Get Out the (Costly) Vote: Institutional Design for Greater Participation

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Abstract. We examine two commonly discussed institutions inducing turnout: abstention penalties (used in 32 countries) and lotteries rewarding one randomly chosen participant (as proposed on the 2006 Arizona ballot). We analyze a benchmark model in which voters vary in their information quality and participation is costly. We illustrate that both institutions can improve collective outcomes, though lotteries are a more effective instrument asymptotically. Experimentally, we provide strong evidence for selective participation: lab voters participate more when better informed or when institutionally induced. Lotteries fare better than fines, suggesting that they may be a useful alternative to commonly used compulsory voting schemes.

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1. Introduction

Institutions designed to induce greater participation have a long legacy in countries all over the world. Belgium has the oldest existing compulsory voting system, introduced in 1892 for men and in 1949 for women. Over the years, 31 countries had followed suit, instating sanctions for political abstention. Nowadays, 19 countries have de-facto punishments for non-participation. While western countries without mandatory voting exhibit what are perceived as rather low turnout rates (e.g., in the U.S., since 1970, election turnout has been between 50%-55% during presidential election years, and between 35%-40% during non-election years), countries with some abstention sanctions unsurprisingly show rather high participation rates, with turnout often exceeding 90%, regardless of GDP per capita.[1]

While participation is at the core of democracy, there is an ongoing debate in the political sphere as to the value of institutions designed to uniformly increase participation. On the one hand, having a greater fraction of the population participate in the political decision-making process is considered more democratic. On the other hand, there is concern that introducing fines for abstention, or prizes for participation would induce the "wrong" voters to show up at the booth. That is, if participation is costly, only sufficiently informed voters would find it worthwhile to vote. Rewarding participation essentially lowers this cost, thereby inducing less informed voters to vote as well. Thus, from an information point of view, there is an underlying trade-off. More voters imply more pieces of information being communicated. However, the additional information may be of lower quality, and suddenly gain greater voice in determining electoral outcomes.

Our goal is to provide a theoretical framework for discussing the trade-offs inherent in increased participation. In addition, we test predictions on both behavior and institutional performance using controlled laboratory experiments.

Specifically, as a benchmark model, we consider an information aggregation setup in which a majority election determines which of two alternatives will be collectively implemented. Each individual receives some private information regarding which is the superior alternative. The accuracy

[1] See https://www.cia.gov/library/publications/the-world-factbook/ and http://www.idea.int/vt/compulsory _voting.cfm.

of individual signals is randomly distributed. After the private signal and its accuracy are realized, each voter decides whether to abstain or cast a costly vote, where the cost of participation is fixed and uniform across all voters.

The first step in our analysis is to characterize equilibria in such environments. Symmetric equilibria in this setup take a simple form of threshold strategies. That is, each individual has a cutpoint accuracy such that they vote if and only if the accuracy of their private signal surpasses that cutpoint, thereby generating a form of *selective participation*. Voting in this setup is a form of public good and, as is common in such setups, voters do not internalize "enough" the positive externality of voting. When the electorate is large enough, there is less voting than is socially optimal.

When the state has some funds to allocate to elections, a natural way to encourage participation is to consider the optimal (welfare maximizing) mechanism, subject to a budget constraint determined by these funds. The optimal mechanism of this sort entails payment schemes to voters that are contingent on the full tally of votes. Such mechanisms are rarely observed in reality. However, sanctions that are tantamount to fines are used in countries with compulsory voting and lotteries amongst participants had been suggested (e.g., Proposition 200 on the Arizona November 2006 ballot suggested entering primary and election day voters in a lottery for a $1 million prize). More generally, the use of lotteries to collect funds targeted at public goods is both common empirically and theoretically justified.[2] The next step in our theoretical analysis is to illustrate the potential merit of such institutions in voting contexts.

Our results show that while fines and lotteries are effective in increasing the accuracy of collective decisions, they are not equally beneficial. Fines essentially reduce the cost of participation. They therefore lead voters to participate more frequently. Nonetheless, any fixed level of per capita fine does not eliminate the free rider problem inherent in our setting. As the electorate grows large, less and less agents participate and the probability the electorate makes the wrong decision given the overall amount of information voters have is bounded above zero.

Lotteries, on the other hand, introduce a negative externality to the act of voting. Indeed,

[2] For instance, from Douglas (1995), in 1992, among 26 reporting states approximately $6 billion were raised through lotteries by private charities. See Morgan (2000) for references, as well as for a theoretical and empirical investigation of such scenarios.

whenever a voter participates, she reduces the probability that another voter who turns out wins the lottery. As it turns out, per capita fixed lotteries can be effective at solving the free rider problem and, in the limit, majority elections aggregate information completely (in particular, the electorate makes the correct decision with near certainty).

