Accuracy of Verdicts under Different Jury Sizes and Voting Rules*

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Abstract

Juries are a fundamental element of the criminal justice system. In this paper, we model jury decision-making as a function of two institutional variables: jury size and voting requirement. We expose the critical interdependence of these two elements in minimizing the probabilities of wrongful convictions, of wrongful acquittals, and of hung juries. We find that the use of either large non-unanimous juries or small unanimous juries are alternative ways to maximize the accuracy of verdicts while preserving the functionality of juries. Our framework – which lends support to the elimination of the unanimity requirement in the presence of large juries – helps appraise U.S. Supreme Court decisions and state legal reforms that have transformed the structure of American juries.

Keywords: jury size, voting requirement, criminal trial
JEL Codes: K0, K4

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1 Introduction

Jury design is a critical element of criminal adjudication. After more than six centuries without changes, the structure and functioning of juries have recently undergone several significant transformations regarding jury size and voting requirements. Juries in a criminal case were traditionally composed of 12 members, who needed to reach a unanimous agreement to render a decision.[1] Although most Americans view the 12-member jury as a fixture of American legal procedure, several U.S. Supreme Court decisions have affirmed the constitutionality of juries with fewer than 12 members, as well as juries operating under a voting requirement less stringent than unanimity. This paper seeks to evaluate the desirability – or lack thereof – of these institutional transformations, comparing the impact of changes in jury size to that of changes to voting requirements on the probability of wrongful convictions and of wrongful acquittals (i.e. convicting the innocent and acquitting the guilty, respectively), as well as of hung juries.

Prior literature on jury design has investigated jury size and voting requirement as independent policy variables or in pairwise choice frameworks, but often neglected their critical interdependence in maximizing the accuracy of verdicts. Prior contributions have separately investigated how large a jury should be (Paroush, 1997; Ben-Yashar and Paroush, 2000; Dharmapala and McAdams, 2003; Helland and Raviv, 2008; Luppi and Parisi, 2013), and how juries should vote to reach an accurate verdict (Klevorick and Rothschild, 1979; Klevorick et al., 1984; Ladha, 1995; Young, 1995; Neilson and Winter, 2005).

Our paper contributes to the existing literature by exposing the critical interplay between jury size and voting requirement in criminal adjudication. We extend the criminal trial model developed in Neilson and Winter (2000, 2005) by *both* relaxing the unanimity requirement *and* varying the jury size. We investigate how different combinations

[1] In the leading 1898 case *Thompson v. Utah*, the Court construed the Sixth Amendment to require that in all criminal cases, a jury must be comprised of exactly 12 persons.

of these two institutional variables affect the probabilities of accurate verdicts, wrongful verdicts, and hung juries. Our results reveal that jury size and voting requirements should inversely depend on one another: large non-unanimous juries or small unanimous juries are alternative solutions to maximize the accuracy of verdicts. We discuss these findings in the light of recent legal transformations to jury structure and we offer insights for policy analysis.

The paper is organized as follows. Section 2 briefly reviews the legal and economic backgrounds on jury design. Section 3 presents the criminal trial model. Section 4 introduces a numerical example to investigate how different combinations of a jury's institutional characteristics affect the probability of wrongful convictions and wrongful acquittals, as well as the ability for the jury to reach a deliberation. Section 5 concludes with a discussion of our results and their relevance for policy purposes.

2 Related Literature

For the last six centuries, criminal verdicts have been rendered by juries composed by 12 members, deliberating unanimously. In recent years, the U.S. Supreme Court has granted states the freedom to reduce the size of juries and to relax the juries' voting requirement, allowing non-unanimous verdicts. The changes have taken place through a series of cases decided by the U.S. Supreme Court between 1968 and 1979. In one of these cases, the well-known *Williams v. Florida*,[2] the Supreme Court recognized that a verdict rendered unanimously by fewer than 12 jurors was not necessarily inconsistent with the Constitutional right to have a trial by jury. In a subsequent decision, *Ballew v. Georgia*,[3] the Supreme Court set a lower limit on jury size, affirming that any jury with fewer than 6 members would be unconstitutional because it would be too small to be representative of the relevant community.

Other important changes took place with respect to the jury's voting requirement.

[2] *Williams v. Florida*, 3399 U.S. 78. (1970).

[3] *Ballew v. Georgia*, 435 U.S. 223 (1978).

Unanimity for criminal verdicts has generally been viewed as an important requirement to preserve the public confidence in the criminal justice system, since wrongful convictions of innocent defendants are less likely under unanimity (Coughlan, 2000).[4] However, unanimity allows any single juror to veto a proposed verdict and single-handedly lead to a mistrial. The increasing administrative and financial cost of mistrials led some states to consider criminal justice reforms that relaxed the unanimity requirement.[5] These state reforms were challenged at the federal level.

