Sequential Deliberation

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Abstract. We present a dynamic model of deliberation that is a collective action version of sequential sampling as in Wald (1947). In this model 'jurors' must decide every period whether to continue deliberation or stop and take a binding vote. Stopping yields a decision. Continuation yields additional information but comes with a cost. If the jurors are homogeneous, this is just a reinterpretation of the classic Wald sequential test of statistical hypotheses. When jurors are heterogeneous, no single juror can unilaterally decide to stop. Thus, continuation carries the risk that others may want to continue further than optimal from the single juror's perspective. The focus of the paper is to explore the role of heterogeneity and of alternative decision making rules (e.g., unanimity v. majority). The model also delivers predictions about the relation between the outcomes of the process, namely conviction, acquittal, or hung jury, and the time taken to reach a verdict.

Keywords: Deliberation, Voting, Juries

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1. Introduction

1.1 Overview

Decision making in groups often involves deliberation. Juries, boards of directors, congressional and university committees, government agencies such as the FDA or the EPA, and many other committees, spend time deliberating issues before reaching a decision or issuing a recommendation. This paper presents a simple model of deliberation to study the effect of the structure of the deliberative process, and of the composition of deliberating groups, on outcomes such as the accuracy of decisions, the length of deliberation, and the degree of disagreement.

Previous literature on deliberation has focused on asymmetric information among members of the deliberating group, on how this information asymmetry can impede effective decision making, and how different voting rules interact with this information asymmetry.[1] We abstract from private information and focus on a simpler aspect of collective action: how information collection responds to conflicting preferences. As in individual decision making, in a deliberating committee, there are two types of decisions to make: *deliberation decisions* and *action decisions*. Deliberation decisions are about whether to keep deliberating in order to obtain additional information. Action decisions regard the choice to be taken at the end of deliberation. Deliberation is in service of action decisions since the information that is obtained is supposed to allow more informed action decisions. The focus of this paper is the novel dimension that emerges because of a consideration of sequential deliberation in committees: the distinction between *deliberation rules* and *voting rules*. A deliberation rule governs the deliberation process and determines when information acquisition must stop. A voting rule governs the voting over issues at the end deliberation. There are many examples where deliberation rules are different from voting rules. For instance, in many committees, the chairman of the committee has the same power as all the other members of the committee over action decisions, but has a special role to play (and more power) in deliberation decisions. However, while voting rules are often quite precisely described – some issues require majority voting, others require supermajority or unanimity – deliberation rules are often vague. Despite this

[1] E.g., Austen-Smith and Feddersen (2005 and 2006), Coughlan (2000), Meirowitz (2006), Gerardi and Yariv (2006 and 2007), Persico (2004).

vagueness, it is useful to think broadly of committees that have more inclusive deliberation protocols than others. We will initially model this inclusiveness as a threshold rule R_d such that deliberation ends as soon as R_d members of the committee vote to end deliberation. Voting rules are analogously captured by a rule R_v that describes the specific qualified majority required for reaching a decision. Our analysis discusses the effects of deliberation and voting rules on the length of deliberation, the accuracy of decisions, and the welfare of the committee and of society at large. We show that there is a sense in which deliberation rules are more "effective" than voting rules. For instance, we show that under certain assumptions, voting rules are irrelevant, while deliberation rules affect the length of deliberation. Furthermore, we show that, in a range of parameters where the voting rule does have an effect, in contrast with Feddersen and Pesendorfer (1998) and Persico (2004), unanimity leads to more informative outcomes than majority rule. We also show that a committee would like to delegate deliberation power to a moderate chairman, explaining why deliberation rules sometimes take this form. Finally, we contrast sequential deliberation with static deliberation and argue that the sequential case displays a richness that is closer to the phenomena that are associated with deliberation.

The formal analysis in this paper is relevant for a variety of collective decision processes. However, we focus much of our discussion on juries. This is for three reasons. First, in juries, the deliberation process is clear-cut and circumscribed: there is a well-defined beginning and end of deliberation, the time it takes the jury to deliberate is measurable, and one single verdict is the typical outcome of such deliberation. Second, juries have been the focus of much prior literature on deliberation so it is useful to relate our framework to the analysis in these prior papers. Third, the literature has documented some patterns of deliberation in juries that we will attempt to explain with our model.

Technically, our analysis is a natural extension of much of the analysis of individual decision making into group contexts. Indeed, an important aspect of individual decision making is the appropriate amount of information to acquire before making a decision. An individual must weigh the cost of information against the value of making more accurate decisions. A classic and natural approach to this question, going back to Wald (1947), is Bayesian sequential analysis.[2] In this approach an individual acquires information sequentially, and at every stage evaluates whether he has sufficient information to make a decision: if he does, he stops and takes a decision; if he does not, he proceeds to acquire additional information. In that respect, one of the goals of the present paper is to understand how the structure of collective action affects such information acquisition. We use the term deliberation for such collective information acquisition.

In fact, our model is a collective action version of the analysis of sequential sampling introduced by Wald (1947). In our model, a homogeneous committee deliberates in a manner that is analogous to the decision maker testing a hypothesis sequentially a' la Wald: at every date, the committee evaluates its current information and decides to do one of three things: continue sampling — i.e. continue deliberating, or stop and take one of two decisions. Wald shows that the optimal procedure involves a sequential likelihood ratio test, whereby intermediate values of the likelihood ratio require obtaining a new sample, while high (low) values of the likelihood ratio require stopping and taking one (the other) decision. We depart from Wald by introducing two possible dimensions of disagreement among committee members. The first involves disagreement exclusively on the importance of the decision (or, equivalently, on the cost of information acquisition), and hence on the length of the deliberation process. In this first version, committee members share preferences over decisions conditional on the information available, but disagree on how much information is required before making the decision. The second version involves disagreement on the appropriate decision: for example, some jurors require a higher standard of evidence in order to vote to convict. In this version, there can be disagreement at the deliberation *and* at the decision stage.

We now briefly discuss some evidence from the literature on deliberation in juries that our model can explain and help interpret.

Deliberation matters One strand of the literature studies opinion formation by jurors. This is relevant for our model for two reasons. First, this establishes that the deliberation process is very important in forming jurors' opinions.[3] Second, some features of the opinion

[2] See also De Groot (1970) and Moscarini and Smith (2001).