Testing empirically for the performance of these institutions is both incredibly important and inherently difficult. Private information, as well as preferences, are very hard to control in the field, and some institutions (such as lotteries) have not yet been put to practice so data would be impossible to collect without the introduction of dramatic institutional shifts. Laboratory experiments are useful in that they provide a highly controlled environment in which we can test for the effectiveness of different institutions in both inducing more turnout, as well as increasing the overall welfare of election outcomes.

In an array of experiments, we test the performance of simple majority, as well as simple majority combined with (theoretically optimal) fines for abstention or (theoretically optimal) prizes, in the form of a lottery for participation. In our experiments, we use two notions of optimality – welfare (voters' payoffs not including payoffs from lotteries or fines), and efficiency (the accuracy of the ultimate decision).[3]

We obtain several conclusions. First, we find confirmation of the theoretical prediction that voters will participate selectively: lab voters' behavior is consistent with threshold strategies under all three types of institutions. Second, the empirical comparative statics follow our theoretical analysis. In particular, institutions that are constructed to induce greater participation are effective in doing so. Third, precise levels of voting do not match the theoretical predictions. Specifically, subjects consistently over-vote. Fourth (and consequently), the welfare and efficiency implications the theory suggests are not matched in our data. In fact, the baseline treatment in which no fines or lottery prizes are present generates very good relative results for both welfare and efficiency. Furthermore, lotteries provide significant improvements over fines in terms of both welfare and efficiency.

Thus, the experimental results suggest that institutions designed to stimulate participation are

[3] Efficiency may be the appropriate notion for cases in which a small group of experts determines outcomes that affect a large population (as may be the case in, e.g., political decision making processes in which a handful of politicians, the decision makers, determines outcomes for a large number of people).

effective in doing so. In addition, lotteries may be a useful instrument for collective choice environments. Nonetheless, the impact these institutions have may be hindered by voters' tendencies to over-participate.

Methodologically, while our model fares rather well in illustrating individual *patterns* of participation, it does not do very well in predicting precise *levels*, which are crucial for welfare and efficiency of institutions. In particular, the rational choice model may benefit from some modification in order to predict the relative performance of institutions.

Political participation has been a topic of much research. Some of the original work focused on the factors that determine participation and highlighted the fact that demographic characteristics such as race, gender, and socioeconomic status play an important role (Verba and Nie, 1972, Wolfinger and Rosenstone, 1980, and Verba, Shlozman and Brady, 1995). In recent years, political scientists have recognized that increasing voter turnout may indeed have a downside if it lowers the average quality of participants (Verba, 2004).

The rational choice paradigm has opened the door to thinking of voting institutions as providing a strategic structure to be analyzed with game theoretic tools (see, e.g., Austen-Smith and Banks, 1996 and Feddersen and Pesendorfer, 1996, 1998). Related to one of the insights of the current paper, Feddersen and Pesendorfer (1996) consider differentially informed voters and illustrate how less informed voters may abstain in equilibrium, even when participation is free. An important conceptual difference between their environment and that of costly participation arises when looking at aggregate *outcomes* for the electorate. While with free information large elections generate outcomes close to the collective optimum, when information is costly, the quality of the collective decision is bounded away from the optimum (see our Proposition 2). In terms of institutional design this insight is of tremendous importance. Indeed, when participation is free, for sufficiently large elections, even simple majoritarian rules may fare very close to the ideal institution. In contrast, when participation is costly, alternative institutions may in principle improve welfare in a significant way.

Most of the theoretical literature pertaining to costly voting has focused on equally informed voters and is broadly divided into work studying elections with private values (so that elections aggregate *preferences*) and work studying voting with common values (so that elections aggregate *information*). Borgers (2004) considered simple private value majoritarian elections with costly participation and illustrated the superiority of voluntary voting to mandatory voting institutions.[4] When voters have common preferences, as in our setting, Ghosal and Lockwood (2009) show that majority voting with compulsory participation can Pareto dominate majority voting with voluntary participation.

Empirical evidence regarding the effectiveness of voter mobilization has focused on estimating the effect of voter mobilization tactics such as phone banking, leafleting, and door-to-door canvassing.[5] There is also some empirical support for a relationship between voters' information and their turnout decision. Lassen (2005) analyzes data from a natural experiment, finding that districts where voters were more informed about the effects of decentralization (due to randomly being selected for a pilot program), were more likely to turn out to vote in a decentralization referendum. Oberholzer-Gee and Waldfogel (2009) find that introducing local Spanish-language news increases turnout of Hispanic voters by a statistically significant and large amount. These studies suggest that providing voters with better (local) information makes them more likely to participate politically.