In the leading cases — *Duncan v. Louisiana*, *Johnson v. Louisiana*, and *Apodaca v. Oregon* — the U.S. Supreme Court ruled that verdicts reached under a qualified majority rule do not violate the U.S. Constitution.[6] This gave states the flexibility to pursue criminal justice reforms by allowing verdicts to be reached under a qualified majority rule. In 1979, *Burch v. Louisiana* held that states could reduce jury size or lessen the voting requirement but could not do both at the same time: non-unanimous verdicts could only be rendered by juries of 12, and smaller juries could only deliberate unanimously.[7] As of today, only the states of Oklahoma, Oregon, and Louisiana allow non-unanimous verdicts in misdemeanor cases; Oregon and Louisiana allow them also in felony cases.[8]

The abolition of the unanimity requirement for criminal verdicts was met with a mixture of approval and skepticism. Supporters viewed non-unanimous decision-making as a possible solution to the hung-jury problem (e.g., Amar, 1994; Glasser, 1996; Morehead, 1997). Opponents viewed the abolition of the unanimity requirement

[4]See Rule 31 of the Federal Rules of Criminal Procedure.

[5]See, for example, the multi-phased Hannaford-Agor et al.'s (2002) NCSC research on mistrials, motivated by the concern that mistrials were reaching unacceptably high levels in some jurisdictions. See also Kalven and Zeisel's (1966) study of the American jury, which briefly discussed the phenomenon of mistrials in criminal cases.

[6]See *Duncan v. Louisiana*, 391 U.S. 145 (1968); *Apodaca v. Oregon*, 406 U.S. 404 (1972); *Johnson v. Louisiana*, 406 U.S. 356 (1972).

[7]*Burch v. Louisiana*, 441 U.S. 130 (1979).

[8]See Oregon Revised Statutes §136.450, and Louisiana Laws Code of Criminal Procedure 782. Several states permit non-unanimous verdicts in civil trials. See State Court Organization, 1998, Figure 42 (Trial Juries: Size and Verdict Rules). For a more extensive discussions on these state regulations and mistrials, see Hannaford-Agor et al. (2002) and Luppi and Parisi (2013).

as a violation of a fundamental principle of criminal justice for the protection of innocent defendants (e.g., Kachmar, 1996; Smith, 1996; Klein and Klastorin, 1999).[9] The views in the literature are split, revealing an objective difficulty in balancing the policy goals of accuracy in adjudication and reduction of the costs of criminal justice.

Several law and economics contributions have investigated the effects of changing jury size on the expected trial outcomes. A central argument in the literature on juries and jury decision-making is that a group will make a better decision than an individual (Condorcet's Jury Theorem). Some contributions refined the Condorcet's Jury Theorem and demonstrated that, under certain conditions, this theorem does not hold (e.g., in the presence of strategic voting, as shown by Feddersen and Pesendorfer, 1998). For example, larger, unanimous juries may be more likely to reach an accurate deliberation, but may fail to reach any decision at all. Hence, a tradeoff emerges between accuracy and decisiveness (Luppi and Parisi, 2013). Notwithstanding the widespread adoption of smaller juries in state criminal courts, statistics indicate that overall mistrial rates have not declined (Kalven and Zeisel, 1966; Hannaford-Agor et al., 2002). A few empirical studies have attempted to evaluate how jury size affects trial results. Most of them concluded that there is no detectable difference between 6-member and 12-member juries with respect to mistrial rates (e.g., Hannaford-Agor et al., 2002; Eisenberg et al., 2005). By contrast, experimental studies and statistical models on jury size found that jury size does affect trial outcomes and jurors' behavior (e.g., Mukhopadhaya, 2003; Helland and Raviv, 2008; Guarnaschelli et al., 2000). For example, Guarnaschelli et al. (2000) revealed that larger juries may convict fewer innocent defendants than smaller juries under unanimity.

Our key original contribution to the literature is the specification of a different ob-

[9] See also Ben-Yashar and Nitzan (1997), proving that the optimal rule for fixed-size committee in dichotomous choice situations is the qualified weighted majority. Feddersen and Pesendorfer (1998) showed that, when jurors behave strategically, the probability of convicting the innocent in large juries is higher under the unanimity rule than under qualified majority rules. When there is uncertainty about jurors' preferences, in the presence of strategic jurors with private information the unanimity rule may still be preferable to protect innocent defendants against wrongful convictions (Luppi and Parisi, 2013).

jective function that should guide the design of juries. While previous studies focused on either jury size or voting requirement, in this paper we reveal the crucial interdependence of these two variables and we analyze their optimal combination in minimizing the probabilities of wrongful convictions and hung juries.

3 Criminal Trial Model

In this section we construct a simple model of the criminal trial process to analyze how varying jury size and voting requirement affects different expected trial outcomes. Our model relies upon Neilson and Winter's (2005) theoretical setup, with the main difference that we vary not only voting requirements, but also jury size.[10]

We consider a criminal trial where nature chooses whether or not the defendant committed a crime (guilty), and the strength of evidence that is found against the defendant. Let $P(G)$ denote the probability that nature chooses the defendant to be guilty and $1-P(G)$ the probability that nature chooses the defendant to be innocent. Let s be the strength of evidence found against the defendant, whereby stronger evidence is associated with a higher probability of guilt. Let $f(s|G)$ and $f(s|I)$ be the probability density functions of the strength of evidence given that the defendant is guilty or innocent, respectively – and let $F(s|G)$ and $F(s|I)$ be the corresponding cumulative functions. The two density functions are represented in Figure 1.