[3] This is in partially in contrast with the prior received wisdom that comes from the Kalven and Zeisel landmark jury study.

formation process seem to mirror the updating process postulated in our model.

Hannaford, Hans, Mott, and Musterman (2000) studied the timing of jury opinion formation. They used a special case study of a jury reform implemented in Arizona in 1995 that allowed for discussions during civil trial (Rule 39(f) of the Arizona Rules of Civil Procedure). Their data includes survey responses of $1,385$ jurors from 172 trials in four counties (accounting for a large majority of cases in Arizona) concerning when they formed their initial opinions, whether and when they changed their minds, and when they made up their minds about the final outcome. They find that fewer than 10% of jurors began leaning toward one side or the other during the opening statements of a case and over 25% of jurors reported establishing their initial leaning following discussions with other jurors. Furthermore, over 95% of jurors reported changing their mind at least once over the course of the trial and 15% reported changing their minds more than once during trial Importantly, over 20% reported changing their minds in discussions during the trial and over 40% reported changing their minds during the final deliberations.

Similarly, Hans (2001, 2007) used surveys conducted by the National Center for State Courts (NCSC). Hans' data contains reports from close to $3,500$ jurors that had participated in felony trials in four large, urban courts. Hans (2001, 2007) documents patterns of opinion change that are consistent with information collection. When the initial vote in the jury strongly supports a particular outcome, that outcome is more likely to come through (77 of the 89 juries with strong majorities for guilt convicted the defendant, and 67 of the 71 juries with strong majorities for innocence acquitted the defendant). However, weaker majorities or closely divided juries showed a more variable pattern.[4]

Irrelevance of the decision rule. Baldwin and McConville (1989) studied British juries in Birmingham following a reform that was put in place in 1974 and qualified potential jurors. In particular, the reform allowed for majority verdicts in criminal trials, while prior to reform unanimity was required. They studied details regarding jurors' characteristics and case outcomes pertaining to 326 cases in a 21months period in 1975 and 1976. In only 15

[4] These observations should be interpreted with some care, as initial polls within the jury sometimes take place after some amount of deliberations has already taken place. Thus, consensus may be overstated.

of these trials did juries determine the verdict with a mere majority.[5]. Devine et al. (2001) report that in many mock jury studies there is no evidence that the decision rule has any effect on the verdict. In lab experiments Goeree and Yariv (2009) find that, when subjects cannot talk before voting, the decision rule has an effect, whereas, when subjects can talk, the decision rule has no effect.

Our model provides a possible explanation for the fact that the decision rule seems to have little or no effect. We show that, when costs of deliberation are sufficiently low, in equilibrium, deliberation always ends with unanimous decisions. We show that, whenever there is disagreement on the appropriate decision to take, members of the committee agree that it is worthwhile to continue deliberating.

Effect on length of deliberation Hans (2001) and Devine et al. (2001) report that the voting rule affects length and quality of deliberation. Unanimity verdicts take as long as majority verdicts on average in mock juries. The quality is measured by legal experts.

In our model the length of deliberation can be affected by the decision rule because pivotal members at the deliberation stage may, if not pivotal ad the decision stage, prolong deliberation in order to convince the holdouts at the decision stage.

Jury composition Increased heterogeneity has been found to increase quality and length of deliberation (Sommers 2006, Goeree and Yariv 2009).

In our model, increased heterogeneity increases the length of deliberation because it makes the pivotal members at the deliberation stage more extreme, and therefore, more in need of extreme information in order to stop deliberation. This translates immediately into longer deliberation and, in symmetric committees, more accurate decisions.

1.2 Literature Review

Albrecht, Anderson, and Vroman (2009) and Compte and Jehiel (2009) study how group search is affected by voting. Messner and Polborn (2009) study a two-period model where

[5] A caveat to this observation is that under simple majority, when a majority of jurors agrees, any other juror's vote cannot affect the final outcome. In particular, those jurors may vote against their private assessment to satisfy social pressures at no consequence to the defendant.

voters receive information over time about the desirability of an irreversible decision. They show that the optimal voting rule requires a supermajority.

Feddersen and Pesendorfer (1998) study a model where jurors have private information about guilt or innocence of the defendant. They show that unanimity leads to less informative outcomes than does simple majority in large juries. Persico (2004) studies a related model but also allows for private information collection prior to voting. He characterizes the optimal voting rule and shows that unanimity leads to inferior information collection. Austen-Smith and Feddersen (2006) extend Feddersen and Pesendorfer (1998) in another way by allowing for a round of cheap-talk communication before voting. They show that unanimity leads to less communication and poor information aggregation. Gerardi and Yariv (2006, 2007) depart from these papers by studying general communication protocols and focusing on the entire set of equilibria. They show that the set of equilibria is invariant to the voting rule.

Wald (1947a and b) pioneered the study of sequential testing, and provided a characterization of the optimal sequential test as a sequential likelihood ratio test. We briefly describe the most directly relevant result in section 3.1.

Moscarini and Smith (2001) consider an extension of Wald's analysis, where they allow for simultaneous as well as sequential experimentation, and they assume discounting and convex costs of sample size.

Bognar, Meyer-ter-Vehn, and Smith (2009) also study a model of dynamic deliberation, but with very different ingredients. In their model jurors have common preferences and private information about a payoff relevant state. They assume that jurors sequentially exchange coarse messages. In their model there are many equilibria that can be ranked in welfare. Surprisingly, longer conversations are better.

Strulovici (2010) discusses a model of voting over experimentation. He shows that voting by heterogeneous voters who are learning their preferences leads to an inefficient level of experimentation. He then describes a voting rule that can restore efficiency.

In comparison to all of this existing work, the main contribution of the framework proposed in this paper is that allows an analysis of the interplay between deliberation rules and voting rules. We identify when each plays an important role for outcomes, and how collective consequences are affected by different aspects of the environment (deliberation costs, preference heterogeneity, etc.).

2. The Model

A jury of n individuals has to determine the fate of a defendant. There are two states: I (the defendant is innocent) and G (the defendant is guilty), which we assume are equally likely ex-ante.

Juror i's preferences are given by:

$$u_i(C,G) = u_i(A,I) = 0, \quad u_i(A,G) = -(1-q_i), \quad u_i(C,I) = -q_i,$$

where $q_i \in (0,1)$ denotes juror i's threshold of reasonable doubt (capturing her concern for convicting the innocent relative to that for acquitting the innocent). Without loss of generality, we assume $q_1 \leq q_2 \leq ... \leq q_n$.

