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The Elimination of Hung Juries: Retrials and Nonunanimous Verdicts

William S. Neilson [a,*], Harold Winter [b]

[a] *Department of Economics, Texas A&M University, 4228 TAMU, College Station, TX 77843-4228, USA*
[b] *Department of Economics, Ohio University, Athens, OH 45701, USA*

Abstract

Relaxing the unanimity requirement for verdicts in a given criminal trial leads to fewer hung juries and more verdicts of all four types: correct and wrongful convictions, and correct and wrongful acquittals. A criminal proceeding, however, does not necessarily end when a jury hangs. We demonstrate that if retrials occur until a verdict is reached, a unanimous verdict rule is generally more accurate than a nonunanimous rule with respect to the probabilities of all four types of verdicts. Thus, a tradeoff between hung jury costs and verdict accuracy exists when considering unanimous versus nonunanimous verdict rules.

JEL classification: K4

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1. Introduction

An often-discussed concern of the criminal justice system is the frequency of mistrials due to hung juries. In their classic study *The American Jury*, Kalven and Zeisel (1966) found a hung jury rate of 5.5% in their sample of over 3500 criminal trials. Since then, there have been few studies to add to our knowledge of hung jury rates. Two other studies of hung jury rates in California, one conducted in 1975, the other in 1995, found hung jury rates in different counties to often exceed 10% and sometimes

* Corresponding author. Tel.: +1 979 845 7352; fax: +1 979 862 8483.
E-mail addresses: w-neilson@tamu.edu (W.S. Neilson), winter@ohio.edu (H. Winter).

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20%.[1] Hannaford et al. (1999) compiled a data set of hung jury rates across federal and state courts. Their findings placed federal criminal hung jury rates between 2% and 3% over the period 1980–1997. They also examined hung jury rates in several large urban state courts, finding an average rate of approximately 6%. Given that there were 13,173 criminal jury trials in California state courts and 17,343 in Texas courts in fiscal year 2000–2001, for example, hung juries are a significant problem.[2] In this paper, we examine an often-discussed proposal for reducing the hung jury rate—nonunanimous jury verdicts.

Currently, two states (Louisiana and Oregon) allow for nonunanimous verdicts in many criminal trials. The Supreme Court upheld the constitutionality of nonunanimous verdicts in two 1972 decisions.[3] In *Johnson v. Louisiana*, the Court ruled that having a minority of three jurors voting to acquit does not violate the "proof beyond a reasonable doubt" standard the due process clause of the Fourteenth Amendment is interpreted as guaranteeing.[4] In *Apodaca v. Oregon*, the Court ruled that a nonunanimous verdict does not violate the right to a trial by jury specified by the Sixth Amendment.[5] In the aftermath of the Court's decisions, there has developed a vast legal literature debating the pros and cons of nonunanimous jury verdicts.

The leading argument in favor of nonunanimous verdicts is that they would reduce the hung jury rate.[6] If hung juries are often caused by lone jurors or a very small minority of jurors, moving from unanimous verdicts to a 9-3 rule, for example, would prevent the minority from blocking a verdict. Trial costs would be saved as fewer retrials would be needed.[7] Critics of nonunanimous verdicts argue that unanimity adds yet another level of protection for the innocent defendant, and the prevention of a wrongful conviction is a well-established goal of the legal system.[8] It is interesting that both sides of the debate often discuss the lone hold-out juror. Those in favor of nonunanimous verdicts argue that they eliminate the *flake factor*, that is, they prevent a single "irrational" juror from preventing a correct conviction. But those against nonunanimous verdicts argue that they may circumvent a single "rational" juror from preventing a wrongful conviction.[9] Thus, both supporters

[1] See Flynn (1977) and Hannaford, Hans, and Munsterman (1999).

[2] These numbers are from the *2002 Court Statistics Report* from the Judicial Council of California Administrative Office of the Courts and the *Texas Judicial System 2001 Annual Report* from the Office of Court Administration and the Texas Judicial Council.

[3] While the constitutional issues involved with nonunanimous jury verdicts are of great importance, we consider them beyond the scope of this paper. For a discussion of these issues, see Abramson (1994, chap. 5).

[4] *Johnson v. Louisiana*, 92 S. Ct. 1620 (1972).

[5] *Apodaca v. Oregon*, 92 S. Ct. 1628 (1972).

[6] For supporters of nonunanimous jury verdicts, see Amar (1995), Glasser (1997), Morehead (1998), and Rosen (1998).

[7] Also, it is argued that many first trials will be prevented as defendants may be more willing to accept plea bargains since they will no longer be able to rely on the possibility that just one juror can hang the jury.

[8] For critics of nonunanimous jury verdicts, see Kachmar (1996), Osher (1996), Saks (1997), Smith (1997), and Klein and Klastorin (1999).

[9] Another leading argument against nonunanimous verdicts, taken as beyond the scope of this paper, is that the deliberation process will be seriously damaged. Minority viewpoints that may eventually sway other jurors will be silenced if, once the necessary majority is reached, deliberations end. We do not model the deliberation process, as each juror votes independently. For models of the deliberation process and strategic voting, see Klevorick

and critics of nonunanimous verdicts appear to agree that nonunanimity will increase the conviction rate. Supporters focus on the additional correct convictions, while critics focus on the additional wrongful convictions.

Our focus is on how nonunanimous rules affect the probabilities of *every* type of verdict—correct conviction, correct acquittal, wrongful conviction, and wrongful acquittal. Using a model developed in Neilson and Winter (2000) to examine the effect of peremptory challenges on jury verdicts, we demonstrate here that nonunanimous rules lead to more first trial verdicts—*both* convictions and acquittals.[10] Thus, the first trial probability of each verdict type increases as the unanimity requirement is weakened. However, it is misleading to argue that nonunanimous verdicts reduce the hung jury rate. While this is true when considering the first trial only, it is not true when properly considering the effect of these rules on the *final disposition* of the trial. When retrials are taken into account, there ultimately is no such thing as a hung jury as every case reaches an eventual verdict. We demonstrate that when eventual verdicts are considered, a unanimous jury rule tends to lead to more accurate verdicts when compared to nonunanimous rules.

The model of criminal trials used in the remainder of the paper is introduced in the next section.[11] Section 3 introduces the numerical example we use to facilitate the discussion of our results. Section 4 compares the verdict accuracy of unanimous and nonunanimous jury rules in the first trial and with retrials. Section 5 offers a thorough discussion of the robustness of our results to the numerical example. Section 6 compares our work to the strategic voting literature on nonunanimous verdicts. Finally, Section 7 offers some concluding comments.

2. Criminal trial model

In order to analyze the characteristics of different verdict procedures, we construct a simple model of a criminal trial. The model has the following key features: (i) evidence is presented to 12 jurors and each juror compares the evidence to a reasonable doubt standard; (ii) juror heterogeneity is binary; and (iii) a verdict is reached by the jury according to the verdict procedure under consideration.

and Rothschild (1979), Klevorick, Rothschild, and Winship (1984), Feddersen and Pesendorfer (1998), Coughlan (2000), and Gerardi (2000).