Experiments have recently been used to analyze voting behavior. Indeed, Guarnaschelli, McKelvey, and Palfrey (2000) and Goeree and Yariv (2011) illustrated strategic voting in the laboratory.[6] Related to the current paper, Battaglini, Morton, and Palfrey (2010) consider an information aggregation setup and illustrate the difference between simultaneous and sequential institutions when voting is costly. Lastly, Klor and Winter (2007) study private value setups and test for the effects that information regarding the electorate's preferences has on voters' costly turnout decisions and consequent welfare. They suggest the limitations of the canonical pivotal voting calculus.[7] For an

[4]When preferences are heterogeneous, Goeree and Grosser (2007), as well as Taylor and Yildrim (2010), illustrate that institutions that affect participation in an indirect way such as polls, revealing information regarding the realized preference composition of voters, may be welfare reducing, since they stimulate minorities to participate "too much". Agranov, Goeree, Romero, and Yariv (2015) illustrate that, experimentally, polls exhibit no such detrimental effects.

[5]A variety of randomized field experiments have documented that door-to-door canvassing and volunteer phone banking are particularly effective means of mobilizing voters, while leaflets and pre-recorded phone calls are less effective (Gerber and Green, 2000, 2001 and Gerber, Green, and Nickerson, 2003, and some differing implications in Imai, 2005).

[6]Battaglini, Morton, and Palfrey (2007), as well as Morton and Tyran (2011), provided further evidence for strategic voting in small groups, illustrating how uninformed voters abstain more frequently and give the decision power to those who are informed.

[7]Without participation costs, Feddersen, Gailmard, and Sandroni (2009) analyze and experimentally test a model in which some voters are "ethical expressive" and enjoy voting for an alternative they find morally superior. The existence

overview of some of the recent voting experiments, see Palfrey (2006).

The paper is organized as follows. Section 2 spells out the benchmark model and Section 3 provides the main theoretical insights on individual behavior and the value of participation inducing institutions (proofs are relegated to an Appendix). Section 4 describes our experimental design, while Section 5 describes the experimental observations, in terms of both behavior and collective outcomes. Section 6 concludes.

2. Theoretical Framework

2.1 The Model

Consider a group of $N = 2n+1$ individuals (subjects, voters, jurors, etc.) who collectively choose one out of two alternatives, $\{red, blue\}$ (this can serve as a metaphor for choosing one of two political candidates, convicting or acquitting a defendant, and so on). Our underlying setup is reminiscent of the standard jury model (see, e.g., Austen-Smith and Banks, 1996 or Feddersen and Pesendorfer, 1998). At the outset, a state of nature is chosen randomly from $\{R, B\}$ (indicating, e.g., which of two political candidates is more competent, or whether the defendant is guilty or innocent). The two states are equally likely. All individuals have identical preferences depending on the state of the world and the chosen alternative as follows:

$$\begin{array}{ll} u(red \mid R) = 1 & u(red \mid B) = 0 \\ u(blue \mid R) = 0 & u(blue \mid B) = 1 \end{array}$$

Individuals all receive some information before the election takes place and vary in the accuracy of their information (a metaphor for different levels of education, heterogeneous access to media, etc.). Formally, prior to casting votes, each agent i observes a signal that is determined in two stages. First, the accuracy of the signal $q_i \in \left[\frac{1}{2}, 1\right]$ is determined through a cumulative distribution function F with density f independently across agents. Second, agent i observes a conditionally

of such voters can help explain what would appear as excessive voting relative to the model in which there are no such effects.

independent signal $s_i \in \{\rho, \beta\}$ of accuracy q_i. That is,

$$\Pr(s_i = \rho \mid R) = \Pr(s_i = \beta \mid B) = q_i.$$

Each agent's accuracy and signal realization are private information.

After observing their private information, agents decide whether to cast a costly vote or abstain. That is, each agent can decide on an action $v \in \{r, b, a\}$, where actions r or b entail a cost of $c \in (0,1)$. The group choice is determined by simple majority. That is, if the majority of cast votes are r (b), then the group choice is *red* (*blue*). Ties are broken randomly (with equal probabilities).

To summarize, each agent i, selecting action v_i, receives a utility $U(A, v_i \mid \omega)$, where $A \in \{red, blue\}$ is the collective choice and $\omega \in \{R, B\}$ is the underlying state, specified as follows:

$$U(A, v_i \mid \omega) = \begin{cases} 1 & A = red, v_i = a, \omega = R, \text{ or } A = blue, v_i = a, \omega = B \\ 1 - c & A = red, v_i \neq a, \omega = R, \text{ or } A = blue, v_i \neq a, \omega = B \\ 0 & A = red, v_i = a, \omega = B, \text{ or } A = blue, v_i = a, \omega = R \\ -c & A = red, v_i \neq a, \omega = R, \text{ or } A = blue, v_i \neq a, \omega = B \end{cases}.$$

2.2 Institutions Designed to Increase Participation

We focus on two types of mechanisms that are intended to induce participation and have been considered in practice:

1. **Participation Lottery:** After agents make their action choices, an amount $m \geqslant 0$ is given to a randomly picked agent from the set of agents who had participated, i.e., chose one of the costly actions r or b.