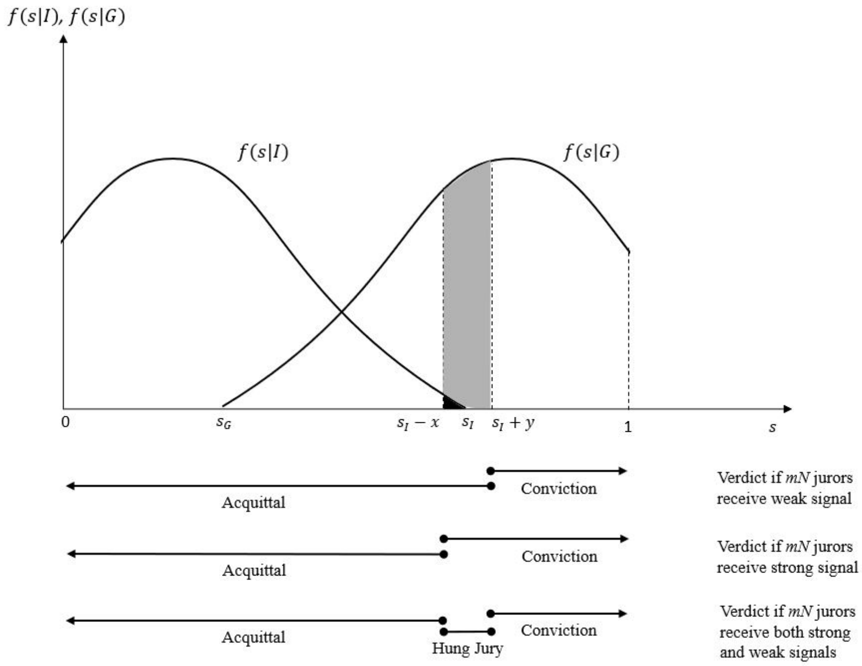
The traditional standard of proof in criminal trials in the United States is *proof beyond a reasonable doubt*, where each juror must *individually* believe in the guilt of the accused beyond any reasonable doubt.[11]

As in Neilson and Winter (2000, 2005), to model the reasonable-doubt standard we assume that some evidence is inconsistent with an innocent defendant. Specifically,

[10] For a similar formulation of the court's problem, see also Rubinfeld and Sappington (1987).

[11] The beyond a reasonable-doubt standard has been used in criminal trials since at least the 1700s. It was adopted by most jurisdictions even before the case *In re Winship* (397 U.S. 358, 1970) and recognized it as a constitutional requirement.

Figure 1: The distribution of evidence (Neilson and Winter, 2000, 2005)



an innocent defendant can generate evidence in the interval $[0, s_I]$, whereas a guilty defendant can generate evidence in the interval $[s_G, 1]$, with $0 \leq s_G < s_I < 1$. If a juror observes $s \geq s_I$, that juror can state that the defendant is guilty beyond a reasonable doubt. The opposite holds when $s < s_I$. Put another way, s_I represents the reasonable-doubt standard threshold.[12]

Analytically, this is equivalent to assuming that the probability density function for a guilty defendant first-order stochastically dominates the probability distribution function of an innocent defendant. Thus, under first-order stochastic dominance, it is more likely to find incriminating evidence for a guilty defendant than an innocent

[12]The reasonable-doubt standard threshold follows from Judge Blackstone's dictum, that it is "better that ten guilty persons escape than that one innocent suffer" (Blackstone, 1769). Blackstone's ratio of 10 to 1 – or any variation of such ratio in state case law (Rizzolli and Saraceno, 2013; Pi et al., 2019) – follows from the fact that a wrongful conviction in criminal adjudication (convicting the innocent) is perceived to be worse than a wrongful acquittal (acquitting the guilty). For a discussion on the standard of proof in criminal law, see, e.g., Garoupa (2017) and Wickelgren (2017). Variations in the standard of proof may impact the optimal combination of jury size and voting requirement, and vice-versa. For an analysis on the optimal standard of proof in conjunction with alternative combinations of jury size and voting requirements, see Guerra et al. (2019).

defendant.[13] Graphically, the first-order stochastic dominance is represented by the fact that the $f(s|G)$ distribution is shifted further to the right than the $f(s|I)$ distribution.[14]

As in Neilson and Winter (2005), we introduce juror heterogeneity by assuming that they do not directly observe the true evidence s, but they rather observe signals of varying strength related to the evidence.[15] Juror heterogeneity is a necessary assumption: if all individual jurors were perfectly able to observe the true strength of evidence, juries would always reach unanimous verdicts. However, this is not the case in real-world criminal trials, as the actual rates of hung juries and judicial errors show (e.g., Hannaford-Agor et al., 2002). Each juror assesses evidence differently and, as a result, can express different opinions when deliberating for a verdict.

Specifically, each juror has a probability π of receiving a strong signal of incriminating evidence, $s_S = s + x$, with $x \geq 0$, and a probability $1 - \pi$ of receiving a weak signal of incriminating evidence, $s_W = s - y < s_S$, with $y \geq 0$. A juror who receives the strong signal votes to convict if $s_S \geq s_I$, that is, if $s \geq s_I - x$, as represented in Figure 1. A juror who receives the weak signal votes to convict if $s_W \geq s_I$, that is, if $s \geq s_I + y$, as represented in Figure 1. Basically, a juror receiving the strong signal is more likely to believe that the defendant is guilty beyond any reasonable doubt than is a juror receiving the weak signal.

