpha,\beta)}{\partial \beta} < 0$ and then the symmetric equilibrium is not trembling hand perfect for asymmetric trembles.

7 Appendix B: Alternative Interpretations Based on Bounded Rationality

7.1 Quantal response equilibrium

In the literature on voting experiments, it is common to consider quantal response equilibrium (QRE; McKelvey and Palfrey, 1995) to see whether the experimental data on subjects' actions can be interpreted as deviation from a particular equilibrium prediction of interest. Let us see whether subjects' aggregate behaviour can be systematically linked to the symmetric mixed equilibrium in Proposition 3, which is more efficient than the obedient equilibrium and the informative voting equilibrium without public information.[38]

Let us derive the logistic quantal response function for the rationality parameter λ, where $\lambda \to \infty$ corresponds to perfect rationality and the symmetric mixed equilibrium under consideration and $\lambda = 0$ corresponds to complete randomization (voting for either alternative with 50% regardless of the information). Let $\bar{\alpha} = v_{-i}(A, A) = v_{-i}(B, B)$ and $\bar{\beta} = v_{-i}(B, A) = v_{-i}(A, B)$ for any $-i \in \{1, 2, ..., i-1, i+1, ..., n\}$. That is, $\bar{\alpha}$ is the probability that all agents except agent i vote according to the signals in agreement, and $\bar{\beta}$ is the probability that all agents except agent i vote according to the private signal when the signals disagree. Given that the expert signal is correct, the probability of each agent $-i$ voting for the correct state is $r_a \equiv p\bar{\alpha} + (1-p)(1-\bar{\beta})$. Also, given that the expert signal is correct, the probability of each agent $-i$ voting for the correct state is $r_b \equiv p\bar{\beta} + (1-p)(1-\bar{\alpha})$. Suppose these agents follow the mixed strategy as described in Proposition 3.

If agent i votes according to the signals in agreement, his expected payoff is given by

$$\begin{aligned} E[u_i^{AA}(\bar{\alpha}, \bar{\beta})] &= \frac{pq}{pq + (1-p)(1-q)} G(n-1, (n+1)/2, r_a) \\ &+ \frac{(1-p)(1-q)}{pq + (1-p)(1-q)} G(n-1, (n+1)/2, r_b), \end{aligned}$$

where

$$G(n, l, x) \equiv \sum_{k=l}^{n} \binom{n}{k} x^k (1-x)^{n-k}.$$

[38]As observed by Guarnaschelli et al. (2000) (see pp.417-8), if one allows asymmetric strategies in voting games, the QRE correspondence for each voter may bifurcate and as a result become too complex to obtain numerically or interpret, which is the case in our model.

If agent i votes against the signals in agreement, his expected payoff is given by

$$\begin{aligned} E[u_i^{AO}(\bar{\alpha},\bar{\beta})] &= \frac{pq}{pq+(1-p)(1-q)} G(n-1,(n+1)/2,r_a) \\ &+ \frac{(1-p)(1-q)}{pq+(1-p)(1-q)} G(n-1,(n+1)/2-1,r_b). \end{aligned}$$

If agent i votes according to the private signal when the private and public signals disagree, his expected payoff is given by

$$\begin{aligned} E[u_i^{DP}(\bar{\alpha},\bar{\beta})] &= \frac{q(1-p)}{q(1-p)+p(1-q)} G(n-1,(n+1)/2,r_a) \\ &+ \frac{p(1-q)}{q(1-p)+p(1-q)} G(n-1,(n+1)/2-1,r_b). \end{aligned}$$

If agent i votes according to the public signal when the private and public signals disagree, his expected payoff is given by

$$\begin{aligned} E[u_i^{DE}(\bar{\alpha},\bar{\beta})] &= \frac{q(1-p)}{q(1-p)+p(1-q)} G(n-1,(n+1)/2-1,r_a) \\ &+ \frac{p(1-q)}{q(1-p)+p(1-q)} G(n-1,(n+1)/2,r_b). \end{aligned}$$