2. **Abstention Fine:** Choosing the action a entails a cost (the abstention fine) of $f \geqslant 0$.

Note that the crucial difference between these two types of mechanisms is that under the participation lottery, the "price" of participation relative to abstention is a function of other participants' actions and therefore determined endogenously. In contrast, in the presence of abstention fines, the relative "price" of participation is $c - f$.[8]

We assume that any additional transfers ($-f$ or m) are added linearly to agents' utilities. Lotteries have been used extensively for charitable giving around the world (see Morgan, 2000). In the context of collective choice, they have recently been discussed in the U.S. as an institutional innovation. Technically, we stress that risk neutrality implies that an equivalent institution would be one in which a reward m would be split equally among all those participating in the election.

In principle, for any given budget and social welfare valuation (e.g., the probability that the final collective decision matches the state), one can characterize the optimal mechanism. Such a mechanism would potentially associate messages from agents regarding the accuracy of their signals and their realizations to action recommendations (abstain, vote r, or vote b) and transfers. Optimal mechanisms can then involve rather complex payment schedules. In order not to deter from the main point of the paper, we do not pursue this type of analysis.

2.3 Strategies and Equilibrium

A strategy is a mapping $\sigma : \left[\frac{1}{2}, 1\right] \times \{\rho, \beta\} \rightarrow \Delta\{r, b, a\}$, which associates a probability of participating and voting for red or blue, or abstaining, for each signal accuracy and realization. Our analysis focuses on *symmetric* Bayesian Nash equilibria in weakly undominated strategies. All equilibria of this type are characterized by threshold strategies, in which the voter chooses thresholds $\hat{p}_\rho, \hat{p}_\beta \in \left[\frac{1}{2}, 1\right]$, then votes according to her signal (that is, chooses r when observing ρ and chooses b when observing β) if the information quality is higher than the threshold $\hat{p}_s$ and the signal is $s \in \{\rho, \beta\}$, and abstains otherwise. Since our problem is symmetric, we will assume that agents use identical thresholds, i.e., that $\hat{p}_\rho = \hat{p}_\beta \equiv \hat{p}$ (this simplifies our presentation but does not restrict any of our qualitative results). In our setup, equilibria exhibit simple *selective participation*: an individual participates (and votes for her preferred alternative) if and only if the accuracy of her information is sufficiently high.

Suppose all voters but one use a threshold of p, and denote the last voter's expected utility

[8] In our setup, an abstention fine is equivalent to a reduction of the costs of voting that, in practice, can also be easily achieved, say, by abolishing registration requirements.

from voting and following her signal when her own signal accuracy is p by $\tilde{u}(v,p)$, and her expected utility from abstaining when her own signal accuracy is p by $\tilde{u}(a,p)$. Define the benefit function $B(p) = \tilde{u}(v,p) - \tilde{u}(a,p)$. An equilibrium threshold is identified with a level p^* that makes voters indifferent between voting and abstaining, i.e., for which $B(p^*) = 0$.

The function $B(p)$ is continuous in p. Consider the two extremes of $p = \frac{1}{2}$ (corresponding to voting regardless of the accuracy realization) and $p = 1$ (corresponding to voting with probability 0). If $B\left(\frac{1}{2}\right) \geqslant 0$, then using the threshold $\frac{1}{2}$ is a best response when all other agents use the threshold $\frac{1}{2}$. Else, $B\left(\frac{1}{2}\right) < 0$. Now, either $B(1) \leqslant 0$, in which case using the threshold 1 is a best response when all other agents use the threshold 1. Otherwise, $B(1) > 0$. But, if $B\left(\frac{1}{2}\right) < 0$ and $B(1) > 0$, the Intermediate Value Theorem would assure the existence of $p^* \in \left(\frac{1}{2}, 1\right)$ for which $B(p^*) = 0$. It therefore follows that a symmetric Bayesian equilibrium in weakly undominated strategies always exists, as summarized in the following proposition.

Proposition 1 (Existence) *For all costs c, fines f, and lotteries m, there exists at least one equilibrium threshold p^* that satisfies $B(p^*) = 0$.*

Note that the Proposition is sufficiently general to encompass any of the specific voting institutions we consider for a proper choice of the lottery parameter m, the fine parameter f, and the cost parameter c.

3. Theoretical Implications

We take an institutional design perspective and, therefore, our ultimate goal is to inspect the potential usefulness of policy instruments designed to increase participation. In equilibrium, there is an externality that voters do not internalize. A voter's action (a vote in favor of a certain alternative or abstention) determines the quality of the final decision. This, in turn, affects the welfare of all other voters. The following numerical example (that will later be used for our experimental design) is helpful in illustrating the effects of this externality.

