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Perspective

Elections, information aggregation, and strategic voting

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A central role of elections is the aggregation of information dispersed within a population. This article surveys recent work on elections as mechanisms for aggregating information and on the incentives for voters to vote strategically in such elections.

Elections have two distinct roles in society. First, they serve as a mechanism to decide policies when individuals disagree about appropriate actions. Second, they aggregate information dispersed in the population. This second role can be found even in situations where all individuals agree on the appropriate policies. The focus of this essay is on information aggregation in elections and on the incentives private information creates for strategic behavior by voters.

As an illustration, consider a jury in a criminal trial. All jurors agree that the defendant should be convicted if guilty and acquitted if innocent. However, jurors may have different information about the guilt or innocence of the defendant. This informational difference may come about because each juror has a different area of expertise that allows her to evaluate some of the evidence more effectively. By voting, a jury may aggregate this information and collectively reach a better decision than any individual juror could.

The idea of viewing elections as devices to aggregate information goes back to Condorcet (1) and has generated substantial literature (2–5). The basic insight of this literature may be summarized as follows. Assume that each juror votes to convict with probability P_G if the defendant is guilty and with probability P_I if the defendant is innocent and that, conditional on the guilt of the defendant, the behavior of jurors is independent. The assumption of independence captures the idea that jurors have private information that the election might aggregate. Let q be the fraction of voters required for conviction. If $P_G>q>P_I$, then under the rule requiring a q fraction to convict, a large jury will convict a guilty defendant and acquit an innocent one with probability close to one. However, if $q>P_G$, then even large juries may acquit the guilty. Similarly, if $q<P_I$ then large juries may convict the innocent. For a general heterogeneous population, necessary and sufficient conditions for information aggregation are described in ref. 2.

By changing q in the example above, we can change the frequency of each error. For example, requiring a supermajority to convict the defendant will reduce the probability of convicting an innocent individual. This model then provides a rationale for the requirement of unanimous jury verdicts as a rule that minimizes the probability of convicting innocent defendants (6).

Recent work (7–9) has shown that the behavioral assumption at the foundation of Condorcet's analysis, that voters will reveal their private information through their vote, is inconsistent with individual optimizing behavior. The following example illustrates this behavior.

Strategic Voting in Juries

Suppose there are n jurors who must vote to convict or acquit a defendant in a criminal case. *Ex ante*, the defendant is equally likely to be guilty or innocent. Each juror privately and independently observes a "signal." A signal should be interpreted as evidence of the defendant's guilt or innocence. To simplify matters, we assume that the signal may take on one of two values: g (guilty) or i (innocent). Suppose that, when the defendant is guilty, each juror independently observes a signal g with probability 0.8 and signal i with probability 0.2, whereas, when the defendant is innocent, the probabilities are reversed. Note that different jurors receive different signals and hence may have different views as to the guilt or innocence of the defendant. The probability the defendant is guilty conditional on a guilty signal is

$$(0.8)(1/2)/[(0.8)(1/2) + (0.2)(1/2)] = 0.8. \qquad \textbf{[1]}$$

Conversely, if the juror receives the innocent signal then this probability is

$$(0.2)(1/2)/[(0.2)(1/2) + (0.8)(1/2)] = 0.2. \qquad \textbf{[2]}$$

The probability the defendant is guilty, conditional on k jurors of n jurors receiving guilty signals, is given by the formula

$$\beta(k,n) = 0.8^k 0.2^{n-k}/[0.8^k 0.2^{n-k} + 0.2^k 0.8^{n-k}]. \qquad \textbf{[3]}$$

How should a juror vote in this setting? Suppose that each juror prefers conviction if she believes that the defendant is guilty with probability greater than 0.7. We refer to this as the "threshold of reasonable doubt." The optimal voting behavior in a jury with one member is for the juror to vote to convict when she observes the guilty signal and vote to acquit otherwise. This behavior is optimal, because the probability the defendant is guilty when the juror observes the guilty signal is 0.8 (and therefore above the threshold of reasonable doubt) and 0.2 when she observes the innocent signal. We refer to this rule as "naive voting," because it corresponds to the optimal rule of a juror who believes she alone determines the outcome. Naive voting also corresponds to the behavioral assumption in the Condorcet-inspired literature cited above. The following example shows that naive voting may not be optimal in larger juries.

Suppose there are three jurors who each observe one signal (g or i as described above). Consider the problem facing a juror who has observed the innocent signal and knows the other two jurors are voting naively. Under the unanimity rule, if either of the other jurors has voted to acquit then the juror's vote does not change the outcome. The juror's vote changes the outcome only in the event that the other two have voted to convict. Therefore, the juror, when deciding how to vote, should assume that the other two have voted to convict even if she thinks that event unlikely. Because the other two jurors are voting naively, she should assume, therefore, that two of three

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signals were guilty. According to the formula above $\beta(k = 2, n = 3) = 0.8$. Because her threshold of reasonable doubt is 0.7, this juror strictly prefers to vote for conviction even when she observes the innocent signal. Naive voting by all jurors is therefore inconsistent with juror incentives in this example. On the other hand, naive voting is consistent with majority rule in this example, because, in the event a vote is pivotal, the remaining two jurors must have observed different signals.