Let $N \in [3, 12]$ denote the size of a jury, ranging between a 3-member jury and a 12-member jury. This allows us to determine when a jury with fewer than 6 members – which is the lower limit set forth by the U.S. Supreme Court – could be warranted. Let $m \in [0.5, 1]$ denote the required percentage of votes to reach a verdict. For the majority

[13]The assumption of first-order stochastic dominance has also been used by Rubinfeld and Sappington (1987); Miceli (1990); Miceli (2009, p.125); and Feess and Wohlschlegel (2009).

[14]Formally, for any evidence level s, $f(s|G) \geq f(s|I)$. Equivalently, in terms of cumulative distribution function, $F(s|G) \leq F(s|I)$. Note, in the following analysis, as jury design changes the shapes of the functions, $f(s|I)$ and $f(s|G)$ remain unchanged. For a similar setting, see Miceli (1990), Neilson and Winter (2005), and Rizzolli and Saraceno (2013).

[15]This is equivalent to assuming that jurors observe s with bias, as in Neilson and Winter (2000), or that jurors hold different beliefs about the true strength of evidence, as in Feddersen and Pesendorfer (1998) and Guarnaschelli et al. (2000). For other forms of juror heterogeneity, see, e.g., Arce et al. (1996); Alpern and Chen (2017).

rule case, mN is the least integer greater than $N/2$; for the unanimity case, $m = 1$.[16]

Let $B(mN,N,\pi)$ denote the binomial probability distribution of having at least mN jurors receiving the strong signal, where m is the majority requirement. Put another way, let P_C denote the probability that the jury is entirely prone to convict, with $P_C = B(mN,N,\pi)$. Similarly, let P_A denote the probability that the jury is entirely prone to acquit (or, equivalently, the probability that mN jurors receive the weak signal), with $P_A = B(mN,N,1-\pi)$. The probability that a jury is neither entirely prone to convict nor entirely prone to acquit is $P_B = 1 - P_A - P_C$.

We can now derive the probabilities of a wrongful conviction, a wrongful acquittal, and a hung jury in a single trial.[17]

A wrongful conviction occurs when: (a) the defendant is innocent, which occurs with probability $1-P(G)$; (b) the jury is likely to convict (or, equivalently, mN jurors receive the strong signal), which occurs with probability P_C; and (c) the evidence is sufficiently strong to meet the reasonable-doubt standard, that is $s \geq s_I - x$. Putting this all together, the probability of a wrongful conviction P_{WC} is given as:

$$P_{WC} = [1-P(G)][1-F(s_I - x|I)]P_C \tag{3.1}$$

A wrongful acquittal occurs when: (a) the defendant is guilty, which occurs with probability $P(G)$, but (b) the evidence is not strong enough to convict him. Formally, the probability of a wrongful acquittal P_{WA} is given as:

$$P_{WA} = P(G)[P_A F(s_I + y|G) + (1-P_A)F(s_I - x|G)] \tag{3.2}$$

[16]For the purpose of our analysis, we assume that a jury reaches a decision by taking a simultaneous vote, that is, jurors ignore any group strategy aspects and decide independently from other jurors. This means that jurors do not vote against their signal: if a juror receives a guilty (innocent) signal, he votes to convict (acquit). This assumption – which is the behavior assumed by Condorcet – allows us to isolate the role of our two institutional variables from the possible effects of signaling and informational cascades (e.g., Luppi and Parisi, 2013), and the possibility of strategic voting of jurors (e.g., Ladha, 1992; Feddersen and Pesendorfer, 1998; Kaniovski and Zaigraev, 2011).

[17]For the purpose of the present analysis, we focus on the outcome of a single trial. Our basic framework can be extended to consider appeals and retrials. See Neilson and Winter (2005).

The first term within the squared brackets is the probability that at least mN jurors receive the weak signal (P_A) and the evidence is not enough strong to convict ($s < s_I + y$). The second term is the probability that at least mN jurors receive the strong signal (P_C), or receive both the strong and weak signals ($1 - P_C - P_A$), but the evidence is not enough strong to convict ($s < s_I - x$).

The probability of a wrongful verdict is given by $P_W = P_{WC} + P_{WA}$.

A hung jury occurs (a) if the jury is neither entirely prone to convict nor entirely prone to acquit, which happens with probability $P_B = 1 - P_A - P_C$, and (b) if the true strength of evidence is sufficiently close to the reasonable-doubt standard, i.e., it ranges between $s_I - x$ and $s_I + y$ (the hung jury range, as shown in Figure 1). In this range, jurors who receive the strong signal vote to convict, and those who receive the weak signal vote to acquit, resulting in a mistrial. Formally, the probability of a hung jury P_H is given as:

$$P_H = [1 - P(G)][1 - F(s_I - x|I)]P_B + P(G)[F(s_I + y|G) - F(s_I - x|G)]P_B \tag{3.3}$$

where the first term is the probability of a mistrial when the defendant is innocent, and the second term is the probability of a mistrial when the defendant is guilty.

From the equations above, it is straightforward to derive the probability of an accurate verdict, that is $P_V = 1 - P_W - P_H$.