Example Let the number of voters be $N = 5$, the cost of voting $c = 0.1$, and the distribution over accuracies uniform over $\left[\frac{1}{2}, 1\right]$. Then, welfare (expected accuracy of the decision minus the

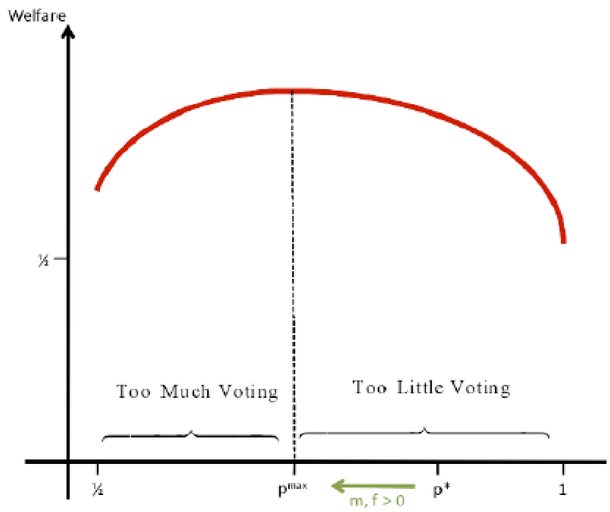


Figure 1: Voting Frequency and Welfare

expected expenditure on participation) per individual as a function of the electorate's threshold takes an inverted U-shaped form (see Figure 1, and note that when the electorate's threshold is 1, the expected welfare per person is $\frac{1}{2}$ since no one votes with certainty). The optimal level of voting can then be calculated to be $p^{\max} = 0.76$. Nonetheless, the unique equilibrium threshold is $p^* = 0.87$.[9] In particular, in equilibrium there is not enough voting (i.e., voters do not internalize "enough" the positive externality of voting), as highlighted in Figure 1. Imposing positive fines or lottery levels increases the incentives to participate, and can therefore assist in terms of expected welfare. In fact, choosing a lottery prize of $m = 0.2$ or a fine level of $f = 0.08$ can generate the optimal level of participation $p^{\max}$.[10] A similar image emerges when one plots the corresponding efficiency curve (corresponding to the expected accuracy of the collective decision, ignoring information costs, which may be particularly relevant in situations in which only a small group of agents can participate and bear the voting costs, while the election outcome affects many more). In that case, the optimal efficiency maximizing threshold can be calculated to be $p_{eff}^{\max} = 0.69$ and implemented with a lottery prize of $m = 0.3$.

[9] This, in fact, identifies a unique symmetric equilibrium.

[10] As stressed, this ignores the direct effects of fines or lottery prizes on expected utility.

The above example is useful for our experimental investigation. In what follows, we inspect the generality of its main insights regarding the positive impacts of fines and lottery prizes.

Since most real-life institutions designed to increase participation pertain to large elections, and the study of large elections is easier to present, we concentrate our analysis on the asymptotic effects of fines and lottery prizes.[11]

Given an equilibrium threshold p_n, let $\Pr(W, n, p_n)$ denote the probability that the final collective decision is wrong when the state is R. From symmetry, this probability coincides with the probability of the final collective decision being wrong when the state is B. Note that the expected efficiency (per individual) of the election would then be $1 - \Pr(W, n, p_n)$.

With an electorate of $N = 2n + 1$ voters playing the equilibrium characterized by p_n, an agent who receives a signal of accuracy p_n is indifferent between voting, thereby incurring the cost of c, and abstaining. Intuitively, if $\Pr(W, n, p_n)$ became very small for large n, this would suggest that the electorate approximates the optimal (full information) choice and at some point the value of voting would fall below the cost of c for any accuracy. It follows logically that the sequence $\Pr(W, n, p_n)$ is bounded above zero. Formally,

Proposition 2 (Asymptotic Mistakes) *Suppose that $f = m = 0$. For any sequence of equilibrium thresholds $\{p_n\}$,*

$$\lim_{n\to\infty} \inf \Pr(W, n, p_n) \geqslant c.$$

Proposition 2, the proof of which appears in the Appendix, suggests a conceptually different picture than that emerging in the world in which participation is free (a-la Feddersen and Pesendorfer, 1996). Indeed, (common value) free participation models usually imply that when the electorate becomes very large, the probability of choosing the full information optimal alternative becomes arbitrarily close to 1 (i.e., there is complete information aggregation asymptotically). This insight is rather sensitive to the introduction of voting costs. When participation is costly, Proposition 2 indicates that there is significant room for improvement over the strategic voting game outcomes even

[11] Technically, this eases dramatically our exposition since equilibrium multiplicity can occur for intermediate electorate sizes. Dealing with such cases requires additional care that would deter from the main goal of the paper.

when the electorate is very large. Lotteries and fines are potential instruments for such improvements.