Hence we have

$$\bar{\alpha}(\lambda) = \frac{exp(\lambda E[u_i^{AA}(\bar{\alpha},\bar{\beta})])}{exp(\lambda E[u_i^{AA}(\bar{\alpha},\bar{\beta})]) + exp(\lambda E[u_i^{AO}(\bar{\alpha},\bar{\beta})])}, \tag{23}$$

$$\bar{\beta}(\lambda) = \frac{exp(\lambda E[u_i^{DP}(\bar{\alpha},\bar{\beta})])}{exp(\lambda E[u_i^{DP}(\bar{\alpha},\bar{\beta})]) + exp(\lambda E[u_i^{DE}(\bar{\alpha},\bar{\beta})])}. \tag{24}$$

The $\bar{\alpha}$ and $\bar{\beta}$ that satisfy the system of (23) and (24) for $p = 0.65$, $q = 0.7$, and $n = 7, 15$ as in the experiment are plotted on Figure 3, where the square dots correspond to $\lambda \to \infty$ and thus the symmetric mixed equilibrium for each treatment. Clearly the data, represented by the circle dots, is further away from the QRE predictions.

In particular, with respect to the predictions, the likelihood of making an error when the signals agree is significantly different from when the signals disagree (as can also be seen in Table 2 and Figure 1). This is because, while the voting behaviour with signals in agreement is very close to the equilibrium prediction (voting for these signals with probability 1), the voting behaviour with signals in disagreement deviates substantially from that in the symmetric mixed strategy equilibrium. Thus we are unable to assign a reasonable common parameter to reflect the degree of error for this equilibrium.

Moreover it is easy to show from (24) that, if we fix $\bar{\alpha} = 1$ and posit that the error occurs only when the signals disagree, we have $\bar{\beta}(\lambda) \geq 1/2$ for any $\lambda \in [0, \infty)$. This is inconsistent with the data which indicates β around 32-35% (Table 2).