The key to understanding voter incentives is that a vote matters only when it is pivotal. If other voters are voting on the basis of their private information, it follows that the event of a vote being pivotal reveals some of this information. Strategic voters must take into account not only their private information but also the information revealed by the event that a vote is pivotal.

Alternate Models of Voter Behavior

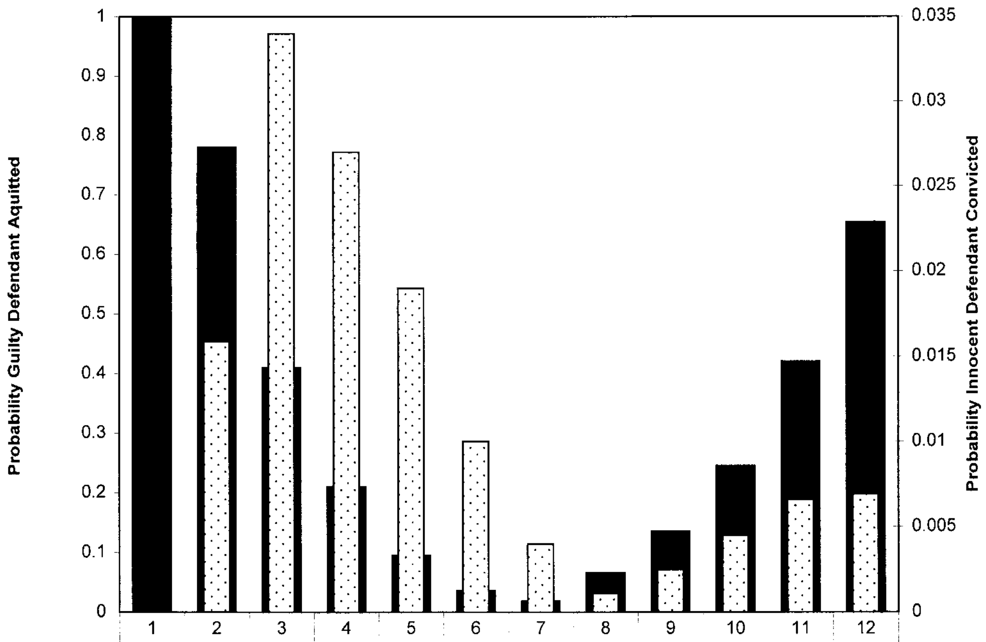
If not all jurors reveal their information through their vote, then some information will not be reflected in the ultimate outcome of the election. This raises questions about the performance of different electoral rules when jurors do not behave naively. To address these questions, it is necessary to develop an alternative model of voter behavior. Researchers have developed this alternative by modeling the situation described above as a game among the jurors and using the tools of game theory. Specifically, behavior that constitutes an equilibrium of the game will be consistent with individual incentives in the sense that every juror behaves optimally given the behavior of every other juror. Nash equilibrium is the standard concept by which games such as this one are analyzed. (For an introduction to game theory, see refs. 10 and 11.) Voting behavior that is an optimal response to the behavior of the other jurors is called strategic voting.

Under strategic voting, the information-aggregation properties of elections change. In some settings, information may not be aggregated at all (7), whereas, in other environments, strategic voting actually reduces error probabilities (see refs. 12 and 13).

Strategic voting also changes the way that electoral rules trade off error probabilities. For example, under the assumption of naive voting, the unanimity rule minimizes the probability of convicting an innocent defendant. Strategic voting causes the unanimity rule to result in much higher probabilities of convicting innocent defendants than other rules (14). The intuitive reasoning behind this result is that strategic voters compensate for the bias introduced by the voting rule and are more likely to vote to convict. In particular, they vote to convict when observing a guilty signal and randomize between voting to convict and voting to acquit when observing an innocent signal. As a result, even in a large jury, the probability of convicting an innocent defendant must stay bounded away from zero.

How does the unanimity rule compare with other rules? Fig. 1 illustrates the error probabilities for a 12-person jury with a threshold of reasonable doubt equal to 0.9 under various voting rules (14). Note that the error probabilities of convicting an innocent and acquitting a guilty defendant are higher for the unanimity rule than for simple majority rule (where seven or more jurors are required to convict). A rule that requires eight or more jurors to vote to convict provides optimal protection to an innocent defendant, while also generating a positive probability of convicting a guilty defendant. The probability of convicting an innocent defendant is minimized when—counterintuitively—the rule requiring only a single vote to convict is used. In fact, the defendant is never convicted. When no juror votes to convict, then, under this rule, a vote is always pivotal. Therefore, a juror with signal g concludes that the defendant is guilty with probability 0.8 if her vote is pivotal. Because this probability is smaller than the threshold of reasonable doubt (0.9), acquittal is optimal. Finally, the probability of convicting an innocent defendant reaches a maximum when only 3 of the 12 jurors are required to convict.