In determining the verdict, the jury participates in two phases: deliberation and voting.

We assume that deliberation allows each juror to publicly learn something about the guilt of the defendant. We formalize this collective information generation as follows. If the jurors still deliberate at time t, all observe the realization of the sequence of discrete random variables $X_1, ..., X_t$, where $X_1, X_2, ...$ are independent and identically distributed conditional on the guilt or innocence of the defendant.[6] Each random variable is drawn from a distribution characterized by a cumulative distribution function $F_G(\cdot) \equiv F(\cdot|G)$ and $F_I(\cdot) \equiv F(\cdot|I)$. In some of the analysis, we will assume information is symmetric. That is, for any $s \geq 0$, $F_G(s) = F_I(-s)$.

The cost of deliberating an additional period is given by $k > 0$ per unit of time per agent (which can be thought of as the opportunity costs of time spent in court).

At each period t, a jury decides whether to continue or stop deliberating using a threshold voting rule. Namely, at each point in time t, after having observed the history $X_1, ..., X_t$, each agent casts a vote whether to continue or stop information collection. Under *deliberation rule* $R_d = 1, ..., n$, whenever at least R_d jurors choose to stop deliberating, the deliberation phase ends.

Once deliberation comes to a halt, the decision phase takes place. The jury selects an

[6] Allowing for continuous random variables would just complicate notation without any major differences

alternative by voting. Each juror can vote to acquit, a, or to convict, c. Under the *voting rule* $R_v = \lceil \frac{n}{2} \rceil, \ldots, n$, the alternative C is selected if and only if R_v or more jurors vote to convict, the alternative A is selected if and only if R_v or more jurors vote to acquit, and the jury is hung otherwise. We assume that when the jury is hung, A or C are determined by the flip of a fair coin.[7] We will restrict attention to strategies that depend only on posterior beliefs p (and not on the history of prior votes). Therefore, a pure strategy is a pair (σ_d, σ_v), where the *deliberation strategy* is $\sigma_d : [0,1] \to \{\text{stop, continue}\}$ and the *voting strategy* is $\sigma_v : [0,1] \to \{a, c\}$.

For much of our analysis, it is useful to consider deliberation strategies that are characterized by two fixed thresholds for the posterior $p^a \leq 1/2 \leq p^c$. That is, each agent chooses to stop deliberation whenever the timed posterior p_t (that the defendant is guilty) satisfies $p_t \leq p^a$ or $p_t \geq p^c$.[8] We will refer to these thresholds as *deliberation thresholds.*

2.2 Discussion of the model

The model is an extension of Wald (1947a,b) to study how collective action affects information collection. In the model, longer deliberation corresponds to additional signals received by the committee. Our *interpretation* is that this is a reasonable shortcut for thinking about how deliberation helps jurors gain an understanding of the evidence presented at trial. Of course, in a jury setting, it could be argued that no additional information is received by the jurors during deliberation. We argue that one role of deliberation is to sift through the mass of sometimes conflicting evidence presented by two opposing parties (prosecution and defence) during the trial to figure out the relevance of different pieces of information, and the appropriate weight to attribute to these in establishing guilt or innocence of the defendant. One analogy is that the trial is like a lecture given by a professor, and the jury is like a study group who looks through the notes taken during class to gain some further understanding of the problem.

[7] The exact assumption we make about the payoff consequences of hung juries is for the most part inconsequential. Our initial analysis focuses on cases where hung juries do not occur (low costs of deliberation). Section ??? discusses the case of hung juries.

[8] Recall that the prior probability that the defendant is guilty is 1/2. In particular, choosing a threshold $p^a \geq 1/2$ (or $p^c \leq 1/2$) would lead to no information collection. Our assumption that $p^a \leq 1/2 \leq p^c$ is therefore without loss of generality.

As mentioned above, there are alternative applications that may fit more directly with the model because actual additional signals are received as deliberation continues.

We assume that all information in the jury is public: signals are observed by all jurors, and preferences are common knowledge. This assumption represents a sharp departure from the literature on juries discussed before where the focus is on the aggregation of private information. We do not claim that our assumptions are superior, but we believe that our model is a natural alternative extreme benchmark that is worth studying. It would be interesting to allow for private information.

3. PRELIMINARIES

We start by considering a homogenous jury containing agents with the same preference parameter: $q_1 = ... = q_n \equiv q$. In that case, the agents all face the same objective at both phases of the decision process. Consequently, we will focus on equilibria that emulate the single person decision (by, say, voting in unison during both the deliberation and voting stage). In this section we therefore focus on the case in which $n = 1$.[9] From Wald (1947), we know the solution is unique. Formally,

Proposition 1 (Wald, 1947) *There exists a solution $(p^a(q), p^c(q))$ for any q. Furthermore, whenever there is an interior solution, it is unique.*

While we do not provide the proof of Proposition 1, it is useful for our analysis to illustrate the intuition behind the proposition as it is translated to our setup.[10] For any posterior probability p, denote by $V^S(p)$ the value function associated with stopping immediately at posterior p.

$$V^0(p) = \max\{-q(1-p), -(1-q)p\} \tag{1}$$

[9] This could be viewed as the result of a particular form of refinement. Namely, one could consider finite truncations of the game. Equilibria surviving iterated elimination of weakly dominated strategies in the agent-form game would correspond to (timed) thresholds, and that sequence of thresholds converges to the thresholds we analyze here as the horizon of the game grows indefinitely.

[10] See De Groot (1970).

Denote by $V^1(p)$ the value associated with continuing at least one more period, and $V(p)$ the overall value function for any posterior probability p. It follows that

$$V(p) = \max\left\{V^0(p), V^1(p)\right\}. \tag{2}$$

Note that $V(0) = V(1) = 0$, and therefore, $V^1(0) = V^1(1) = -k$. Furthermore, $V^C(p)$ is a convex function of p. Indeed, consider an alternative world in which with probability α, the probability that the defendant is guilty is given by p_1 and with probability $1-\alpha$, the probability that the defendant is guilty is given by p_2. If the (one) juror is not told which of the two probabilities had been realized, then she can guarantee the continuation value corresponding to $\alpha p_1 + (1-\alpha)p_2$. However, if she is told which of the two probabilities is realized, then with probability α, she can guarantee the continuation value of p_1 and with probability $1-\alpha$ the continuation value of p_2. Naturally, she can ignore the information provided to her, so in the latter case she must be gaining at least as much. Convexity follows. From linearity of $-q(1-p), -(1-q)p$, and the fact that their maximum at $p = 0, 1$ is 0, it follows that there are two posteriors probabilities (that the defendant is guilty) p^a, p^c that define the stopping region, as in Figure 1 (see De Groot, 1970, page 307).