[10] While the models used here and in Neilson and Winter (2000) are similar, the uses of the model are quite different. Neilson and Winter (2000) analyzes the effects of peremptory challenges exclusively, and it does so assuming that hung trials are not resolved and by using an explicit social loss formulation. To allow for the *voir dire* process, juror heterogeneity takes the form of a bias that attorneys can recognize and use as a basis for peremptory challenges. The paper establishes that the peremptory challenge system can reduce social loss when challenges are awarded in a way that makes up for the overall bias of the population from which the jury is drawn. In this paper, in contrast, juror heterogeneity does not take a form that can be exploited in voir dire, hung trials are resolved, and no explicit social loss formulation is employed. This more positive analysis is concerned with establishing the differences between various jury decision rules, and not jury selection.

[11] The model of the criminal trial is incomplete in that it does not consider the deliberation process, and changing from a unanimous to a nonunanimous verdict rule might change the manner in which jurors deliberate. This issue is addressed explicitly in Neilson and Winter (2002), and is also considered in the strategic voting literature on jury verdicts, as discussed in Section 6.

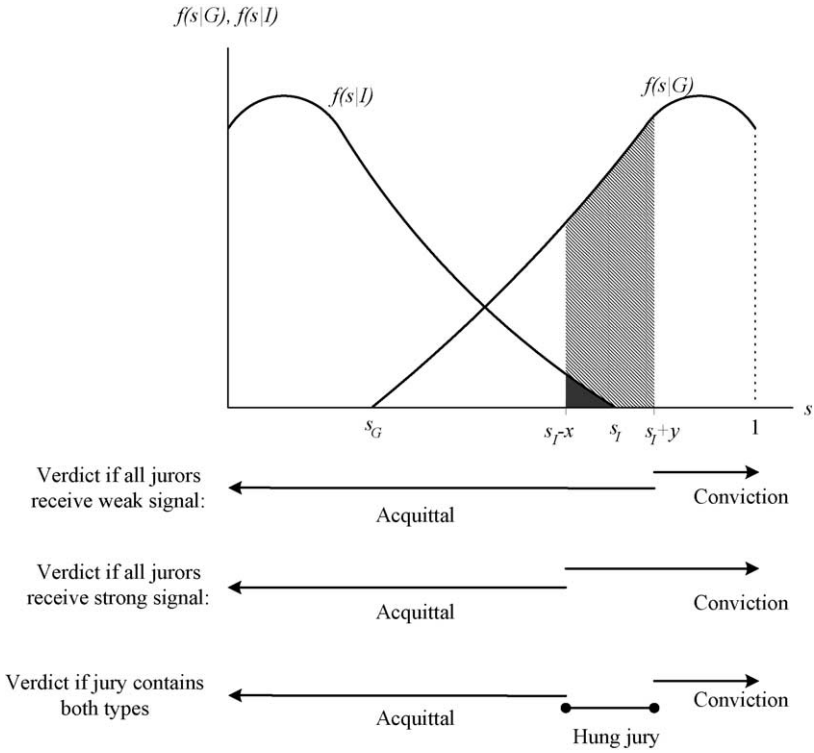

Fig. 1. The distribution of the evidence.

2.1. Evidence and reasonable doubt

A trial consists of evidence for a defendant who is either guilty or innocent. The defendant is guilty with probability $P(G)$ and is innocent with probability $1 - P(G)$. The evidence against the defendant is of strength s, with stronger evidence associated with a higher probability of guilt. Operationally, we assume that there are two probability density functions, $f(s|I)$ and $f(s|G)$, with s drawn randomly from $f(s|I)$ when the defendant is innocent and drawn randomly from $f(s|G)$ when he is guilty. The two density functions are shown in Fig. 1.

As shown by the figure, a guilty defendant generates stronger evidence than does an innocent one. The figure also shows a strength of evidence s_I such that it is impossible for an innocent defendant to generate evidence of strength $s \geq s_I$. Thus, if the evidence is of strength $s \geq s_I$, the defendant must be guilty with probability one. This leads to our *reasonable doubt standard*: the defendant is guilty beyond a reasonable doubt according to the evidence if and only if $s \geq s_I$.[12]

[12] Put another way, we adopt as a reasonable doubt standard the condition that $\text{Prob}\{G|s\} = 1$. A less stringent standard would not alter our qualitative results. Robustness is discussed in Section 5.

2.2. Juror heterogeneity

We assume that in the jury room, juror heterogeneity exists in the form of differences in jurors' perceptions of the evidence. Juror heterogeneity is a *necessary* assumption. With homogeneous jurors, there would be no difference between any of the jury verdict rules we consider since all jurors would vote identically. The minimum amount of heterogeneity required for hung juries, which in turn require juror disagreement, is for jurors to perceive the evidence in two different ways. We assume that each juror has a probability π of receiving a strong signal of the evidence, s_s, which is believed to be the true strength of evidence.[13] (Stated another way, each juror has a probability $1-\pi$ of receiving a weak signal, $s_w < s_s$.) Thus, by allowing for binary heterogeneity, any number from zero to 12 of the jurors can end up with the strong signal.[14] Also, by using the binomial probability distribution, it is a simple task to calculate the probability of having a certain number of the 12 jurors receive the strong signal.[15]

A key aspect of our model is that all trial outcomes are driven by the strength of the evidence against the defendant. No juror completely ignores the evidence, and the signal a juror receives is directly related to the true strength of the evidence by the equation $s_s = s + x$ for the strong signal, and $s_w = s - y$ for the weak signal, with $x, y \geq 0$. A juror who receives the strong signal votes to convict if $s_s \geq s_I$, or when $s \geq s_I - x$ as in Fig. 1. Similarly, a juror who receives the weak signal votes to convict if $s_w \geq s_I$, or when $s \geq s_I + y$, as in Fig. 1. According to this formulation, a juror who receives the strong signal is more likely to believe that the defendant is guilty beyond a reasonable doubt than is a juror who receives the weak signal. Notice, however, that the stronger the true strength of the evidence, the stronger are *both* the strong and weak signals.[16]

2.3. Trial outcomes

If we consider a single trial and assume (for the time-being) a unanimous jury verdict rule, there are three possible trial outcomes: acquittal, conviction, and hung jury. An acquittal occurs if either the evidence is too weak to meet the perceived reasonable doubt standard for any juror regardless of his signal ($s < s_I - x$), or if all jurors receive the weak signal and the evidence is still sufficiently weak ($s < s_I + y$) as in Fig. 1. A conviction occurs if either the evidence is so strong that it exceeds the perceived reasonable doubt standard for any juror regardless of his signal ($s \geq s_I + y$), or if all jurors receive the strong signal and the evidence is still sufficiently strong ($s \geq s_I - x$), as in the figure. Thus, even with a unanimous

[13] We are not concerned with how the twelve jurors who end up hearing the case were selected, but how the final jury members decide the case based on several different jury rules.