In the example above, as illustrated in Figure 1, a threshold not matching the optimal one, $p^{\max}$ or $p_{eff}^{\max}$, implied the threshold utilized was either too low and there was excessive participation (in which case increasing participation would not be beneficial), or the threshold was too high (in which case inducing more participation would be useful).

Note that absent fines or lottery prizes, and for any set of parameters, as the electorate becomes large equilibria thresholds must approach 1. Otherwise, if thresholds were bounded below some value, say $\bar{p} < 1$, then as the population grew, a simple law of large numbers would assure that the electorate would approach the right decision, which would then imply that the marginal effect of one vote would ultimately be lower than its cost $c > 0$. Thus, as the electorate grows large, each individual's likelihood of participation approaches 0. From Proposition 2, the growing number of participants does not fully counteract the reduction in participation of each individual and the accuracy of decisions is bounded above.

Certainly, imposing a fine that is greater than the participation costs, $f > c$, or a lottery prize that covers the cost in expectation, $m > Nc = (2n + 1)c$, would induce all voters to participate in equilibrium. Since the expected signal accuracy of each voter is greater than $\frac{1}{2}$, a simple law of large numbers would then assure that asymptotically, the electorate would achieve the optimal full information decision and generate a better outcome than that absent any fines or lottery prizes.

We start with the case of fines. The example illustrated the potential usefulness of fines for small groups of voters. For large electorates, recall that a fine $f \in (0, c)$ effectively reduces the cost of participation to $f - c$. We can therefore use Proposition 2 to deduce that as long as the fine is fixed below the cost c, asymptotic mistakes are bounded above 0 (though the lower bound decreases). Namely,

Corollary (Limited Effects of Fines) *Fix $f \in (0, c)$ and let $m = 0$. For any sequence of equilibrium thresholds $\{p_n\}$,*

$$\lim_{n\to\infty} \inf \Pr(W, n, p_n) \geqslant c - f.$$

In particular, fines may be useful for small groups, but when capped, cannot eliminate mistakes altogether even when the electorate is unboundedly large.

Interestingly, lotteries are a more useful instrument in that respect. Unlike fines, lotteries introduce a negative externality in our setup. Indeed, in the presence of lotteries, when an individual participates, they reduce the chance of each other participant to receive the lottery prize. This negative externality counterbalances the positive externality that is inherent in the underlying environment. In fact, it turns out that even when lotteries are not so high as to get everyone to vote, they can be high enough to induce a positive fraction of the population to vote even in large electorates. Consequently, for large enough electorates sufficient information can be transmitted in equilibrium. The following proposition formalizes this result.

Proposition 3 (Positive Effects of Lotteries) *Fix $z \in (0, c)$. For every n, let $m_n = (2n+1)z$ denote the prize of the lottery and suppose $f = 0$. There exists a sequence of equilibrium thresholds $\{p_n(m_n)\}$ such that*

$$\lim_{n\to\infty} \Pr(W, n, p_n(m_n)) = 0$$

The proof of Proposition 3 appears in the appendix. The proposition illustrates the increased efficiency of elections even when lottery prizes are not so high as to force everyone into voting always (regardless of signal accuracy).[12]

As mentioned above, while we presented lotteries in a very pure way, namely one voter receiving all of the rewards, an equivalent way to think about our model (when payoffs are linear in money) would be to fix the total amount of rewards (at a level lower than $(2n+1)c$) and split it across all participants. Such an institution would generate identical equilibrium thresholds to those analyzed for the case of lotteries and, in particular, yield complete information aggregation asymptotically.[13]

[12] An interesting extension to the model would entail budget caps on lottery expenditures. In order to maintain a focused discussion, our current setup is designed to serve as a convenient benchmark for some empirical/experimental testing.

[13] The negative externality imposed would then translate to the reduction one voter's participation creates in the (certain) reward each other participant receives.

To summarize, there are several insights our theoretical analysis highlights. First, symmetric Bayesian Nash equilibria in weakly undominated strategies are identified by threshold strategies. Second, fines and lotteries induce agents to participate and can improve welfare and efficiency in small electorates (generating similar levels of both). Last, for very large electorates, lotteries are more effective than fines in eliminating asymptotic mistakes.

We now turn to our experimental design, mimicking the example above, and inspect both voters' behavioral responses to different institutions, as well as the outcomes these institutions generate.