These calculations show that, when incentives of jurors are properly taken into account, some of the "natural" implications of voting rules may be wrong. For example, unanimity is no longer the rule that guarantees small probabilities of convicting innocent defendants. More generally, voters may have incentives to withhold private information and thereby reduce the information-aggregation potential of elections. On the other hand, large



	1	2	3	4	5	6	7	8	9	10	11	12
■ Guilty Defendant Acquited	1	0.78	0.41	0.21	0.095	0.036	0.019	0.066	0.135	0.245	0.42	0.654
□ Innocent Defendant Convicted	0	0.0159	0.034	0.027	0.019	0.01	0.004	0.0011	0.0025	0.0045	0.0066	0.0069

FIG. 1. Equilibrium error probabilities in a 12-person jury with a threshold of reasonable doubt of 0.9 as a function of the number of votes needed to convict.

elections still provide good information aggregation, provided the rule does not require unanimity or near unanimity.

New Directions

The research on strategic voting in elections with private information is now moving in several directions. The basic question of how elections aggregate information is being broadened to include sequential and multialternative elections. The behavioral implications of the strategic-voting model are being fleshed out and tested empirically in laboratory settings. Finally, the policy implications of the results on unanimity rule have led to more realistic models of actual jury trials and a broader inquiry into the interaction of voting rules with incentives to acquire and convey information. In this section, we conclude our essay by discussing some of the directions the research is taking.

One feature of the above example was that jurors vote simultaneously. Clearly, in real world situations, votes are often conducted openly and some individuals may wait to see how others have voted. In some situations, sequential voting may improve the information-aggregation properties of elections (E. Dekel and M. Piccione, unpublished work). However, strategic-voting behavior may remain the same when voting is sequential (E. Dekel and M. Piccione, unpublished work). This result is surprising, because later voters have observed the choices made by earlier voters and, hence, seem to have more information. However, in symmetric environments, this informational difference is irrelevant, because all strategic voters condition their vote on being pivotal. The information contained in being pivotal includes all the information that came before.

In the above discussion, it was assumed that voters had to choose which of two alternatives to vote for. A natural extension is to allow voters to abstain as well. Less well informed voters may have a strict incentive to abstain to avoid adding noise to the election outcome (8). Such strategic abstention can occur in a wide variety of settings, in a manner consistent with empirically observed participation patterns (15).

Does strategic voting occur in the real world? Strong evidence for strategic voting in a laboratory setting has been found by R. D. McKelvey and T. R. Palfrey (unpublished work). These experiments also point out that subjects make errors. Actual behavior is consistent with the hypothesis that each juror plays optimally against the strategies used by other players plus a random error. Other laboratory experiments have been conducted (K. Ladha, G. Miller, and J. Oppenheimer, unpublished work) that reinforce these findings.

The work on the unanimity rule discussed above suggests that requiring unanimous verdicts in jury trials is counterproductive. Recent work has focused on modeling jury trials more accurately. Two features of actual jury trials, mistrials and deliberations, have been examined by P. Coughlan (unpublished work). Mistrials may overturn some of the results on jury voting. Consider a setting where a unanimous verdict is required either to convict or to acquit. If no unanimous decision is reached—a mistrial—then a new trial is conducted. In this setting, naive behavior may be an equilibrium and both types of errors are minimized under the unanimity requirement. In a mistrial system, a voter can be pivotal either when all other jurors vote to convict *or* when all other jurors vote to acquit. Thus, even if other jurors vote naively, a juror cannot infer that the defendant is guilty with high probability if her vote is pivotal. Therefore, naive voting is compatible with incentives for a wide range of parameters (P. Coughlan, unpublished work).

Nevertheless, the mistrial system with the unanimity requirement uses information inefficiently. Consider a mistrial system in which the expected number of signals needed to reach a verdict is m. A jury of size m using simple majority rule will produce lower probabilities of both types of errors than those generated by the mistrial system.

In the simple model above, all jurors shared a common threshold of reasonable doubt. In such a setting, there is an easy way to circumvent incentive problems caused by the unanimity rule: jurors reveal their private information to one another before voting. Indeed, real jury trials often include a period of deliberations in which exactly such an exchange of information is expected to take place. It has been shown (P. Coughlan, unpublished work) that, if juror preferences are sufficiently similar, deliberations can completely overcome the problems introduced by different voting rules, essentially making the voting rule irrelevant. However, in laboratory experiments (R. D. McKelvey and T. R. Palfrey, unpublished work), deliberations do not entirely eliminate strategic-voting behavior. General models of the interaction of deliberation and voting with significant preference diversity remain to be analyzed.

The demonstration that voters have an incentive to behave strategically in elections with private information raises important questions about the performance of a variety of institutions ranging from jury trials to large elections. Although the initial results in the strategic-voting literature are striking and, in the case of the unanimity rule in criminal trials, very disturbing, it is premature to suggest changing such institutions. In particular, the simple demonstration that private information creates incentives for strategic voting only scratches the surface. Clearly, we must be concerned with the interaction between voting rules, communication among voters before voting, and the incentives various voting rules create for voters to acquire information in the first place. For these reasons and others, the current game-theoretic voting models can serve only as a point of departure for more comprehensive formal and empirical analyses that focus on these relationships and that may ultimately lead to proposals for reform.

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