The social loss function – which depends on the social costs of a wrongful conviction, of a wrongful acquittal, and of a mistrial – can be expressed as following:

$$\min_{N,m} L(N,m) = P_{WC}C_{WC} + P_{WA}C_{WA} + P_H C_H \tag{3.4}$$

where C_H, C_{WA}, and C_{WC} are the monetary social costs for a hung jury, wrongful acquittal and wrongful conviction, respectively.[18]

[18] As in Neilson and Winter (2000), the administrative costs of increasing N are omitted. The social function in Equation (3.4) is similar to the social loss function considered by Miceli (1990). The main differences are that Miceli (1990) did not analyze jury size and voting requirement as factors influencing

The objective of the social planner is to minimize the social loss as expressed in Equation (3.4) by optimally choosing jury size and voting requirement. In the next section, we analyze how different combinations of the two aforementioned institutional variables affect accuracy in adjudication and probability of mistrials through changes in P_{WC},P_{WA}, and P_H.

4 Optimal Jury Size and Voting Requirement

In this section, we analyze how different combinations of jury size and voting requirement affects expected trial outcomes. We use a numerical example to explore the implications of the model depicted in Section 3.[19]

Following Neilson and Winter (2000, 2005), in the numerical analysis we assume that $s_G = 0.4$ and $s_I = 0.6$, and that $f(s|I)$ and $f(s|G)$ follow a triangular distribution. We also assume that $P(G) = 0.8$, and that the signals toward conviction and the signals toward acquittal are of equal magnitude, $x = y = 0.05$. These parameters yield the probability of mistrial to range between 0% and 10%, which is consistent with stylized facts.[20]

We focus on the relative probability of different trial outcomes, without resorting to any restrictive assumptions on the relative magnitude of C_{WC}, C_{WA}, C_H introduced in the social function (3.4). This allows us to engage in a positive economic analysis on

accuracy of decisions, and omitted to consider the costs associated with mistrials. Our social function is also comparable to the social loss function considered by Neilson and Winter (2000). The main differences are that Neilson and Winter (2000) did not analyze how different combinations of jury size and voting requirement affect the accuracy of adjudication and the probability of mistrials.

[19]We use a numerical example for several reasons. As pointed out by Urken and Traflet (1983), numerical example depict scenarios that we can expect under idealized conditions. As in Neilson and Winter (2005), it is here impossible to derive simple mathematical characterizations (e.g., comparative statics derivatives) because variations in the voting requirement, and/or in jury size, make the binomial distributions to change in discontinuous ways.

[20]For example, among others, Klaven and Zeisel (1966) found a hung jury rate of 5.5% in their sample of more than 3,500 criminal trials. Flynn (1977) and Hannaford et al. (1999) analyzed criminal trials in California and found hung jury rates to often exceed 10% and even 20%. Hannaford-Agor et al. (2002) further examined hung jury rates in federal and state courts, finding an average rate between between 2% and 3% in federal state courts, and of approximately 6% in urban state courts.

the accuracy and effectiveness of jury decision-making, avoiding normative or ethical considerations on desirability of alternative jury structures.

Let us start by discussing the benchmark case of varying jury size under unanimous verdicts. By restating the Condorcet's jury theorem under unanimity, we obtain the following lemma:

Lemma 4.1 (Jury-Size Effect)**.** *The probability of a wrong verdict decreases in jury size. However, given the greater incidence of mistrials, the probability of reaching an accurate unanimous verdict decreases in jury size.*

Lemma 4.1 unveils an interesting paradox. Larger juries are less likely to be wrong but are also less likely to reach an accurate verdict, because of the greater difficulty in deliberating unanimously. An increase in the majority required for a verdict reduces the probability of wrongful convictions but leads to an increase in mistrial.

Next, let us discuss the implications of varying the voting requirement under a given jury size.

Lemma 4.2 (Voting Requirement Effect)**.** *For any given jury size, the probability of a wrong verdict decreases with the required majority, whereas the probability of a mistrial increases with the required majority.*

Similar to what we observed in Lemma 4.1, we can see that changes in the voting requirement have a double-edged effect. Relaxing a jury's voting requirement (i.e., allowing non-unanimous verdicts) facilitates the reaching of a verdict, but at the same time increases the probability of adjudication errors. As the majority requirement is reduced, more verdicts will be reached, but wrongful convictions (wrongful convictions) and wrongful acquittals (wrongful acquittals) will also increase.

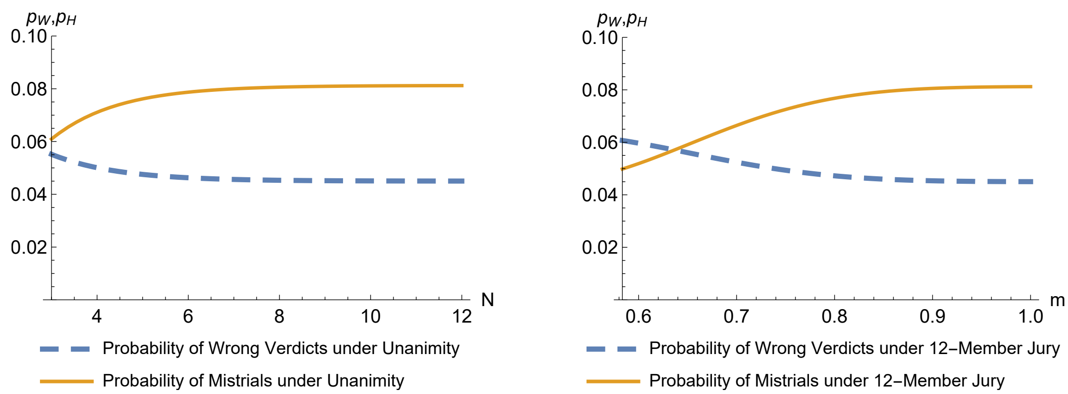
The effect of changes in jury size and voting requirements are quantitatively similar, but as it will be discussed in Section 4, they are qualitatively different. The two alternative modifications to jury structure allowed by the U.S. Supreme Court under *Burch v. Louisiana* have different effects on juries' accuracy in criminal adjudication.