When costs are high, they outweigh the benefits of information collection and stopping occurs immediately (in terms of Figure 1, when k is sufficiently high, the curve corresponding to the continuation payoff lies below that corresponding to the instantaneous utility from stopping). When costs are sufficiently low, there is an interior solution. Note that convexity of the value function assures the uniqueness of such an equilibrium.

For any two thresholds p^a, p^c, $p^a \leq 1/2 \leq p^c$, expected utility can be expressed as:

$$U(q; p^a, p^c) = -q\left(1 - \mathbb{E}\left(p|p^c\right)\right)\Pr(p^c \text{ first} \mid p^a, p^c) - (1-q)\,\mathbb{E}\left(p|p^a\right)\Pr(p^a \text{ first} \mid p^a, p^c) - kT(p^a, p^c), \tag{3}$$

where $T(p^a, p^c)$ denotes the expected time to approach one of the posterior thresholds p^a or p^c. The expected time $T(p^a, p^c)$ is decreasing in p^a and increasing in p^c. The terms $\Pr(p^a$ first$|\ p^a, p^c)$ or $\Pr(p^c$ first$|\ p^a, p^c)$ correspond to the probabilities that the threshold p^a or p^c is reached first, respectively.[11] The expectations $\mathbb{E}(p|p^a)$ or $\mathbb{E}(p|p^c)$ denote the expected value

[11] Note that $\Pr(p^c \text{ first}|\ p^a, p^c) = 1 - \Pr(p^a \text{ first}|\ p^a, p^c)$.

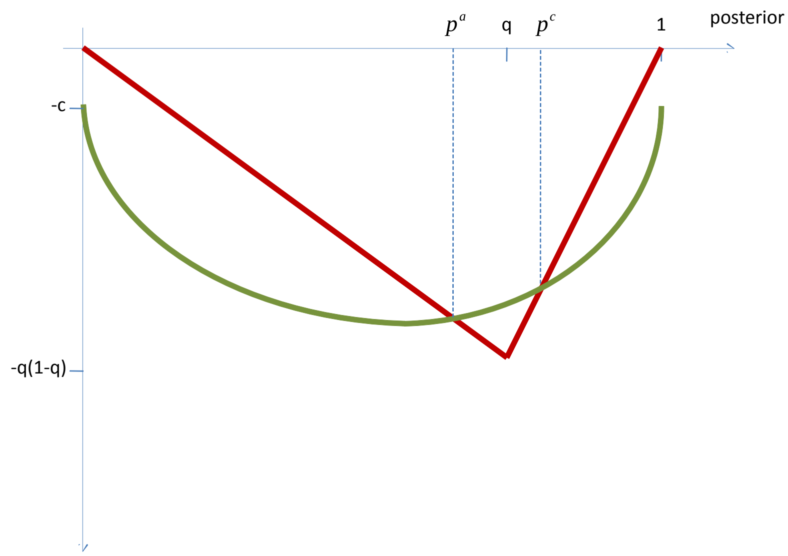

Figure 1: Homogeneous Groups – Existence and Uniqueness

of the posterior upon the end of deliberation conditional on passing the threshold p^a or p^c first, respectively.

We now turn to some properties of the homogenous jury's deliberation process that prove useful subsequently.

In homogeneous committees, agents agree on what should be done both during deliberation as well as during the final decision making stage. Therefore, from an institutional perspective, the interesting parameters to inspect are the preference parameter q and the cost of deliberation k. The following proposition summarizes the effects of changes in these two parameters.

Proposition 2 (Homogeneous Juries – Comparative Statics)

1. **Preference Parameter** q**.** $p^a(q), p^c(q)$ *weakly increase with* q*.*

2. **Cost** k. $p^a(q)$ *is weakly increasing in* k, $p^c(q)$ *weakly decreasing in* k*. Consequently, the time to take a decision is decreasing in* k*.*

Intuitively, as q increases, agents care more about convicting the innocent relative to acquitting the guilty. It follows that they are willing to spend more time preventing the former relative to the latter, and that the range of posteriors for which the jury acquits becomes larger (similarly, the range of posteriors for which the jury convicts becomes smaller). When the cost k increases, less information is gathered (implying that the posterior thresholds shift toward the prior) and therefore deliberation takes less time.

Assume for concreteness that $q \leq \frac{1}{2}$. We now consider a constrained problem defined by two thresholds $\underline{p}$, and $\overline{p}$ such that the juror can only choose to stop and to acquit if $p \leq \underline{p} < q$, and to stop and convict if $p \geq \overline{p} > \frac{1}{2}$. This constrained problem is helpful when considering best responses. For any $\left(\underline{p}, \overline{p}\right)$, we define the constrained value functions as follows. As before, $V^1\left(p|\underline{p}, \overline{p}\right)$ is the value of continuing at least one period. The overall value function is given by:

$$V(p \mid \underline{p}, \overline{p}) = \begin{cases} \max\left\{V^1\left(p|\underline{p}, \overline{p}\right), -(1-q)\,p\right\} & p \leq \underline{p} \\ V^1\left(p|\underline{p}, \overline{p}\right) & \underline{p} < p < \overline{p} \\ \max\left\{V^1\left(p|\underline{p}, \overline{p}\right), -q\,(1-p)\right\} & p \geq \overline{p} \end{cases} . \tag{4}$$

The interpretation of this expression is the following: for $p \leq \underline{p}$ the juror chooses the best option between continuing deliberation and stopping to acquit. For $\underline{p} \leq p \leq \overline{p}$ the juror can only continue deliberation. For $p \geq \overline{p}$, the decision maker chooses the best option between continuing deliberation and stopping to convict.