[14] To be clear, π is not the proportion of jurors who end up receiving the strong signal. Instead, π is the probability that any given juror receives the strong signal.

[15] For example, with $\pi = 0.8$, using the binary probability distribution, the probability of having all twelve jurors receive the strong signal is 0.0687. The probability of having exactly nine jurors receive the strong signal is 0.2362, but the probability of having nine or more jurors receive the strong signal is 0.7946, etc.

[16] In Section 5 we explore an alternative source of juror heterogeneity in which all jurors agree on the strength of the evidence, perhaps because of deliberation, but potentially disagree about the reasonable doubt standard. The alternative source of heterogeneity yields the exact same results as our base model.

verdict rule, a conviction (or acquittal) does not require all 12 jurors to receive the same signal of the evidence: it simply requires a sufficiently strong (or weak) true strength of evidence.

For a hung jury to occur, two things must happen: (i) there must be some jurors who receive the strong signal and some who receive the weak one and (ii) the true strength of the evidence must be "close" to the reasonable doubt standard, that is, s must lie in the hung jury range $[s_I - x,\ s_I + y]$. Obviously, if all 12 jurors end up receiving the same signal, there is no final heterogeneity that can lead to a hung jury. With final juror heterogeneity and the true strength of evidence in the hung jury range, jurors who receive the strong signal vote to convict and those who receive the weak signal vote to acquit, resulting in a mistrial. Thus, in our model, it is a combination of juror heterogeneity and the strength of the evidence that affects the probability of ending with a hung jury. For a given case, if all 12 jurors vote to convict or acquit, unanimous verdict rules yield the same outcome as nonunanimous rules. For the nonunanimous rules to matter, then, the question that must be answered is: what would be the outcome of cases that end with a hung jury under a unanimous verdict rule if a nonunanimous rule was applied instead?

In examining rules that may reduce the probability of a hung jury, we argue that it is important to distinguish between rules that reduce that probability primarily in the first trial, versus rules that reduce that probability through successive trials. Consider the first trial. Assuming that the true strength of the evidence and the value of π do not depend on the verdict rule being used, when the evidence is in the hung jury range, a unanimous rule leads to a verdict whenever all 12 jurors receive the same signal (be it strong or weak). With a nonunanimous rule, 9-3 for example, a verdict is reached if only nine or more jurors receive the same signal. Thus, a nonunanimous rule leads to a higher probability of a verdict being reached because it reduces the constraining impact of final juror heterogeneity. But as more verdicts are reached, what happens to verdict accuracy? We will demonstrate that, compared to a unanimous rule, a nonunanimous rule increases the probabilities of correct verdicts (convictions and acquittals) *and* wrongful verdicts (convictions and acquittals) in the first trial.

In considering retrials with a specific verdict rule, such as a unanimous rule, the key difference between trials is that for any prior probability of guilt the defendant is assumed to have in the first trial, the posterior probability of guilt, given a hung jury, increases with each successive trial. Note from Fig. 1 that a guilty defendant is more likely to generate evidence between $s_I - x$ and $s_I + y$ (the hung jury range) than is an innocent defendant. The dark shaded triangle is the probability that an innocent defendant generates evidence in the hung jury range. The shaded trapezoid, which contains the dark shaded triangle, shows the probability that a guilty defendant generates evidence in the hung jury range. The difference in the sizes of the two regions results from the reasonable doubt standard. For a jury to be hung, the evidence must be close to the reasonable doubt threshold, s_I, and, by construction, guilty defendants tend to generate stronger evidence than innocent ones, so evidence near the reasonable doubt threshold is much more likely to come from a guilty defendant. In each retrial, the increase in the probability of guilt will affect the probabilities of the four verdict types. We will demonstrate that a unanimous jury rule, with retrials, tends to be more accurate than nonunanimous rules.

3. First trial unanimous verdict: a numerical example

In order to explore the implications of relaxing the unanimity requirement in jury trials, it is necessary to discuss the benchmark of unanimous verdicts in the first trial. The first trial has five possible outcomes: the conviction of a guilty defendant (correct conviction), the acquittal of an innocent defendant (correct acquittal), the conviction of an innocent defendant (wrongful conviction), the acquittal of a guilty defendant (wrongful acquittal), and a hung jury. The probabilities of these five outcomes are illustrated using a numerical example.[17] We use a numerical example for several reasons. First, although some of our main results are independent of the probability that a given juror receives the strong signal, π, some results are not, and this is most easily demonstrated using graphs from the example. Second, when we compare the outcomes of unanimous verdicts to the outcomes of nonunanimous ones, the binomial distribution changes in discontinuous ways, making comparative statics derivatives impossible. Third, when retrials are considered, the probability of guilt in each trial changes in nontrivial ways, making simple mathematical characterizations impossible. Finally, as shown in Section 5, our results are robust to the parameter choices.

We choose parameters that yield conviction, acquittal, and hung jury rates that approximate reality. In particular, studies suggest that hung jury rates are between 5% and 10%. Also, 82% of verdicts were convictions in California jury felony trials in fiscal year 2000–2001, and 69% of verdicts were convictions in Texas district and county courts in the same year, suggesting that the conviction rate could be in this range. To this end, we specify $P(G) = 0.8$, $s_G = 0.4$, $s_I = 0.6$, and $x = y = 0.05$. The strength of evidence hung jury range, then, is [0.55, 0.65]. The probability densities $f(s|I)$ and $f(s|G)$ are assumed to be linear with the specified horizontal intercepts. For unanimous verdicts, these parameter values lead to hung jury rates between 0% and 9% and conviction rates between 66% and 75%, roughly in line with the actual hung jury and conviction rates.

Fig. 2 shows the probabilities of the five possible outcomes of the first trial with unanimous verdicts (the curves labeled 12-0) as functions of π, the probability that a given juror receives the strong signal.[18] Beginning with hung juries, notice that hung juries are most likely when π is in the range [0.25, 0.75]. When the probability of a juror receiving the strong signal is in this range, it is unlikely that all 12 jurors will receive the same signal. If there are some of both types of jurors, the jury hangs whenever the evidence is in the hung jury range.[19] Also note that in our numerical example, the probability of a hung jury reaches a maximum at about 9% when $\pi = 0.5$.

In our example, the probability of wrongful conviction is very small—it is negligible until π rises above about 0.6, and it reaches a maximum at about 0.14% when the entire jury receives the strong signal with certainty ($\pi = 1$). A wrongful conviction occurs only

[17] Two other models that simulate the jury process with numerical examples can be found in Schwartz and Schwartz (1992), and Thomas and Pollack (1992). These models are very different than ours, even though some of the questions raised are the same. The most important difference is that our model assumes objective guilt or innocence, which allows for the use of an objective reasonable doubt standard, while the other models do not have objective guilt and innocence and so have endogenous reasonable doubt standards based on the views of a majority of the population.