4.1 Smaller Unanimous Juries vs. Larger Non-Unanimous Juries

As a first step, we consider the constraint sets out by the U.S. Supreme Court in *Burch v. Louisiana* on jury size and voting requirements. Based on that decision, state courts are not allowed to modify jury size and voting requirement at the same time. In the following, we consider the respective advantages of reducing jury size (under unanimity) and relaxing the unanimity requirement (in a 12-member jury).

Figure 2: *Reducing Jury Size* versus *Relaxing Voting Requirement*

(a) *Reducing Jury Size* (b) *Relaxing Unanimity*



Notes. Figure 2 plots the probability of wrongful verdicts (p_W) and the probability of hung jury (p_H) as functions of jury size N (Figure 2a) and voting requirement m (Figure 2b).

Figure 2 compares the two alternative jury structures allowed by *Burch v. Louisiana*, under the parameters of our example. Specifically, Figure 2a shows how changes in jury size N affect trial outcomes under unanimity. Figure 2b shows how changes in the voting requirement m affect expected trial outcomes in 12-member juries.

These results validate the restatements of Condorcet's Jury Theorem under unanimity: the probability of a mistrial increases with jury size (Lemma 4.1). However, the probability functions indicate that varying jury size under unanimity has a relatively small impact on the probabilities of mistrials (Figure 2a). Conversely, relaxing the voting requirement can more significantly mitigate the problem of mistrials (Figure 2b).

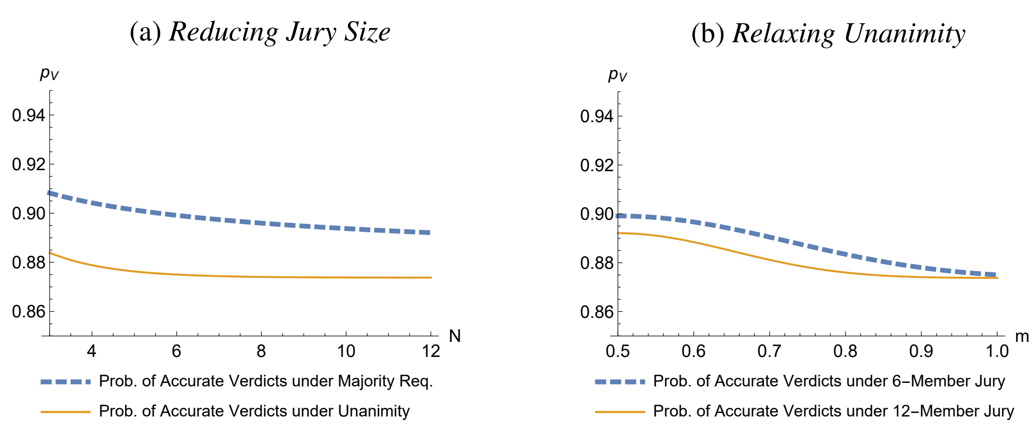
Further, any marginal change in jury size (under unanimity) or any marginal change in voting requirement (in a 12-member jury) have a negligible impact on the probability of wrong verdicts (either wrongful conviction or wrongful acquittals), as shown in Figure 2b.

These results can be summarized in the following proposition:

Proposition 4.3. *Relaxing the unanimity requirement is a more effective alternative to restricting jury size.*

Another way to look at *Burch v. Louisiana*'s trade-offs is to focus on a jury's overall accuracy in reaching a verdict. Figure 3 shows that, for a given voting requirement changing jury size has a relatively small impact on the accuracy of verdicts (Figure 3a), compared to a change in the voting requirement keeping jury size unchanged (Figure 3b). Relaxing unanimity yields greater net benefits compared to a reduction in jury size. Variations in the accuracy of verdicts are mainly driven by variations in the probability of mistrials: when fewer cases end in mistrials, more verdicts are rendered, some of which are correct.

Figure 3: *Accuracy of Verdicts Under the* Burch v. Louisiana *Constraints*



Notes. Figure 3 plots a jury's probability of reaching an accurate verdict, p_V as a function of jury size N (Figure 3a) and voting requirement m (Figure 3b).

The accuracy of verdicts is higher in the presence of non-unanimous juries, whereby varying jury size does not significantly alter the result. Relaxing the unanimity requirement while keeping the 12-member jury size unchanged is a solution the U.S. Supreme Court allows under *Burch v. Louisiana*, which has interestingly been adopted only by three states for misdemeanor cases and only two states for felony cases. Our results suggest that this solution, albeit less popular among U.S. jurisdictions has some advantages over the more popular alternative of jury-size reduction.