Lemma 1 (Convexity for Constrained Problem) *The continuation value function $V^1\left(p|\underline{p}, \overline{p}\right)$ of the constrained problem is convex.*

As before, convexity implies that the solution is determined in a similar manner as described through Figure 1 and uniqueness of the constrained solution $\left(p^a\left(\underline{p}, \overline{p}\right), p^c\left(\underline{p}, \overline{p}\right)\right)$ follows. The constrained solution is monotonic in the imposed thresholds as the following lemma illustrates (see the Appendix for proofs).

Lemma 2 (Monotonicity) *$p^a\left(\underline{p}, \overline{p}\right)$ is increasing in $\overline{p}$ and $p^c\left(\underline{p}, \overline{p}\right)$ is increasing in $\underline{p}$.*

An immediate consequence of Proposition 2 and Lemma 2 is the following:

Corollary 1 (Comparative Statics of Constrained Problem *For any fixed $\left(\underline{p}, \overline{p}\right)$, $p^a\left(\underline{p}, \overline{p}\right)$ and $p^c\left(\underline{p}, \overline{p}\right)$ weakly increase with q.*

4. Heterogenous Preferences

We now shift our attention to juries composed of agents with potentially heterogeneous preferences. Namely, we assume $q_1 \leq q_2 \leq ... \leq q_n$ and allow for some of the inequalities to be strict. In order to isolate the effects of preference heterogeneity on outcomes, we assume in this section that deliberation costs are homogenous and fixed at $k > 0$.[12]

We start by considering the case in which voting rules in the deliberation and decision stage coincide. That is, $R_d = R_v$. This will allow us to focus on one set of pivotal agents, rather than consider pivotal agents at each stage of the decision-making process. Later, we inspect the impacts of discordance between the two types of rules.

Lemma 3 implies that the pivotal agent for stopping when $p_t < 1/2$ is juror R_d and the pivotal agent when $p_t > 1/2$ is juror $n - R_d + 1$. In order to make the comparison with the results pertaining to homogeneous committees transparent, we focus on equilibria that are characterized by stationary thresholds. The following Lemma will be useful throughout our analysis:

Lemma 3 (Reduction to Two Juror Juries) *When $R_d = R_v$, any equilibrium thresholds corresponding to a jury composed of jurors with preference parameters $q_1 \leq q_2 \leq ... \leq q_n$ are also equilibrium thresholds of a jury composed of two jurors with preference parameters q_{n-R_d+1}, q_{R_d} in which both deliberation and decision rules are unanimous.*

Lemma 3 suggests that equilibrium thresholds can be identified through the preferences of two jurors. Importantly, the lemma suggests that equilibrium outcomes need not necessarily be efficient and depend crucially on the preference distribution of jurors other than the pivotal ones. For instance, when unanimity is imposed at the deliberation stage, inefficiencies can arise when there are very many agents of preference $q_j < \frac{1}{2}$, while $q_1 + q_n > 1$.

Best responses of the pivotal agents can be derived through (4). Each of the agents takes one of the thresholds as given and optimally chooses the other one (that corresponds to the region she cares more about).

In general, equilibrium thresholds exhibit some similar comparative statics to those of the homogeneous juries. Namely, equilibrium thresholds respond monotonically to the prefer-

[12] We return to the case of heterogeneous costs in Section 8.

ences of the pivotal agents and entail more information collection for lower deliberation costs. Formally, we get:

Proposition 3 (Heterogeneous Juries – Comparative Statics) *Consider interior equilibrium thresholds p^a, p^c corresponding to pivotal agent's preferences q_{R_d}, q_{n-R_d+1} and cost k.*

1. **Preference Parameters**. *Suppose $\tilde{q}_{R_d} < q_{R_d}, \tilde{q}_{n-R_d+1} > q_{n-R_d+1}$. Then, if there exists an interior equilibrium, there are corresponding interior equilibrium thresholds $\tilde{p}^a < p^a$ and $\tilde{p}^c > p^c$.*

2. **Cost**. *For any $\tilde{k} < k$, there exist interior equilibrium thresholds $\tilde{p}^a < p^a$ and $\tilde{p}^c > p^c$.*

In what follows, we move away from the assumption that $R_d = R_v$ and inspect the effect of different deliberation and decision rules in general juries.

5. ARBITRARY DELIBERATION AND VOTING RULES

We now consider a jury composed of n jurors of arbitrary preferences $q_1 \leq q_2 \leq ... \leq q_n$ and contemplate differing constellations of voting rules. For realism purposes, we will focus on super-majoritarian deliberation rules, i.e., $R_d \geq n/2$.[13]

When $R_d \neq R_v$, there are two sets of relevant pivotal agents: those pertaining to the deliberation stage and those pertaining to the decision stage.

In analogy to Lemma 3, during the decision stage, whenever juror j would prefer to convict if she were dictator, so would any juror $l < j$. Whenever juror j would prefer to acquit if she were dictator, so would any juror $l > j$. It follows that the jurors to focus on are those pivotal during deliberation: juror R_d and $n - R_d + 1$, and those pivotal during the decision stage: juror R_v and $n - R_v + 1$.

We first analyze environments in which deliberation costs are low. In such cases, equilibrium behavior will entail a high volume of information collection. This would suggest that in equilibrium, when information collection ends, agents would be at a consensus on what should be done. Formally,

[13] Allowing for $R_d < n/2$ does not change our technical analysis. The main conceptual difference can be seen inspecting Lemma 2. When $R_d < n/2$, it is the pivotal agent who *cares less* about convicting the innocent that dictates when deliberation stop when $p_t < 1/2$.

Lemma 4 (Low Costs – Convergence of Opinions) *For any R_v and R_d, and any $\tilde{q}_1, \tilde{q}_2 \in (0,1)$, for sufficiently low deliberation costs, there exists an interior equilibrium characterized by thresholds $p_* < \tilde{q}_2$ and $p^* > \tilde{q}_1$.*

Lemma 4 implies that any set of jurors would agree on the decision ex-post when costs are sufficiently low even if unanimity is not a requirement for making decisions.[14]

This lemma also implies that for sufficiently low costs, deliberation will render the jury in consensus on what should be done. In particular, the voting rule R_v in the decision stage would not matter. The following proposition outlines two important scenarios where the decision rule does not matter for the final outcome.