[18] The other curves in Fig. 2 labeled 11-1, 9-3, and 7-5 will be discussed in the next section.

[19] From Fig. 1, the evidence is outside the hung jury range in 91% of the cases, independent of the value of π.

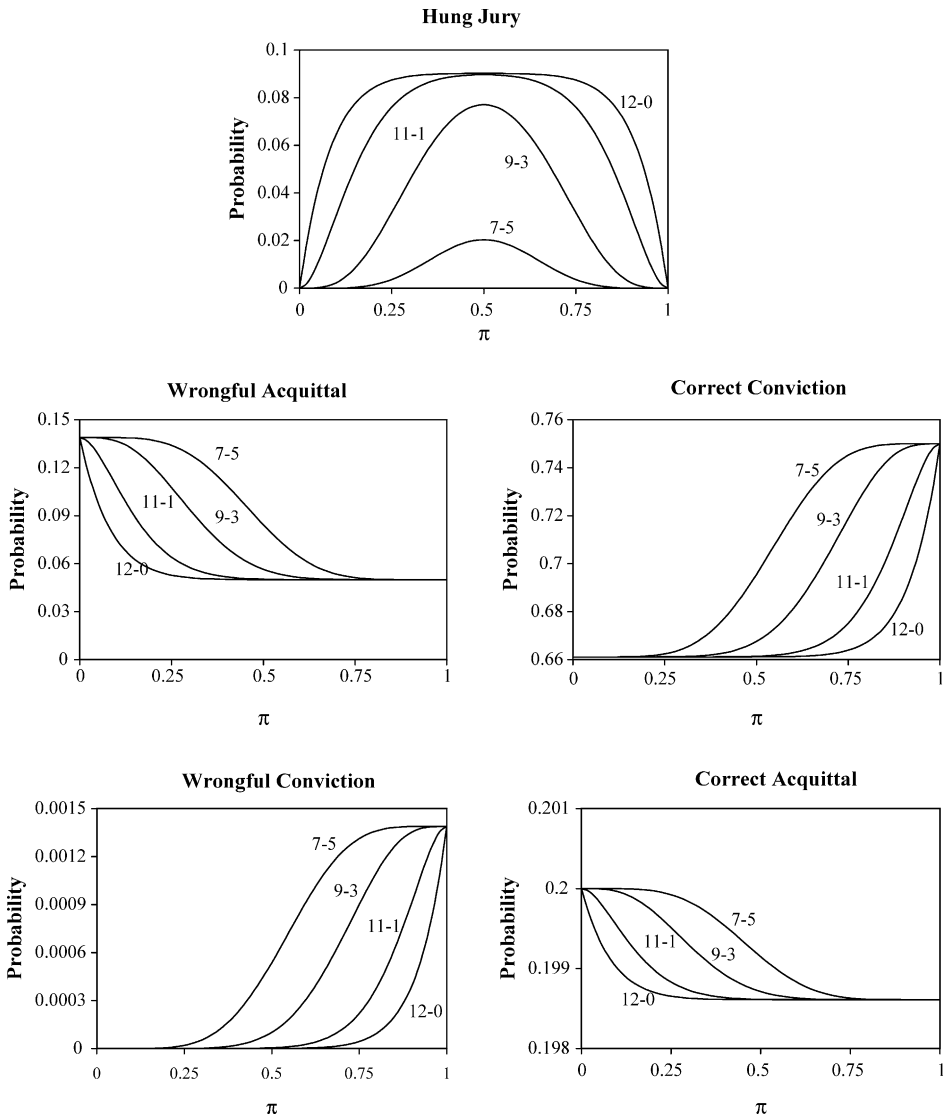

Fig. 2. The outcome of the first trial.

when the entire jury receives the strong signal and an innocent defendant generates evidence $s \geq s_I - x$. For our numerical example, the probability that an innocent defendant generates evidence in this range is 1/144, and the probability that a defendant is innocent is assumed to be 1/5, making the maximum probability of a wrongful conviction $1/720 \approx 0.14\%$. The minimum probability of a wrongful conviction is zero.

In comparison to wrongful convictions, the probability of a wrongful acquittal is quite high, ranging from 5% to 14%. Wrongful acquittals can occur for two reasons, either by a

guilty defendant generating evidence so weak that no one votes to convict, or by a guilty defendant generating evidence near the reasonable doubt standard and all jurors receiving the weak signal. Regarding the former, the probability that a guilty defendant generates evidence $s \leq s_I - x$ is 1/16, and the probability that the defendant is guilty is assumed to be 4/5, combining for a baseline wrongful acquittal probability of 5%. This number is independent of π because it arises from the evidence being too weak for *any* jury to convict. The second type of wrongful acquittals is added to this one, which is why the wrongful acquittal probability is higher when π is low (i.e. when jurors tend to receive the weak signal). In all, the reasonable doubt standard does a good job of reducing the probability of a wrongful conviction, but at the cost of increasing the probability of a wrongful acquittal.

The right-hand panels of Fig. 2 show correct verdicts. Recall that $P(G) = 0.8$, so the probability of a correct conviction cannot exceed 0.8, and $P(I) = 0.2$, so the probability of a correct acquittal cannot exceed 0.2. Also remember that the minimum probability for wrongful acquittals is 5%, so the maximum attainable value for correct convictions is 0.75. Variations in the probabilities of correct verdicts are caused by variations in hung jury probabilities, because when fewer cases hang there are more verdicts, some of which are correct. When π is in an intermediate range, the hung jury probability is high. When π is in the upper range, the hung jury probability is lower, and these additional verdicts are mostly convictions because jurors tend to receive the strong signal. Since most defendants who generate evidence in the hung jury range are guilty, most of these new convictions are correct. Thus, the correct conviction probability rises when π is large. For low levels of π, in contrast, most of the new verdicts are acquittals, leading to an increase in the correct acquittal probability.

Since the primary purpose of this paper is to address the outcomes of trials that would hang under a unanimity rule, the hung juries are worth a second look. In particular, it is worthwhile to determine the probability that the defendant in a hung trial is guilty, because if the case is retried, this is the prior probability of guilt in the second trial. As already mentioned, for our numerical example, the probability that an innocent defendant generates evidence in the hung jury range is 1/144. The probability that a guilty defendant generates evidence in the hung jury range is 1/9. So, a guilty defendant is 16 times more likely to generate evidence in the hung jury range than is an innocent one, and the lighter shaded region in Fig. 1 is 16 times larger than the darker shaded region. Furthermore, since the defendant is assumed to be guilty with probability 0.8, a random defendant is four times more likely to be guilty than to be innocent. Combining these establishes that a defendant in a hung trial is 64 times more likely to be guilty than to be innocent, yielding a probability of 1/65 of innocence and a probability of 64/65 of guilt.