In the following, we will move beyond the constraints set forth by *Burch v. Louisiana* to investigate the extent to which it might be desirable to allow the unanimity requirement to be relaxed even in the presence of smaller juries.

4.2 Beyond *Burch v. Louisiana*

In this section we abstract away from the constraint set forth by *Burch v. Louisiana* to consider different combinations of jury size and voting requirements. We will examine the effects of relaxing *both* the 12-member jury size and the unanimity requirement on the accuracy of verdicts.

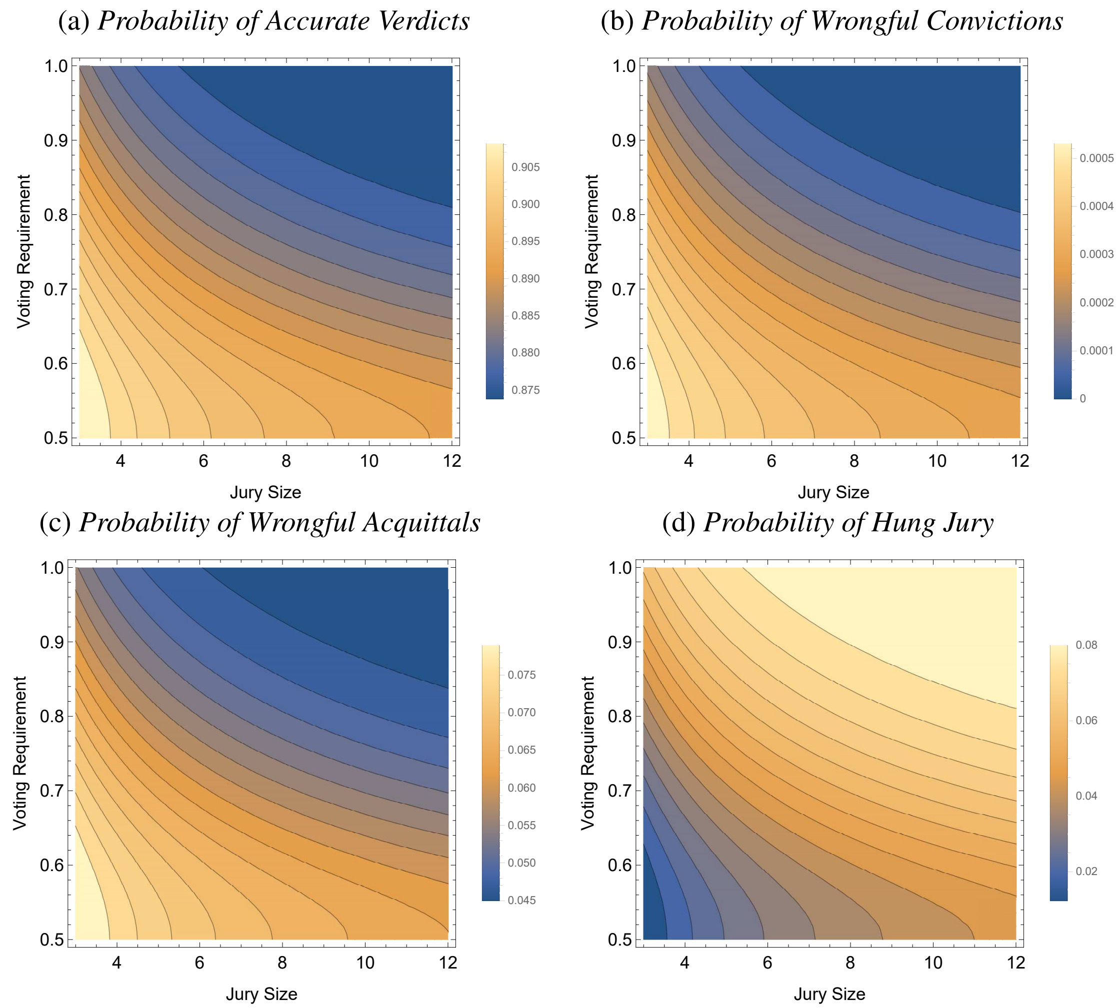
Figure 4 shows how different combinations of jury size and voting requirement affect the accuracy of verdicts, the probabilities of wrongful acquittal and of wrongful conviction, as well as the probability of a hung jury.

Figure 4a depicts the core of Proposition 4.3: relaxing the unanimity requirement can increase the accuracy of verdicts. Furthermore, relaxing unanimity can substantially reduce the probability of mistrials (Figure 4d). The effect of a change in the voting requirement on wrongful convictions and wrongful acquittals is instead relatively small for any jury size (Figures 4b and 4c).

In economic terms, this implies that a small departure from the unanimity rule is capable of generating large benefits with respect to mistrial rates, with no substantial increase in adjudication errors. In contrast, a reduction in jury size only generates a modest reduction in mistrial rates, with a more noticeable increase in error rates. Changes in voting requirement and jury size have asymmetric effects on social welfare.