4. Experimental Design

The theoretical model was tested in a laboratory experiment using groups of size 5. The states and the quality of information were emulated in the experiment as follows:[14]

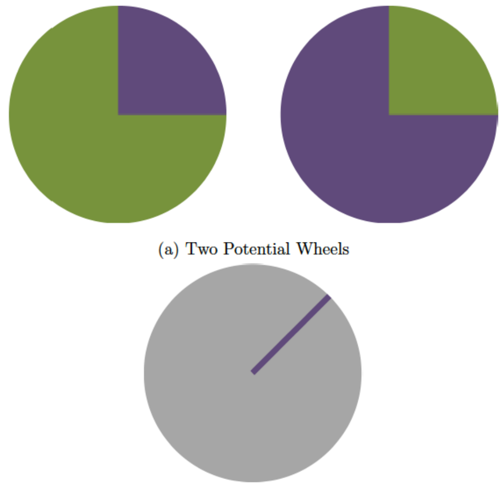
Determining States Each of the two states was a colored pie called a green wheel and a magenta wheel.[15] Each wheel consisted of a slice of green and magenta color. The green wheel had a larger green slice and the magenta wheel had, symmetrically, a larger magenta slice (of identical size to the green slice on the green wheel).

Information Generation The size of the dominant slice was randomly chosen *independently for each subject in the group* uniformly between 50 and 100 at the outset. Each subject knew the size of the dominant slice corresponding to their green and magenta wheel (provided both graphically, as in Panel (a) of Figure 2, and numerically), but not which of the wheels would be relevant for their decision. The wheel's dominant color was then randomly chosen by the computer, *for the entire group.* Therefore, the prior of each wheel being the relevant one was $\frac{1}{2}$. Each subject, not knowing which of the two possible wheels had been chosen, could spin their own relevant wheel and observe a thin slice of color, as in panel (b) of Figure 2.[16] Note that, while the dominant color of the wheel was shared within the group, the size of the dominant

[14] The full experimental instructions are available at: http://participates.googlepages.com/

[15] While red and blue were convenient colors to use for our model and stress the potential political application, in the experiment we aimed at maintaining the decisions free of political content, so as not to confound the induced preferences with subjects' ideological affiliations, and hence chose green and magenta as state indicators.

[16] The spinning was done so that the location of the thin slice itself would not be suggestive of which wheel had been chosen.



(a) Two Potential Wheels

(b) Private Signals

Figure 2: States and Information

slice was not. The size of the dominant slice determined the individual signal accuracy.[17] The larger the dominant slice, the more accurate the individual signal. Everything was transparent to the subjects. To iterate, subjects were told that the computer would randomly choose one dominant wheel color for their entire group. They were also informed that other subjects in their group would have a different randomly chosen accuracy of information for the signal that they receive (different sized slices of green and magenta on their wheels).

Voting After observing their private information, subjects could each choose (simultaneously) to vote for the green wheel, the magenta wheel, or abstain.

In all of our treatments the value of matching the group choice with the actual color generated 100 points, which translated into \$1, and the cost of participation was fixed at 10 points, or \$0.10.

In the **Baseline** treatment, no fines or lotteries were introduced. Assuming that voters use symmetric equilibrium strategies, we derived predictions for the theoretical welfare levels (the sum of utilities from correct decisions minus the expected cost of voting) and resulting efficiency (the

[17]For instance, suppose a subject's wheels were identified by a large slice of size 75% and a smaller slice of size 25% (as in Figure 2(a)). Then, observing a thin cut in the color of magenta (as in panel (b) of Figure 2) would suggest a posterior of 75% that the common dominant wheel color in the group is magenta.

	Parameters			Theoretical Predictions		
Treatment	Cost (c)	Lottery (m)	Fines (f)	Cutpoint	Efficiency	Welfare
Baseline	c=10	m=0	f=0	87	0.85	82.3
Efficiency Max Lottery	c=10	m=30	f=0	69	0.91	84.9
Welfare Max Lottery	c=10	m=20	f=0	76	0.90	85.5
Welfare Max Fine	c=10	m=0	f=8	76	0.90	85.5

Table 1: Parameters and Theoretical Predictions

share of correct decisions) when voters use the optimal cutpoint under different levels of fines and lotteries, tracking the Example of Section 3 above. For the **Efficiency Maximizing Lottery** treatment, we chose the lottery parameter that maximizes theoretical efficiency. That is, we chose the lottery size that maximizes efficiency, assuming that subjects follow equilibrium strategies. Similarly, we chose a parameter for the lottery and fine that maximize the theoretical welfare levels in the **Welfare Maximizing Lottery** and **Welfare Maximizing Fine** treatments, respectively. Our experimental parameters were designed to determine whether theoretically optimal institutions generate optimal outcomes, taking into account the equilibrium effects of voting incentives on average information quality. The parameters and theoretical predictions for each of the four treatments are summarized in Table 1.