The only difference between a retrial and the first trial is the initial probability of guilt. In the first trial, the probability of guilt is a parameter of the model, and is set to 0.8. For the second trial, the probability of guilt is determined from the probability that the defendant in a hung first trial is guilty, in this case 64/65. Because wrongful convictions must occur for innocent defendants, and the defendant is very unlikely to be innocent in a retrial, wrongful conviction probabilities are even lower in the retrial. On the other hand, wrongful acquittals occur for guilty defendants, and since almost all defendants in retrials are guilty, wrongful acquittals are more likely in retrials. Of course, so are correct convictions.

4. Eliminating hung juries

4.1. First trial nonunanimous verdicts

Now considering all the curves, Fig. 2 demonstrates the effects on the probabilities of interest of changing the unanimous verdict rule to several different nonunanimous rules.[20] One of the most common arguments in favor of nonunanimous rules is that they lower the probability of ending with a hung jury, and this is shown in the top panel of the figure. For all values of π, the probability of a hung jury continues to fall as we move from a unanimous verdict rule to 11-1, 9-3, and 7-5 rules. With a unanimous verdict rule, a hung jury occurs because the strength of the evidence is in the hung jury range and not all 12 jurors receive the same signal. As we weaken the unanimity requirement, the probability of having the appropriate number of jurors receive the same signal increases and, therefore, the probability of ending with a hung jury falls. With fewer hung juries there are more verdicts, and Fig. 2 shows that the probabilities of all four verdict types increase.

At extreme values of π, nonunanimous verdict rules quickly reduce the probability of a hung jury because of the increasing likelihood of having the appropriate number of jurors receive the same signal. The shapes of the four verdict curves can be explained in the following way: for high values of π, most of the new verdicts are convictions—correct and wrongful; for low values of π, most of the new verdicts are acquittals—correct and wrongful. As the unanimity requirement is weakened from 11-1 to 7-5, at middle values of π *both* types of verdicts occur more frequently.[21] Thus, the fewer jurors needed to reach a verdict in the first trial, the more verdicts there are–both correct and wrongful.

4.2. Retrials and eventual verdicts

In Fig. 3, the unanimous rule is once again compared to several nonunanimous rules in terms of the probabilities of the four types of verdicts. The difference between Figs. 2 and 3, however, is that in the latter figure it is assumed that a trial that ends in a hung jury is continuously retried until a verdict is eventually reached. Each eventual verdict curve is drawn assuming that whatever verdict rule is used in the first trial, the same rule is used in successive trials. As discussed in Section 2, the key element in our model with retrials is how the probability of guilt changes with each successive trial. For a jury to hang, the evidence must be in the hung jury range close to the reasonable doubt standard, and this evidence is more likely to be generated by a guilty defendant than by an innocent one.[22] This implies that in each successive retrial, the probability of guilt, given a previous hung jury, increases.

[20] To avoid clutter, we do not graph the nonunanimous rules 10-2 and 8-4.

[21] At middle values of π, moving from 11-1 to 7-5 increases the probability of having the appropriate number of jurors receive the *same* signal (be it strong or weak).

[22] Because a trial that ends in a hung jury must have evidence in the range $[s_I - x, s_I + y]$, it may be reasonable to consider a truncated distribution of the strength of evidence when considering a retrial. We, however, use the original distribution. After a case is litigated, both sides have new information about the trial strategies of their opponent. Thus, it is unclear how the strength of evidence in a retrial compares to the strength of evidence in the first trial. We did check the robustness of our results to using a truncated distribution of evidence for retrials. We found very little quantitative difference, and no qualitative difference, in our results.

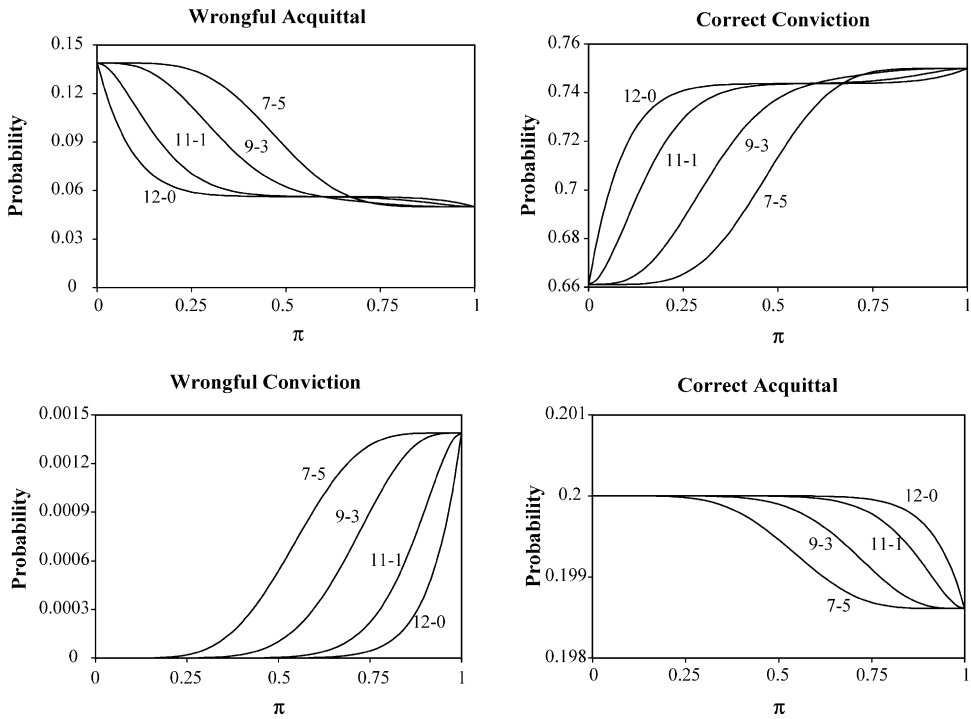

Fig. 3. The eventual outcome after retrials.

As the probability of guilt increases, the probabilities of correct and wrongful verdicts are affected.

One other distinction between Figs. 2 and 3 can be made. In Fig. 2, as hung juries are reduced with nonunanimous verdicts, the probabilities of *all* four types of verdicts can increase. In Fig. 3, however, because all the curves represent eventual verdicts, there are no hung juries at all. Thus, if a rule increases the probability of a wrongful acquittal, it must exactly offset a reduction in the probability of a correct conviction. Likewise, if a rule increases the probability of a wrongful conviction, it must exactly offset a reduction in the probability of a correct acquittal.[23]

Consider first the effects of reducing the unanimity requirement on the probabilities of wrongful convictions and correct acquittals (i.e. the final verdict for an innocent defendant). The nonunanimous rules, especially for high values of π, lead to higher probabilities of wrongful convictions and, therefore, lower probabilities of correct acquittals compared to the unanimous rule. In the first trial, weakening the unanimity requirement leads to more convictions that would have been hung under the unanimous rule. Even though a guilty defendant is more likely to generate evidence in the hung jury range, the unanimous rule

[23] The probabilities of wrongful acquittals and correct convictions offset each other because they both involve a guilty defendant. The probabilities of wrongful convictions and correct acquittals offset each other because they both involve an innocent defendant.

in effect protects the rare innocent defendant by creating the need for a retrial. And in the retrial, conditional on the defendant being innocent, it is very likely that he will be acquitted.[24] Thus, compared to nonunanimous rules, the unanimous rule with retrials leads to more accurate verdicts for the innocent defendant.