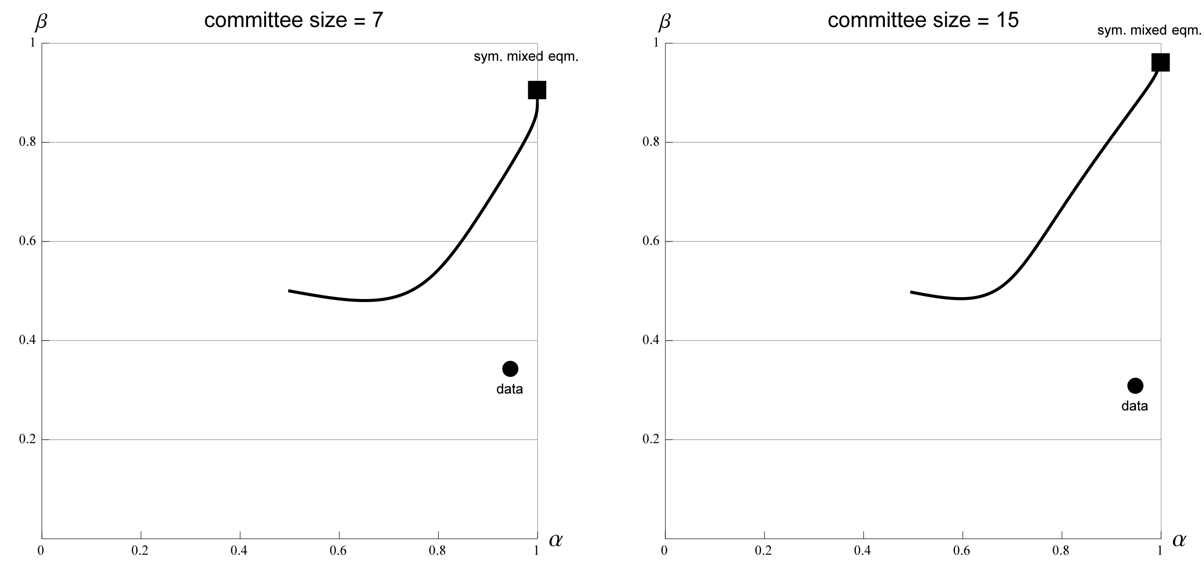

Figure 3: Data and logistic QRE predictions for symmetric mixed equilibrium

Table 11: Proportion of votes for private signal under disagreement

		7-person committees	15-person committees
vote for private signal	first period of session	0.1000 (2/20)	0.1351 (5/37)
	first occurrence of disagreement	0.1190 (5/42)	0.1444 (13/90)

7.2 Cognitive hierarchy

Another approach to understanding the subjects' behaviour especially in the first period or the first occurrence of disagreement would be to use a cognitive hierarchy (level-k) model (Stahl and Wilson, 1995; Nagel, 1995). In such a model, each player in a game has a type denoted by level-k for a positive integer k. Level-k players anchor their beliefs in a non-strategic level-0 players and adjust the beliefs with (virtual) iterated best responses, in such a way that level-k players (for $k \geq 1$) rationally best responds based on the belief that all other players are level-$(k-1)$.

In order to apply the model we need to determine how level-0 voters should behave, which seems non-trivial in our setup. If we assume, following Costinot and Kartik (2007), that level-0 voters vote according to their private signal, level-1 voters should vote according to the public signal, in which case level-2 voters become indifferent with respect to their own vote, and thus it is impossible to obtain clear predictions for the behaviour of level-k voters for $k \geq 2$. This is also the case if level-0 voters randomize equally between the two choices regardless of their signal realizations; and if level-0 voters vote according to the two signals when they agree and randomize equally when they disagree. Meanwhile, if level-0 voters are to follow the public signal, then naturally level-1 voters become indifferent and we have no clear prediction for any k.

In Table 11 we observe that a much higher proportion of the subjects voted for the public signal in the first period or the first period under disagreement, compared to later periods (see also Table 2). One interpretation of this is that a substantive proportion of the subjects believed that the others would vote for the private signal or disregard the signals and randomize, as level-0 voters could do, and best responded to such beliefs by voting for the public signal when the signals disagreed. Unfortunately, the indifference level-2 voters face makes it impossible for us to clearly infer their k from the data.

7.3 Cursed equilibrium

Eyster and Rabin (2005) introduced another form of bounded rationality, where players correctly take into account others' actions, but fail to update their beliefs using the information implied in these actions. A single parameter $\chi \in [0, 1]$ represents "cursedness", where $\chi = 0$ characterizes the standard Bayesian equilibrium and $\chi = 1$ characterizes the "fully cursed" equilibrium, in which agents decide on the best response by taking into account only the information they have.[39]

For the symmetric mixed strategies in our voting game, if $\chi = 0$ then the agents play the equilibrium strategy as described in Proposition 3 and thus vote for the private signal with probability β^* when the signals disagree. If $\chi = 1$, the agents play the obedient equilibrium since they only use their own signals under disagreement and thus from each agent's viewpoint the public signal is more likely to be correct.

If $\chi \in (0, 1)$, each agent's equilibrium best response is derived based on the belief that, with probability χ the other agents vote according to the (equilibrium) distribution of votes regardless of whether their signals agree or disagree; and with probability $1 - \chi$ votes reflect the respective agents' signals through the equilibrium strategy. Suppose χ is large. Then if other agents are to mix under disagreement, the posterior of an agent with signals that disagree would still be in favour of the public signal, since the agent underestimates the fact that, in order to be pivotal, there have to be a sufficient number of private signals contradicting the public signal. As a result the agent votes according to the public signal and obedience is the only symmetric χ-cursed equilibrium strategy for large enough χ. On the other hand, there would be votes for the private signal (under disagreement) as χ becomes smaller, while the agents still underrate their private signal relative to the case where $\chi = 0$. If we allow χ to vary across agents, a potential interpretation of Table 11 would be that a significant proportion of our subjects had high degrees of cursedness.