Along the optimal jury frontier, jury size and voting requirements inversely depend

Figure 4: *Optimal Jury Size and Voting Requirement to Maximize Accuracy of Verdicts*



Notes. Figure 4 plots the probabilities of alternative trial outcomes as functions of jury size N and voting requirement m.

on one another, as stated in the following proposition:

Proposition 4.4. *The accuracy of verdicts is maximized when the majority requirement increases as jury size decreases, and vice-versa.*

The probability of adjudication errors (convicting an innocent or acquitting a guilty) is minimized by requiring unanimous verdicts for small juries, while allowing non-unanimous verdicts with large juries. The probability of a mistrial is minimized if the unanimity requirement is relaxed, regardless of jury size. Hence, to minimize the probability of a mistrial, the adoption of a majority rule is more effective than a reduction in jury size. This result is in line with the empirical evidence on mistrial rates: Oregon and Louisiana, the two states allowing majority verdicts in felony cases, had about half the mistrial rates of the states that adjudicated felonies requiring unanimity, while states that reduced jury size did not observe any noticeable decrease in mistrial rates (Luppi and Parisi, 2013).

If the sole social objective is to minimize the probability of a wrong verdict, the unanimity requirement is always optimal regardless of jury size.[21] When additional objectives are taken into account, unanimity is strictly preferable in small juries, whereas majority voting could be a superior alternative in large juries, since adjudication errors are less likely in large juries. These findings provides a rationale for the constraints introduced by the U.S. Supreme Court in *Burch v. Louisiana*. Even in the absence of *Burch v. Louisiana*, a combined use of small juries and non-unanimous verdicts would not be desirable as a policy matter.

As a final remark, it is worth further distinguishing between the probability of wrongful convictions and wrongful acquittals. Variations in jury size and voting requirements have a relatively small impact on the probability of wrongful convictions, the magnitude of which ranges in a narrow interval. The impact of variations in jury size and voting requirement on the probability of wrongful acquittals is instead greater. We show that in general, the probability of both types of errors is lower under unanimity or in the presence of a large jury. This is in line with Neilson and Winter (2005), and it is driven by a combination of the following parameters set in our numerical example: the probability that a defendant is innocent is 20%; the reasonable-doubt standard of

[21] Helland and Raviv (2008) stated that, under specific conditions and if jury deliberation follows a random walk, the probability of wrongful convictions and wrongful acquittals is not sensitive to the number of jurors, and is equal to the probability that a single juror would commit these errors. Helland and Raviv (2008) concluded that, since the number of jurors in a trial increases cost, the optimal number of jurors per trial is one. In this paper, we demonstrate that the optimal jury size depends on voting requirement, and vice versa. The optimal combinations of these institutional characteristics should balance the probability of adjudication errors and the probability of mistrials.

$s \geq s_I$ is severe; only a jury entirely prone to conviction can convict an innocent person. This yields wrongful convictions to be a relatively unlikely event, which is one of the main objectives of the legal system. Hence, using larger juries or requiring unanimous verdicts has a limited impact on the probability of convicting an innocent defendant while more substantially increasing the probability of acquitting a guilty defendant.

5 Discussion and Conclusion

Let us now step back to review the previously stated results from a bird's-eye perspective. Our findings help evaluate the effect of the changes to jury structure that have been brought about by the U.S. Supreme Court and state legislation. The results on the capacity of a jury to reach an accurate verdict taken in isolation provides an economic rationale for the constraints introduced by the *Burch v. Louisiana* decision. Large non-unanimous juries or small unanimous juries are alternative ways to maximize the accuracy of verdicts while preserving the functionality of juries. In the choice between these alternatives, the unanimity rule has been retained by the large majority of jurisdictions and it is almost universally required in capital murder cases given the severity of the consequences resulting from wrongful convictions. In these cases the probability of convicting an innocent should be kept to a minimum, avoiding as much error as possible. Notwithstanding the limited adoption of non-unanimous juries in U.S. state courts, our results lend support to the elimination of the unanimity requirement in the presence of large juries: as we move away from capital murder cases, combining a qualified majority rule with larger juries would seem desirable, inasmuch as the undesirability gap between wrongful convictions and wrongful acquittals narrows. Furthermore, our paper shows that under certain parameters, optimal jury size can fall below the lower-limit of 6 members set by the U.S. Supreme Court in the *Burch v. Louisiana* case.

Our result on the capacity of a jury to reach a verdict largely aligns with the conventional wisdom in the existing literature. The use of smaller juries could reduce the probability of a single juror causing a deadlock and thus facilitate the reaching of verdict: small juries may be desirable to empower the jury with the capacity to reach a verdict.

Future research in this field should extend our analysis to investigate how optimal jury design would change when considering retrials (Neilson and Winter, 2005), correlated votes (Rubinfeld and Sappington, 1987), endogenous social values of adjudication errors (Miceli, 1990), behavioral cascades (Luppi and Parisi, 2013), and strategic voting by jurors (Feddersen and Pesendorfer, 1998). For all these extensions, our model could usefully serve as a building block for the understanding of more complex jury decision-making scenarios.

Finally, as shown in Pi et al. (2019), the choice of different Blackstonian ratios by U.S. jurisdictions indirectly implies the jurisdiction's commitment to different "beyond a reasonable doubt" thresholds. The next objective in our research agenda is to explore how the jurisdictions' choices of different standards of proof should influence their choices regarding jury size and voting requirements (Guerra et al., 2019).

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