Now consider the effects of reducing the unanimity requirement on the probabilities of wrongful acquittals and correct convictions (i.e. the final verdict for a guilty defendant). For high values of π, nonunanimous rules, especially the 7-5 rule, lead to slightly lower probabilities of wrongful acquittals and, therefore, slightly higher probabilities of correct convictions. When π is high, the nonunanimous rules lead to more convictions in the first trial compared to the unanimous rule when the evidence is in the hung jury range. With a guilty defendant, therefore, the nonunanimous rules lead to more accurate verdicts. Eventually, the unanimous rule is also likely to lead to conviction, but with each successive retrial, there is a chance that a guilty defendant will be acquitted because the new evidence draw may be too weak. The nonunanimous rules do better in this case because they are likelier to convict in an earlier trial.

For moderate and low values of π, however, the nonunanimous rules do worse than the unanimous rule in terms of wrongful acquittals and correct convictions. When π is low, nonunanimous rules are likely to lead to an acquittal when the evidence is in the hung jury range, but a unanimous rule is likely to lead to a hung jury. With retrials, the unanimous rule has the ability to correctly convict a guilty defendant in a future trial because of the high probability of drawing sufficiently strong evidence in the retrial. In a sense, a unanimous rule is more patient with guilty defendants over a wide range of π. Also notice from Fig. 3 that while the nonunanimous rules do slightly better in terms of wrongful acquittals for high values of π, a unanimous rule can do substantially better for moderate and (especially) low values of π.

Taken as a whole, Fig. 3 demonstrates that a unanimous verdict rule tends to lead to more accurate verdicts than does a nonunanimous rule. At their best, for high values of π, nonunanimous rules lead to slightly lower probabilities of wrongful acquittals, but there is a tradeoff: in that same range of π, the lower probabilities of wrongful acquittals are offset by higher probabilities of wrongful convictions. Conversely, the moderate to low ranges of π do not involve the same sort of tradeoff. When the nonunanimous rules substantially increase the probabilities of wrongful acquittals, there is no offsetting reduction in the probabilities of wrongful convictions. Compared to a unanimous rule, the nonunanimous rules do no better, and often worse, in terms of wrongful convictions.

Other than the slight decrease in the probability of wrongful acquittals, perhaps the best argument that can be made in favor of nonunanimous verdicts is that they lead to more first trial verdicts, and (on average) to quicker verdicts in retrials.[25] To the extent that hung juries are costly, nonunanimous rules do lead to a reduction in that cost. Our model suggests,

[24] In a retrial, the innocent defendant is very likely to generate evidence below the hung jury range.

[25] The expected number of trials until a verdict is reached yielded by each verdict rule depends on the value of π. With $\pi = 0.5$ the probability of a hung jury is maximized. In this case, with a 12-0 unanimous rule the expected number of trials is approximately 1.1, and for a 9-3 nonunanimous rule, for example, it is approximately 1.08. At more extreme values of π, such as 0.25 (or 0.75), the expected number of trials for a 12-0 rule is still approximately 1.1, but for a 9-3 rule it is approximately 1.03.

however, that the savings in hung jury costs should be weighed against the costs of generally less accurate verdicts.

5. Robustness of the results

Since much of our analysis relies on a numerical example, it is important to explore its robustness to changes in the underlying assumptions. The model we use has six parameters: the prior probability of guilt $P(G)$, the magnitude of the error for the strong signal x, the magnitude of the error for the weak signal y, the endpoints of the two evidence distributions s_I and s_G, and the placement of the reasonable doubt standard. The example assumes $P(G) = 0.8$, $x = y = 0.05$, $s_I = 0.6$, $s_G = 0.4$, and the reasonable doubt standard is s_I. The basic result of the paper is the comparison between the unanimous verdict rule and the different nonunanimous rules. To demonstrate the robustness of the example to the parameter choices, we must show that the relative positions of the various curves in Fig. 3 are unaffected by parameter changes.

To do this it is expedient to characterize the incorrect verdicts from a single trial mathematically. To that end, let $F(s|I)$ and $F(s|G)$ be the cumulative distribution functions corresponding to the densities $f(s|I)$ and $f(s|G)$, respectively, and let $B(m, n, \pi)$ be the binomial probability of drawing at least m successes from a sample of n when the probability of a success is π. The probability of a wrongful conviction in a single trial when the majority requirement is m is

$$P(\mathrm{WC}, m) = P(I)[F(s_I|I) - F(s_I - x|I)]B(m, n, \pi). \tag{1}$$

More to the point, $P(\mathrm{WC}, m)/P(\mathrm{WC}, n) = B(m, n, \pi)/B(n, n, \pi)$, which is independent of the parameters of the model. So, if a nonunanimous rule yields more wrongful convictions for some parameter values, it does so for all parameter values.

Similarly, the probability of a wrongful acquittal in a single trial when the majority requirement is m is

$$\begin{aligned} P(\mathrm{WA}, m) = {} & P(G)F(s_I - x|G) \\ & + P(G)[F(s_I + y|G) - F(s_I - x|G)]B(m, n, 1 - \pi). \end{aligned} \tag{2}$$

The first term is the probability of a wrongful acquittal from the evidence being below the hung jury range, and the second is the probability from the evidence being in the hung jury range and enough jurors drawing the weak signal. Changing the majority requirement impacts only the second term. And, once again, the second term is larger for $m < n$ than it is for $m = n$ for all parameter values.

Before exploring the effects of changes in the parameter values, it is worth noting that Eqs. (1) and (2) could arise from a different model of the jury process. Suppose that all jurors agree on the strength of the evidence, perhaps as a result of deliberation, but that they may disagree about the reasonable doubt standard. More concretely, suppose that a fraction π of the jury pool has a low reasonable doubt standard, $s_I - x$, and is therefore more prone to convict the defendant, and the remaining fraction $1 - \pi$ has a high reasonable doubt standard, $s_I + y$, and is thus more prone to acquit. Letting $F(s|I)$ and $F(s|G)$ be the distributions of