Although it may be possible to postulate a value of χ to fit the data, however, the cursed equilibrium predicts that for a given χ, voters are more likely to vote for the private signal in a fifteen-person committee than in a seven-person committee, because conditional on the same mixing probability when the signals disagree, the weight on the

[39]The obedient equilibrium is also a χ-cursed equilibrium for any $\chi \in [0, 1]$, since conditional on the public signal, there is no further information aggregation through votes (i.e. all agents "pool" by voting for the public signal). Therefore cursedness does not affect the agents' posterior.

Table 12: Random effects probit for 15-person committees: dependent variable = vote for private signal under disagreement

Independent variable				
Treatment 5: Expert info as prior	1.3285***	1.3132***	1.5374***	
	(0.3108)	(0.3806)	(0.4782)	
Treatment 6: $q < p$	2.7191***	2.8586***	3.1288***	
	(0.3225)	(0.3958)	(0.4650)	
Correct understanding of		0.7785**	1.2594**	1.0068***
information aggregation		(0.3317)	(0.5599)	(0.3595)
Treatment 5 × Correct understanding			-0.6409	
			(0.7712)	
Treatment 6 × Correct understanding			-0.9284	
			(0.8437)	
Frequency of voting for	-1.2137	-0.3755	-0.5061	-0.0668
signals in agreement	(1.4127)	(1.7617)	(1.7577)	(1.6571)
No. of periods with disagreement	0.0613*	0.0664	0.0594	-0.0166
	(0.0354)	(0.0441)	(0.0444)	(0.0436)
Constant	-1.4214	-2.6551	-2.5085	-2.9721
	(1.6343)	(2.0236)	(2.0207)	(1.9243)
Session dummies	No	No	No	Yes
Observations	4758	3540	3540	3540
Log likelihood	-1857.3269	-1286.9689	-1286.3684	-1277.3767

Note: Standard errors in parentheses. Treatment 2 (expert) is the base treatment.
Correct understanding = 1 if a subject answers both questions correctly and otherwise 0.
The first model includes observations from the three expert sessions without the questionnaire.
*** significant at 1% level; ** significant at 5% level; * significant at 10% level

public signal in the pivotal event is larger in a larger committee and hence the agents correct for it by voting for the private signal (more often).[40] This contradicts our data on individual voting behaviour under disagreement presented in Tables 2and 11, which indicate that, by and large, higher proportions of the voters voted for the private signal in the seven-person committees than in the fifteen-person committees.

8 Appendix C: Supplementary Tables for Section 4.3

8.1 Voting behaviour in the additional treatments with public information

An alternative approach to the OLS estimates we presented in Table 5 is to take each vote (under disagreement), rather than each subject, as one observation in a panel and control for subject heterogeneity. Table 12 presents estimates from random effects probit

[40]This is also reflected in the equilibrium strategy: Proposition 3 implies $\beta^*(p,q,n') > \beta^*(p,q,n)$ for any $n' > n$ and $\beta^*(p,q,n') > 0$. That is, the larger the committee size is, the higher the probability of voting for the private signal under disagreement.

Table 13: Majority decisions by 15-person committees

	$q > p$ as prior (180 obs.)	$q < p$ (180 obs.)
Decision coincided with public signal/bias	0.9222	0.7389
Observed efficiency	0.8056	0.7500
Realized efficiency of prior/public signal (overall)	0.7500	0.5444
Realized efficiency of prior/public signal when it coincides with decision	0.8012	0.7209
Efficiency if subjects had voted for realized private signals	0.9056	0.9056

models, and it is immediately clear that the signs of statistically significant coefficients are the same as those from the OLS.[41] However, the random effects models should be treated with caution, since the dummy for the understanding of information aggregation may be correlated with unobserved individual characteristics of the subjects.