Proposition 4 (Decision Rule Irrelevance) For any deliberation rule R_d,

1. *(Restricted Irrelevance) For any decision voting rules R_v, $\tilde{R}_v \leq R_d$, the set of equilibrium outcomes corresponding to R_v and $\tilde{R}_v$ coincide.*

2. (Irrelevance due to unanimous agreement: low costs) *For any given preference profile, there exists a $\underline{k}$* such that, for $k \leq \underline{k}$, *the voting rule at the decision stage R_v is irrelevant for equilibrium outcomes. In particular, time to decision or probability of mistakes do not depend on R_v.*

Proposition 4 outlines two cases in which the decision rule has no effect on the final outcome. In the first case, this is an almost mechanical effect: when the decision rule has a less demanding majority requirement than the deliberation rule, the deliberation thresholds are the relevant ones for stopping. The second case can be interpreted as follows. When costs of deliberation are relatively low, then information collection leads to consensus on decisions: whenever jurors disagree on the decision, they all agree that it is worth it to continue deliberating. Thus, the decision rule does not play a role because decisions end up

[14]Suppose $\tilde{q}_1 = q_n$ and $\tilde{q}_2 = q_1$. The Lemma suggests that for sufficiently low deliberation costs, if $q_1 > 1/2$ or $q_n < 1/2$, if deliberation were not possible, agents would agree at the outset on the optimal action. In the presence of deliberation, since there is positive probability that at some point $t > 0$, $p_t \in (q_1, q_n)$, agents can disagree on the optimal action to take during the deliberation process. This is consistent with the observations of Hannaford, Hans, Mott, and Musterman (2000) regarding the frequent opinion changes reported to have taken place during deliberations in the 1995 Arizona trials.

being unanimous for any decision rule, and only the deliberation rule drives the length of the deliberation process.

In general (when costs are not necessarily low), whenever the deliberation rule is more demanding than the decision voting rule ($R_d \geq R_v$), if agents R_d and $n - R_d + 1$ follow the strategies they would had they been the only jurors and both deliberation and decision rules were unanimous, they achieve identical outcomes to those with rules R_d and R_v. In particular, the set of equilibrium outcomes does not depend on R_v.

For arbitrary rules, this is no longer the case. Indeed, suppose $R_v > R_d$. If all agents pursued the same strategies as above (corresponding to a two juror jury with preferences q_{R_d} and q_{n-R_d+1} and unanimous rules), there would be disagreement in the decision stage and the jury would end up as hung. The jury then faces a trade-off: it can either prolong deliberation to convince the pivotal jurors in the decision stage, jurors R_v and $n - R_v + 1$, or it can halt deliberations immediately. Intuitively then, one should expect that unanimity will lead to longer deliberation and more accurate decisions than simple majority. We show later that this is true for symmetric juries. When juries are asymmetric, changing the decision rule or the deliberation rule may not lead to uniformly more accurate decisions because for instance, more accurate decisions on the acquittal side may lead to less accurate decisions on the conviction side: it can be the case that p_* is reduced but p^* is also reduced instead of increasing.

6. Symmetric Juries

For simplicity, we first go back to the case $R_d = R_v$. Lemma 2 allows us to restrict attention to two jurors within the jury: $\tilde{q}_1 = q_{n-R_d+1}$ and $\tilde{q}_2 = q_{R_d}$. Assuming $\tilde{q}_1$ and $\tilde{q}_2$ are symmetric around $\frac{1}{2}$, i.e., $\tilde{q}_1 = \frac{1}{2} - \delta$ and $\tilde{q}_2 = \frac{1}{2} + \delta$ for some $\delta \in \left[\frac{1}{2}, 1\right]$, simplifies equilibrium characterization significantly.

Definition (Symmetry in Juries) *We say the jury is quasi-symmetric with respect to $R_d = R_v$ whenever $q_{n-R_d+1} + q_{R_d} = 1$. A jury is* symmetric*, whenever it is quasi-symmetric with respect to all voting rules.*

In quasi-symmetric juries, for sufficiently low costs, there exists a unique stationary symmetric threshold equilibrium.[15]

We start our analysis with juries that are quasi-symmetric with pivotal jurors characterized as above. That is, owning preference parameters $\tilde{q}_1 = \frac{1}{2} - \delta$ and $\tilde{q}_2 = \frac{1}{2} + \delta$ for some $\delta \in \left[0, \frac{1}{2}\right]$. This will allow us to identify the impacts of diversity in the jury, as captured by the spread δ, and open the door for inspecting the effects of the voting rules, which determine how moderate or extreme the pivotal jurors are.

Denote the resulting symmetric equilibrium thresholds by $p_*(\delta) \leq 1/2 \leq p^*(\delta)$. Symmetry entails $p_*(\delta) + p^*(\delta) = 1$.

As δ increases, the juror with preferences $\tilde{q}_1$ is increasingly concerned about acquitting the guilty, while the juror with preferences $\tilde{q}_2$ is increasingly concerned about convicting the innocent. There are now two forces at play. The direct one is that the first agent would like to spend more time collecting information when the posterior is lower than 1/2, while the second agent would like to spend more time collecting information when the posterior is greater than 1/2. Indeed, this follows from the first part of Proposition 2, as it implies that $p^a(\tilde{q}_1) \leq p^a(\frac{1}{2}) \leq p^a(\tilde{q}_2) \leq 1/2 \leq p^c(\tilde{q}_1) \leq p^c(\frac{1}{2}) \leq p^c(\tilde{q}_2)$. The indirect effect comes from the strategic interaction. Consider, say, the first juror and the event in which the posterior $p_t \in (p^a(\tilde{q}_1), p^a(\tilde{q}_2))$, so that if she were by herself she would continue collecting information, while the other juror by herself would not. Importantly, the continuation value for pursuing information collection is now different than the case in which juror 1 is the solo juror. Indeed, juror 1 may suspect that when $p_t > 1/2$, juror 2 will push for prolonging deliberation, even when she herself is ready to make a decision (in the analogous range $p_t \in (p^c(\tilde{q}_1), p^c(\tilde{q}_2))$). Thus, continuation values are lower, suggesting that the resulting equilibrium thresholds are moderate relative to the most extreme individual thresholds $p^a(\tilde{q}_1), p^c(\tilde{q}_2)$, as depicted in Figure 2 and formalized in the following proposition.