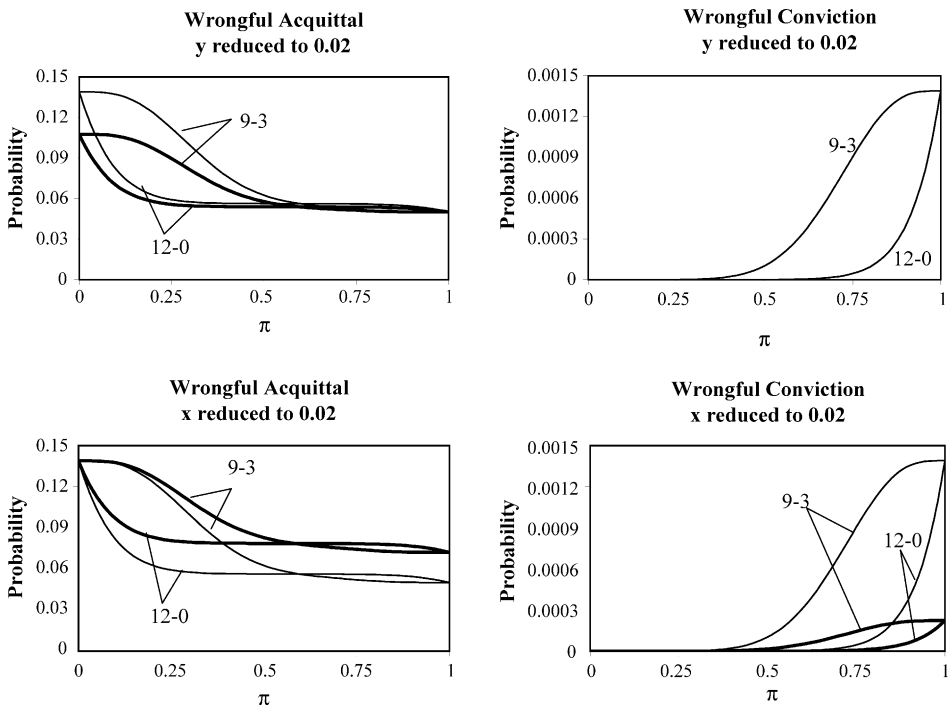

Fig. 4. Robustness of eventual trial outcome to parameter changes.

the evidence generated by an innocent defendant and by a guilty defendant, respectively, the formulas for the probabilities of wrongful convictions and wrongful acquittals are once again given by Eqs. (1) and (2).

It remains to show that the comparisons between unanimous and nonunanimous verdict rules in the original numerical example are robust to parameter changes when hung cases are retried. Fig. 4 illustrates the effects of changing the magnitudes of the signal errors. The graphs in the left column show the effects on the wrongful acquittal probabilities, comparing a unanimous verdict rule to a 9-3 majority rule, and those in the right column show the effects on the wrongful conviction probabilities.[26] The top row shows the effects of lowering y without changing x, and the bottom row shows the effects of reducing x without changing y.

In the top row of graphs, only the magnitude of the weak signal error is changed. This leads to no change in the probability of a wrongful conviction, because wrongful convictions require that jurors receive the strong signal, not the weak one. Reducing y means that jurors receiving the weak signal vote to acquit over a smaller range of evidence (as can be seen with the aid of Fig. 1), which reduces the probability of a wrongful acquittal. In the bottom row of graphs, only x changes. Reducing x makes the strong signal weaker, and reduces the range of evidence over which a juror receiving the strong signal votes to convict. Because

[26] Fig. 4 excludes the graphs for correct acquittals and correct convictions.

of this, convictions become less likely and acquittals become more likely, both correct ones and incorrect ones. Accordingly, the wrongful conviction curves fall when x is reduced and the wrongful acquittal curves rise.

What is important for establishing the robustness of the numerical example, though, is how the relative positions of the unanimous-rule and nonunanimous-rule curves change when the parameters change. Fig. 4 shows that even though changing the parameters can change the position and scale of the pairs of curves, it does not change the relative positions. So, changing x and y does not change the fact that the unanimous rule outperforms the nonunanimous rules in wrongful convictions for the entire range of π and also in wrongful acquittals for the moderate to lower range of π in which the weak signal, and therefore wrongful acquittals, are likely to be prevalent.

As for the prior probability of guilt, raising $P(G)$ reduces the probability of wrongful convictions because a defendant must be innocent to be wrongfully convicted, but it increases the probability of wrongful acquittals because defendants are more likely to be guilty. It also increases the probability of a hung jury in the first trial because guilty defendants are more likely to generate evidence in the hung jury range. Still, even though changing the prior probability of guilt changes all of the curves, it does not change the relative positions of the unanimous and nonunanimous curves, so it does not affect our conclusions.

For the remaining parameters of interest, changing s_I, s_G, or the reasonable doubt standard all have two effects. First, they change the probability with which a guilty defendant generates evidence below the hung jury range, so they change the minimum probability of wrongful acquittals. Second, they change the probability of guilt conditional on the evidence being in the hung jury range, which also changes the mixture of wrongful convictions and wrongful acquittals. However, the relative positions of the unanimous and nonunanimous wrongful conviction curves, and the relative positions of the unanimous and nonunanimous wrongful acquittal curves, do not change, and so our results continue to hold.[27]

6. A comparison with the strategic voting literature

Our primary result, that when all hung cases are retried unanimous verdicts generally provide more accuracy than nonunanimous ones, contrasts sharply with Feddersen and Pesendorfer's (1998) results from their analysis of strategic voting. In their analysis, weaker majority requirements outperform stronger ones, with unanimous verdicts performing worst of all. To understand why the results differ, we must first explain their model in some detail. They assume that there are 12 jurors, each of whom receive a signal of the defendant's guilt or innocence, with guilty defendants most likely to generate signals of guilt and innocent

[27] Another robustness check involves not the parameters, but the model itself. Instead of having two possible signals, one stronger than the true evidence and one weaker, it is possible to consider a model that has a third type of signal that is perfectly accurate. Doing so would, in general, increase the correct verdict probabilities, since jurors receiving the accurate signal would always vote the correct way, and incorrect verdicts could only occur when none of the jurors receive the correct signal. However, the comparison of the incorrect verdict probabilities under the different voting rules remains unchanged, since they depend on the probabilities of jurors getting one or the other of the incorrect signals.

defendants most likely to generate signals of innocence. Jurors then vote simultaneously without knowing the other jurors's signals, and the defendant is convicted if and only if a majority k of the jurors vote to convict. In other words, if the defendant is not convicted he is acquitted, and there are no hung juries. Since jurors vote simultaneously, in Nash equilibrium they should vote under the assumption that their votes are pivotal; i.e. they should vote as if $k-1$ other jurors are voting to convict, so that an additional vote to convict results in a conviction, and another vote to acquit results in an acquittal. This works because if the voter is wrong about being pivotal, his assumption that he is pivotal has no impact on the verdict.

When jurors assume they are pivotal, it gives them a strong predisposition to vote to convict no matter what the signal is, especially under unanimity. When there are 12 jurors, a juror is pivotal only if all eleven other jurors vote to convict. If all of them received the guilty signal, it makes it very likely that the defendant was guilty, and these eleven guilty signals may outweigh the juror's own signal. Of course, if he receives a guilty signal himself, he will vote to convict, but if he receives an innocent signal he may still vote to convict.

Feddersen and Pesendorfer restrict attention to circumstances under which jurors' strategies are responsive, that is, the juror's voting rule depends on the signal he receives, and they also restrict attention to circumstances under which sincere voting is not a Nash equilibrium. Both of these are restrictions on their reasonable doubt standard. Since voting cannot be sincere, and since all jurors receiving the guilty signal vote to convict, jurors receiving the innocent signal can neither always vote to convict (which would make the strategy unresponsive) nor always vote to acquit (which would make the strategy sincere). So, they must employ a mixed strategy.