8.2 Efficiency in the additional treatments with public information

The comparison across the treatments with respect to efficiency has proved difficult, because the signal realizations and especially the accuracies of the public signal varied across treatments. We were particularly "unlucky" that the realized accuracy of the public signal in the treatment where it was presented as a prior was rather high (75%, although on the z-tree code $q = 0.70$), while we were "lucky" that for the expert treatment the realized accuracy of the public signal was exactly 70% as intended. As we can see in Table 13, in the treatment with $q > p$ as a prior, when the majority decisions coincided with public signal the accuracy was even higher, at 80%. Consequently, the efficiency observed in the treatment was very high, 81%.

One possible adjustment for the treatment with $q > p$ as a prior with respect to the difference in the accuracies of the public signal is to assume that the accuracy of the majority decisions was 70% when they coincided with the public signal. The adjusted efficiency is 71%,[42] which is not significant different from the efficiency in the main expert treatment, although a statistical test based on the adjusted figures would be inappropriate.

The efficiency comparison between the expert treatment and the treatment with $q < p$ is slightly less problematic but has a similar issue that, contrary to the treatment with $q > p$ as a prior, the realized public signal was less accurate than it was intended to be (in the z-tree code $q = 0.6$ but the realized efficiency of the public signal was 54%). The observed efficiency is 75%, which lies in between the accuracy of the public signal (54%)

[41]We cannot use models with subject fixed effects here since there are multiple time-invariant variables (session dummies, treatment dummies, answer to the questionnaire).

[42]The decision did not coincide with the public signal in 14 periods, out of which the decision was correct in 12 periods (86%).

and what the subjects could have achieved if all of them consistently followed their private signals (91%).

9 Appendix C: Experimental Instructions[43]

Thank you for agreeing to participate in the experiment. The purpose of this session is to study how people make group decisions. The experiment will last approximately 55 minutes. Please switch off your mobile phones. From now until the end of the session, no communication of any nature with any other participant is allowed. During the experiment we require your complete, undistracted attention. So we ask that you follow these instructions carefully. If you have any questions at any point, please raise your hand.

The experiment will be conducted through computer terminals. You can earn money in this experiment. The amount of money you earn depends on your decisions, the decisions of other participants, and luck. All earnings will be paid to you immediately after the experiment. During the experiment, your payoff will be calculated in points. After the experiment, your payoff will be converted into British Pounds (GBP) according to the following exchange rate: 850 points = £1, and rounded to the nearest pound. Please remain seated after the experiment. You will be called up one by one according to your desk number. You will then receive your earnings and will be asked to sign a receipt.

All participants belong to a single group of fifteen until the end of this experiment.

The experiment has two parts and consists of a total of 70 rounds. The first part of the experiment has10 rounds, and the second part has 60 rounds.

At the beginning of each round, the computer places a prize in one of two virtual boxes: a blue box and a yellow box. [SHOW PICTURE ON FRONT SCREEN] The location of the prize for each round is determined by the computer via the toss of a fair coin: at the beginning of each round it is equally likely that the prize is placed in either box. That is, the prize is placed in the blue box 50% of the time and the prize is placed in the yellow box 50% of the time. You will not directly see in which box the prize is hidden, but as we will describe later you will receive some information about it. [SHOW PICTURE ON FRONT SCREEN] The box that does not contain the prize remains empty.

The group's task is to choose a colour. In every round, each group member has two options, either to vote for BLUE or YELLOW. [SHOW PICTURE ON FRONT SCREEN] The colour that has received the majority of the votes becomes the group decision for the round. In every round, each member of the group earns:

1. 100 points if the group decision matches the colour of the box that contains the prize;

2. 5 points if the group decision does not match the colour of the box that contains the prize.

[43] The instructions here are for the treatment for fifteen-person committees, with expert information and the questionnaire. The instructions for the other treatments are available on request.