Proposition 5 (Equilibrium Spread and Moderation)

1. *(Spread) $p_*(\delta)$ is decreasing in δ, $p^*(\delta)$ is increasing in δ. In particular, the time it takes for a decision is increasing in δ.*

[15] A symmetric threshold equilibrium is one in which both posterior thresholds are symmetric around 1/2 (equivalently, equally distanced from 1/2).

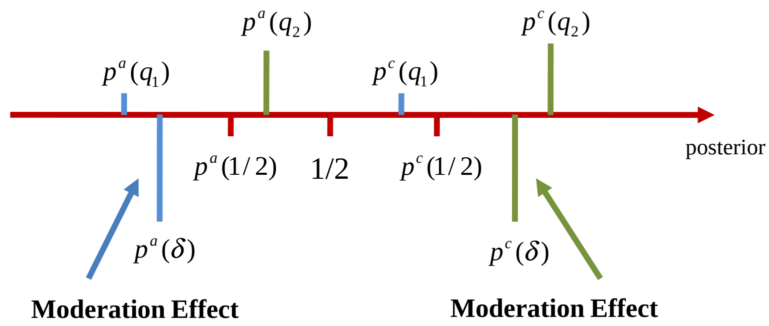

Figure 2: Equilibrium Spread and the Moderation Effect in Quasi-symmetric Juries

2. *(Moderation Effect) For any* $q = \frac{1}{2} + \delta$*, where* $\delta \in \left(0, \frac{1}{2}\right)$, $p^a(q) \geq p_*(\delta) = 1 - p^*(\delta)$ *and* $p^c(q) \geq p^*(\delta)$*. Furthermore, for sufficiently small information costs* k*, these inequalities are strict.*

The proposition implies that increased heterogeneity in the jury (manifested in a higher δ) will reduce the two types of mistakes, and increase the expected time to a decision.

Then, the spread of symmetric pivotal agents can be manipulated through the voting rule. Indeed, the more demanding the deliberation rule (a higher $R_d = R_v$), the greater the spread. Formally, note that $q_{R_d} - q_{n-R_d+1}$ is increasing in R_d. Using part 1 of Proposition 5, we therefore get the following corollary.

Corollary (Accuracy and Deliberation Rules) *In symmetric juries, deliberation length and accuracy of decisions increase with the deliberation and voting rules* $R_d = R_v$*.*

We can now discuss the effect of decision rules when costs are not so low that the irrelevance effect highlighted in Proposition 4 holds.

Proposition 6 (Decision Rule Relevance: Inclusiveness Effect) *Consider a symmetric jury, for any deliberation rule R_d, take two voting rules $\tilde{R}_v > R_v \geq R_d$.*

1. *For any given preference profile, there exist $\underline{k}, \overline{k}$ such that, for $\underline{k} < k < \overline{k}$, equilibrium thresholds $p_*\left(R_d, \tilde{R}_v\right) < p_*\left(R_d, R_v\right)$, and $p_*\left(R_d, \tilde{R}_v\right) > p^*\left(R_d, R_v\right)$: the larger the supermajority required for making a decision, the more information collection there is; the deliberation time and decision accuracy are greater under voting rule $\tilde{R}_v$ than under voting rule R_v.*

2. *Deliberation time and accuracy would be even greater under deliberation rule $\widetilde{R}_d = \tilde{R}_v$:* $p_*\left(\tilde{R}_d, \tilde{R}_v\right) < p_*\left(R_d, \tilde{R}_v\right)$, and $p^*\left(\tilde{R}_d, \tilde{R}_v\right) > p^*\left(R_d, \tilde{R}_v\right)$.

Part 1 of Proposition 6 is in contrast with the results in Feddersen and Pesendorfer (1998), Persico (2004), and Austen-Smith and Feddersen (2006). The intuition for this result can be understood by considering a special case. Consider a jury where R_d is simple majority. We contemplate the effect of moving from R_v = simple majority to R_v = unanimity. Suppose that costs of deliberation are sufficiently high that when R_v is simple majority, it is not worth it for the median juror to deliberate long enough to reach consensus on the decision. Then, under unanimity, the median juror who is still pivotal in the deliberation process understands that, in order to reach a verdict he cannot stop deliberation as early as when R_v = simple majority. In order to avoid a hung jury he must convince the the extreme juror to vote with with everyone else. This requires deliberating longer. When costs are not too high, it is worth it to deliberate just long enough to obtain these jurors votes on the decision.

Part 2 of Proposition 6 says that in, the same example, moving to R_d = unanimity would lead to even longer deliberation. The reason is that the most extreme voters are now in a position to directly affect the deliberation decision, and they desire longer deliberation than the median juror.

Taken together with Proposition 4, Part 2 of Proposition 6, says that Deliberation rules are more powerful than decision rules in affecting the process of jury decision making and deliberation.

These results suggest that, in essence, interior equilibria *always* depend only on two jurors. When $R_v \leq R_d$, the jury outcome is equivalent to that of a jury composed of two jurors with preferences q_{R_d} and q_{n-R_d+1} (and unanimous deliberation and voting rules), while when $R_v > R_d$, any jury outcome entailing non-trivial deliberation is equivalent to that of a jury composed of two jurors with preferences q_{R_v} and q_{n-R_v+1} (and, again, unanimous deliberation and voting rules).

In practice, it may be the case that a change in the decision voting rule is tied to a change in the deliberation rule, a so-called *protocol effect*. In the presence of such a protocol effect, the decision voting rule has a clear impact. Indeed, the more demanding the decision voting rule, Lemma 2 holds and the two pivotal jurors become more extreme. In particular, more demanding decision voting rules would correspond to longer deliberation and more accurate decisions.

7. Welfare

Welfare effects are difficult to assess as they depend on the perspective from which welfare is calculated (in terms of the distribution of preference parameters in the relevant population and the extent to which time costs are internalized).

First consider a homogeneous jury. From the point of view of the agents, deliberation is weakly beneficial. Indeed, the jury can always choose not to deliberate by fixing the prior 1/2, $p^a = p^c = 1/2$. From an institutional point of view, when deliberating groups are homogeneous, a designer (say, the constitution writers) characterized by preference parameter q who internalizes the costs (e.g., when these costs are linked to the time spent on making decisions and not engaging in other profitable activities) is best off with a committee (jury) comprised of identical agents of preference parameter q as well. In fact, a committee composed of more extreme agents than the designer would entail "too much" information collection. The designer may then benefit by increasing the costs of the committee members, or putting a cap on deliberation time.