For a juror receiving the innocent signal to use a mixed strategy, he must be indifferent between voting to convict and voting to acquit. For this to occur, it must be the case that as the number of votes required for conviction rises, so does the probability that a juror receiving the innocent signal votes to convict. Consequently, Feddersen and Pesendorfer get the result that as the majority requirement becomes stricter, jurors receiving the innocent signal are more likely to vote to convict. At the same time, as the majority requirement becomes stricter, the jury is less likely to contain enough jurors who have received the guilty signal. So, as the majority requirement becomes stricter, wrongful acquittal probabilities rise because of juror heterogeneity, and wrongful conviction probabilities also rise because jurors receiving the innocent signal are more likely to vote to convict.

Our model differs from their strategic voting model in two important ways. First, in our model jurors vote sincerely, not strategically. Second, a failure to convict does not necessarily imply an acquittal. This matters because as Coughlan (2000) shows, when k jurors must vote to acquit for an acquittal to occur, Nash equilibrium implies sincere voting in a broad range of circumstances. To see why, when a majority of k is required for either a conviction or an acquittal, a juror can be pivotal in two ways: either $k-1$ other jurors are voting to convict, or $k-1$ jurors are voting to acquit. So, being pivotal does not provide very much information, and the juror votes according to his signal. In fact, Coughlan's analysis justifies our assumption of sincere voting. As we show, once voting is sincere, all that is left for governing wrongful verdict probabilities is juror heterogeneity and the probability of guilt across retrials, and our analysis shows that reducing the unanimity requirement generally reduces the accuracy of verdicts.

7. Concluding comments

In this paper, we develop a model of a criminal trial that identifies two main factors behind a trial ending in a hung jury. First, there must be juror heterogeneity to account for jurors not unanimously agreeing with each other. Second, the true strength of the evidence against the defendant must be "close" to the reasonable doubt standard. When the evidence is close to the reasonable doubt standard, jurors who receive the strong signal of evidence vote to convict the defendant, and those who receive the weak signal vote to acquit. With very strong evidence, all jurors, regardless of their heterogeneity, vote to convict the defendant; with very weak evidence, all jurors vote to acquit. Thus, all trial outcomes are driven by the strength of the evidence.

A nonunanimous verdict rule, by reducing the impact of juror heterogeneity, leads to more first trial verdicts than does a unanimous rule. However, we demonstrate that the nonunanimous rule leads to more of each of the four types of verdicts in the first trial—correct and wrongful convictions and correct and wrongful acquittals. As hung cases are retried, the main difference across trials is the defendant's probability of guilt. Because the strength of the evidence must be sufficiently high for a trial to hang, it is much more likely that a hung jury occurs for a guilty defendant than for an innocent one. Verdict accuracy, in turn, depends on the probability of guilt and the verdict rule used.

When allowing for eventual verdicts through repeated retrials, we identify one advantage in terms of verdict accuracy of a nonunanimous rule over a unanimous rule: a nonunanimous rule leads to a slightly lower probability of a wrongful acquittal when the probability of a juror receiving the strong signal of evidence, π, is sufficiently high. In this same range of π, however, a nonunanimous rule also leads to a higher probability of a wrongful conviction. For moderate to low values of π, a nonunanimous rule does no better than a unanimous rule in terms of wrongful convictions, but does much worse in terms of wrongful acquittals. In this range of π, many first trial acquittals with a nonunanimous rule are wrongful. Had these same cases hung under a unanimous rule, it is extremely likely there would have been a future correct conviction for the guilty defendant. While it is true that a nonunanimous rule can save on hung jury costs, it generally does so at the expense of less accurate verdicts.

One other factor that can be taken into account when considering a nonunanimous verdict rule is how such a rule may circumvent prosecutorial discretion. In our model, all hung juries are retried until a verdict is reached. In practice, however, a case that ends with a hung jury may be retried, dismissed, or reach its final disposition through a plea bargain.[28] It is the prosecutor that plays the largest role in determining the final disposition of a case. To retry or dismiss a case after it has hung can be solely the prosecutor's decision, and a plea bargain at least requires his approval. If there is a case that a nonunanimous rule would resolve, yet a unanimous rule would lead to a hung jury, the nonunanimous rule in effect replaces the discretion of the prosecutor in deciding how best to proceed.

[28] In an exhaustive study of hung juries, Hannaford-Agor, Hans, Mott, and Munsterman (1999) present some evidence on post-hung jury dispositions. Using 453 hung jury cases between 1996 and 1998, they find that 31.8% of those cases were resolved by plea agreements, 21.6% were dismissed, 32.0% were retried as jury trials, 2.4% were retried as bench trials, and 12.2% had other dispositions.

To thoroughly deal with the tradeoffs involved between prosecutorial discretion and nonunanimous rules in dealing with hung juries, a social objective must be identified. Although beyond the scope of this paper, some brief comments can be made. It is unlikely that a criminal trial social loss function and a prosecutor's objective function are identical.[29] A prosecutor, by law, must only prosecute defendants believed to be guilty. Thus, a wrongful conviction to a prosecutor may be considered a personal victory, just as a correct acquittal may be considered a personal loss. As for hung jury costs, even though a prosecutor who retries a case does not bear the full costs of the retrial, budgetary constraints may impose hung jury costs on individual prosecutors. Finally, there may be little difference between prosecutorial discretion and a nonunanimous rule if the decision to retry or dismiss a case that has hung depends on the number of jurors who voted to convict in the initial trial.[30] If, for example, the prosecutor is implicitly using his own decision rule that he retry every case that initially had at least a 9-3 majority to convict (if that information is attainable), and dismiss every case that initially had at least a 9-3 majority to acquit, replacing the unanimous rule with a 9-3 nonunanimous rule would have minimal effect on the final disposition of the case.

In all, because there is currently a mechanism that allows for discretion in dealing with hung juries, the desirability of a nonunanimous verdict rule is weakened. If the prosecutor's objective function diverges wildly from some social objective function, there may be a sound argument in limiting prosecutorial discretion. But even in this case, the ability of nonunanimous verdict rules to lead to accurate verdicts is in question. A tradeoff between hung jury costs and verdict accuracy exists when considering unanimous versus nonunanimous verdict rules.

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[29] A common social objective in the economic literature on criminal trials is to minimize the expected wrongful verdict costs. See Rubinfeld and Sappington (1987), Schrag and Scotchmer (1994), Feddersen and Pesendorfer (1998), and Coughlan (2000). Neilson and Winter (2000) also include an expected hung jury cost in the social loss function. Also, for a complete discussion of the comparison between wrongful conviction and wrongful acquittal costs, see Volokh (1997).

[30] Flynn (1977, p. 134) briefly discusses some evidence on the relationship between the number of jurors initially voting to convict and the final disposition of the case.

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