Note that your payoff for each round is determined exclusively by the group decision. If the group decision is correct, every group member earns 100 points. If the group decision is incorrect, every group member earns 5 points. The payoff is independent of how a particular group member voted.

To summarize, each round proceeds as follows: [SHOW PREVIOUS PICTURES IN TURN]

1. the computer places a prize in one of two boxes (blue box or yellow box with equal chance);

2. each group member receives some information about the location of the box;

3. each group member votes for BLUE or YELLOW;

4. group decision is the colour that has received most votes;

5. each group member receives earnings according to the group decision and the actual location of the prize.

Consider the following example. Suppose you and six other member voted for BLUE and the eight other members voted for YELLOW. This means that the group decision is YELLOW.

If the prize was indeed placed in the yellow box, then each group member, including you, earns 100 points. On the other hand, if the prize was placed in the blue box, each group member, including you, earns 5 points.

The experiment is divided into two parts. Both parts follow what we have described so far, but they are different in terms of i) the information each group member receives before voting, and ii) the number of rounds.

Part 1

The first part of the experiment will take place over 10 rounds. In each round, after the prize is placed in one of the two boxes but before group members vote, each participant receives a single piece of information about the location of the prize. We will call this type of information Private Information. Private Information will be generated independently and revealed to each participant separately, and it can be different for different group members. No other participants of the experiment will see your Private Information. [SHOW SCREEN FOR DECISION]

Private Information is not 100% reliable in predicting the box containing the prize. Reliability refers to how often Private Information gives the correct colour of the box.

Specifically, Private Information gives each of you the colour of the box with the prize 65% of the time, and the colour of the empty box 35% of the time.

The reliability of Private Information can be described as follows:

1. In each round, after the prize is placed in one of the boxes, the computer rolls a fair 20-sided dice for each group member. A real 20-sided dice is on your desk to help your understanding.

2.

a. If the result of the dice roll is 1 to 13 (1,2,4,5,6,7,8,9,10,11,12 or 13), then that member's Private Information is the colour of the box with the prize. Note that 13 out of 20 times means 65%.

b. If the result of the dice roll is 14 to 20 (14,15,16,17,18,19 or 20), then that member's Private Information is the colour of the empty box. Note that 7 out of 20 times means 35%.

Private Information is more likely to be correct than incorrect. Also, all group members receive equally reliable Private Information. However, since it is generated independently for each member, members in the same group do not necessarily get the same information. It is possible that your Private Information is BLUE while other members' Private Information is YELLOW.

Finally, at the end of each round, you will see the number of votes for BLUE, the number of votes for YELLOW, and whether the group decision matched the colour of the box with the prize.

Part 1 will start after a short quiz to check your understanding of the instructions. [PART 1 COMMENCES]

Part 2

The second part of the experiment will take place over 60 rounds. In each round, after the prize is placed in one of the two boxes but before group members vote, each group member receives two pieces of information, namely Private Information and Public Information, about the location of the prize. [SHOW SCREEN FOR DECISION] As before, in each round Private Information will be generated independently and revealed to each group member separately, and no other participants of the experiment will see your Private Information. It gives each of you the colour of the box with the prize 65% of the time, and the colour of the empty box 35% of the time.

The reliability of Private Information can be described as follows:

1. In each round, after the prize is placed in one of the boxes, the computer rolls a fair 20-sided dice for each group member.

2.

a. If the result of the dice roll is 1 to 13 (1,2,4,5,6,7,8,9,10,11,12 or 13), then that member's Private Information is the colour of the box with the prize. Note that 13 out of 20 times means 65%.

b. If the result of the dice roll is 14 to 20 (14,15,16,17,18,19 or 20), then Private Information is the colour of the empty box. Note that 7 out of 20 times means 35%.

In addition to but independently of Private Information, Public Information is revealed to all members of your group. In each round all group members get the same Public Information. It gives you the colour of the box with the prize 70% of the time, and the colour of the empty box 30% of the time.