From the perspective of the participating jurors in any quasi-symmetric jury, we can assess the optimal spread of the pivotal agents. It turns out that little spread is most preferred. This is proved in the next proposition.

Proposition 7 (Optimal Delegation) *Jurors have unanimous preferences over deliberation rules: all jurors in a quasi-symmetric jury prefer pivotal agents with as little spread as possible or* $R_d = \lceil n/2 \rceil$.

Intuitively, consider the expression (3) for a juror's utility. In a quasi-symmetric jury, thresholds are symmetric, and therefore, the first two terms in (3) are a convex combination (via q_i) of an identical expected probability of mistake. It follows that the expected utility does not explicitly depend on q_i. In particular, all of the jurors gain the same level of expected utility as would a juror with preference parameter $\frac{1}{2}$ if she were to have the equilibrium thresholds imposed upon her. However, note that a juror with preference parameter $\frac{1}{2}$ would prefer no spread at all ($\delta = 0$ in our notation above), as then she receives her optimal thresholds. Monotonicity then implies our result.[16]

Proposition 7 is particularly stark because of symmetry. However, the effect highlighted in this proposition is more general: even in a large class of asymmetric juries, the most extreme jurors will not push for unanimity at the deliberation stage because unanimity means that deliberation is long on *both* sides, making the cost of deliberation too high from an ex-ante perspective to make it worth reducing the probability of mistakes further.

8. Heterogeneous Deliberation Costs

Suppose now that jurors differ in the costs that are imposed upon them through deliberation (e.g., if costs are linked with the time away from work, variance in wages may translate to variance in deliberation costs). Formally, in order to assess the effects of cost heterogeneity, we assume that all jurors share the same preference parameter q, but juror i's deliberation cost is given by k_i, where without loss of generality $k_1 \geq k_2 \geq ... \geq k_n$.

Note that the decision rule R_v does not affect outcomes since for any given posterior the jurors all agree on the optimal action to be taken. The voting rule, however, does have an effect. Note that whenever agent j wants to stop information collection, so does any agent with higher cost ($l < j$). It follows that the pivotal juror during deliberation is the R_d'th juror. Consequently, we get the following.

[16] Proposition 7 hints at the possible effectiveness of deliberation taxes. Indeed, increasing the costs of deliberation would lead to shorter deliberation times which may be preferrable to at least a fraction of the population.

Proposition 8 (Heterogeneous Costs) *A jury with rule R_d chooses thresholds of a homogeneous committee with costs k_{R_d} . Hence, deliberation length and accuracy of decisions increase with the decision rule R_d.*

Proposition 8 implies that a designer who does not internalize the jury's deliberation costs would be inclined to choose as demanding a deliberation rule as possible. The welfare optimal deliberation rule, however, depends on the distribution of waiting costs in the relevant population.

9. SIMULTANEOUS DELIBERATION

We now discuss a case in which the decision on the amount of information to be collected takes place in one shot and contrast this case to the sequential one considered until now. When jurors are homogeneous, this is equivalent to the classic case of choosing the optimal sample size for the test of a binary hypothesis (see De Groot (1970). In our version with heterogeneous jurors we need to specify some details of the model. A deliberation decision determines the sample size t. A sample of size t costs each juror kt. At time t, jurors observe the realization of the sequence of random variables $X_1, ..., X_t$, and the vote whether to acquit or convict according to a decision rule R_v just as in Section 2. Deliberation is determined as follows. All voting takes place before the sample is drawn according to deliberation rule R_d. An index moves over discrete time starting from 1. At index τ, if jurors have not yet come to an agreement, then jurors vote on whether sample size τ is acceptable. If at least R_d jurors agree that the sample size is sufficient, then the deliberation process is over and a sample of size τ is drawn. If fewer than R_d jurors agree, then the index moves on to $\tau + 1$. The process continues until an R_d majority is satisfied. This model is the same as our sequential deliberation model if voters have to stop deliberation without seeing the realizations of the random variables. Given our result below that deliberation is always unanimous, the exact deliberating protocol is irrelevant. However, the model described above is easier to work with and is a closer match to the sequential deliberation model.

Let p_t be the posterior if the deliberation process has yielded a sample size t. Then voting at date t for a juror of type q is to vote to convict if $p_t \geq q$, and to vote to acquit if $p_t < q$. If at least R_v votes are obtained, then a decision is reached. Otherwise we have a hung jury.

Let $U(H)$ be the payoff to all jurors when there is a hung jury. We assume that this is independent of q.

$$\begin{aligned} U(R_d, R_v) &= -q\left(1 - E\left(p_t | p_t \geq q_{R_v}\right)\right) \Pr\left(p_t \geq q_{R_v}\right) \\ &\quad - (1-q)\, E\left(p_t | p_t < q_{n-R_v+1}\right) \left(\Pr\left(p_t < q_{n-R_v+1}\right)\right) \\ &\quad + U(H) \left(\Pr\left(q_{n-R_v+1} < p_t < q_{R_v}\right)\right). \end{aligned}$$

With symmetric juries, $q_{n-R_v+1} = 1 - q_{R_v}$, $E\left(p_t | p_t < q_{R_v}\right) = 1 - E\left(p_t | p_t \geq q_{R_v}\right)$, and $\Pr\left(p_t < q_{n-R_v+1}\right) = \Pr\left(p_t \geq q_{R_v}\right)$. Therefore,

$$U(R_d, R_v) = E\left(p_t | p_t < q_{R_v}\right) \Pr\left(p_t < q_{n-R_v+1}\right) + U(H) \left(\Pr\left(q_{n-R_v+1} < p_t < q_{R_v}\right)\right).$$

This expression is independent of q. Thus, jurors are unanimous in their deliberation votes, implying that the deliberation rule R_d is irrelevant. However, the decision rule R_v does matter: a larger R_v raises the probability of a hung jury. This feeds back into the optimal sample size (for the unanimous jurors). Thus, a larger R_v implies a more information collection.

10. Discussion and Extensions (to be completed)

10.1. Random Juries.

10.2. Hung Juries.

11. Appendix (to be completed)

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