The reliability of Public Information can be described as follows:

1. In each round, after the prize is placed in one of the boxes, the computer rolls a fair 20-sided dice (one dice roll for all members of your group), separately from the dice

rolls for Private Information.

2.

a. If the result of the dice roll is 1 to 14 (1,2,4,5,6,7,8,9,10,11,12,13 or 14), then your group's Public Information is the colour of the box with the prize. Note that 14 out of 20 times means 70%.

b. If the result of the dice roll is 15 to 20 (15,16,17,18,19 or 20), then your group's Public Information is the colour of the empty box. Note that 6 out of 20 times means 30%.

Neither Public Information nor Private Information is 100% reliable in predicting the box with the prize, but both pieces of information are more likely to be correct than incorrect.

Note that those two pieces of information may not give you the same colour (it may be that one says BLUE and the other says YELLOW), in which case only one of them is correct. Public Information is more likely to be correct than each member's Private Information. However, it could be that your Private Information is correct and the Public Information is incorrect. Also, even if both pieces of information give you the same colour, it may not match the colour of the box that contains the prize, since neither is 100% reliable.

At the end of each round, you will see the number of votes for BLUE, the number of votes for YELLOW, and whether the group decision matches the colour of the box with the prize.

Part 2 will start after a short quiz to check your understanding of the instructions. [PART 2 COMMENCES]

Part 3

Now you will have the last two rounds of this experiment. You will make two choices for each round. The points you may earn for each choice are tripled compared to the points for each round in the previous two parts of the experiment, so please pay full attention. In the next two rounds, the computer, not the members of the group, casts all votes on your behalf. However, you choose how the computer votes before the computer generates any information about the location of the prize.

In Round 71, your first choice is between the following two options:

Option A: The computer votes according to the Private Information of all members. For example, if 6 members receive BLUE and 9 members receive YELLOW, the computer casts 6 votes for BLUE and 9 votes for YELLOW, and thus the decision will be YELLOW. Note that each member's Private Information is correct 65% of the time.

Option B: The computer votes according to Public Information only. That is, if the Public Information is BLUE, there will be 15 votes for BLUE and thus the decision will be BLUE. Note that the Public Information is correct 70% of the time.

The points you earn depends on the majority decision that follows from your own choice between the two options. That is, the participants who choose Option A will all earn the same points, and the participants who choose Option B will all earn the same points. If the majority decision matches the colour of the box with the prize, you earn 300 points, and 15 points otherwise.

After you have made the choice above, you will be asked to guess, including yourself, which of the two options has been chosen by more members (i.e. 8 or more members of the group).

If your guess is correct, you will earn 300 points. If your guess is incorrect, you earn 15 points.

You will see the results (the votes, location of the prize, points earned, whether your guess is correct, etc.) at the end of the experiment. [ROUND 71 (FIRST QUESTION) COMMENCES]

The next and the final round of the experiment, Round 72, is the same as Round 71, except that Public Information is correct 60% of the time. Your choice is between the following two options:

Option A: The computer votes according to the Private Information of all members. For example, if 6 members receive BLUE and 9 members receive YELLOW, the computer casts 6 votes for BLUE and 9 votes for YELLOW, and thus the decision will be YELLOW. Note that each member's Private Information is correct 65% of the time.

Option B: The computer votes according to Public Information only. That is, if the Public Information is BLUE, there will be 15 votes for BLUE and thus the decision will be BLUE. Note that the Public Information is correct 60% of the time.

If the majority decision that follows from your choice matches the colour of the box with the prize, you earn 300 points, and 15 points otherwise.

After you have made the choice between the two options, you will be asked to guess, including yourself, which of the two options has been chosen by more members (i.e. 8 or more members of the group). If your guess is correct, you earn 300 points. If your guess is incorrect, you earn 15 points. [ROUND 72 (SECOND QUESTION) COMMENCES]

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