We implemented a combination of within subjects and across subjects design. Subjects participated in multiple rounds of the same treatment, allowing a comparison of the cutpoints of subjects across experiments. In each experiment, groups of five subjects were randomly assigned. The same group of five was maintained throughout the experiment. With the exception of one experiment where only one treatment was implemented, each experiment consisted of two sessions of 15 rounds each and each session implemented a different treatment. The sessions began with a practice round that allowed subjects to ask questions.[18]

A total of 60 subjects recruited from a major U.S. university participated in the experiments. Table 2 summarizes the implementation of each of the four treatments in the order they were

[18] We observed no significant order effects and so in the sections that follow, we report results aggregating sessions corresponding to the same treatment (and return to this point when discussing individual cutpoints).

First Session	Second Session	# of Subjects	# of Decisions	Average Payoff
Baseline	—	15	225	$12.55
Baseline	Efficiency Max Lottery	15	450	$26.02
Efficiency Max Lottery	Welfare Max Fines	15	450	$23.46
Welfare Max Fines	Welfare Max Lottery	15	450	$22.54

Table 2: Experimental Sessions

implemented including the total number of subjects and periods played in each experiment. The baseline payments received by subjects are also summarized, to which $5 were added for participation. Total payments ranged from a minimum of $15.12 to a maximum of $31.80.

5. Experimental Results

In analyzing the results of the experiments, we first examine whether subjects' behavior is consistent with the use of a threshold strategy as predicted by our equilibrium analysis, and the extent to which subjects respond to institutional incentives. We next present the experimental impacts of fines and lotteries on welfare. Finally, we analyze some of the dynamic aspects of our data.

5.1 Strategic Behavior

In what follows, we start by describing briefly the aggregate attributes of the data, and continue with describing the analysis of the individual level data.

Aggregate Data

We first look at the relationship between signal accuracy and the decision to vote over all treatments. Figure 3 plots aggregate participation frequencies as a function of signal accuracy. The emerging pattern suggests a rather strong correlation between information quality and the likelihood of participation, if not a crisp step function as would be suggested by a uniform threshold across the population.

Individual Level Analysis

In order to assess whether subjects indeed use threshold strategies, we estimate individual thresholds, or cutpoints, using the classification scheme proposed by Levine and Palfrey (2007). For any

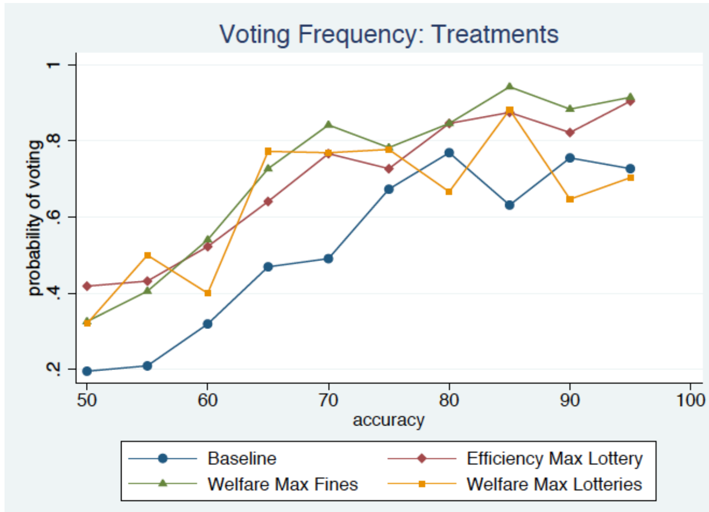


Figure 3: Voting Frequency

specified threshold, a *classification error* for an individual is defined as an event in which the subject voted when their signal accuracy was below the specified threshold, or abstained when their signal accuracy was above that threshold. The *estimated threshold* is the threshold that minimizes the overall classification errors. If there is more than one threshold that minimizes the classification errors, the estimated threshold chosen is the average of the highest and lowest feasible thresholds. Cutpoint strategies are estimated for each individual in each treatment.[19]

The examination of estimated cutpoints suggests that subjects' behavior is close to the theoretical predictions and follows the expected comparative statics. Table 3 shows summary statistics on estimated individual cutpoints and classification errors for each of the four treatments. The table also shows the theoretically predicted cutpoints. A t-test is used to compare the average cutpoints in each of the four treatments to their theoretical predictions. The comparative statics are as predicted by the theory. We see that lottery prizes as well as fines do produce a change in behavior; observed thresholds are lower on average than they are in the baseline treatment. However, while voters do appear to use threshold strategies, their identified thresholds are lower than the theoretical benchmarks, implying that subjects are voting more often than predicted by the theory.[20] The difference between average

[19]Therefore, most individuals will have two different cutpoints, one for each of the treatments they participated in during an experiment.

[20]We can rule out that our subjects are making decisions completely naively. A benchmark for naive behavior is

Treatment	Predicted	Mean	Std Err	Mean Classification Error	N
Baseline	87	71.2	2.60**	1.8	30
Efficiency Max Lottery	69	63.2	2.10**	1.2	30
Welfare Max Lottery	76	63.6	3.68**	2.5	15
Welfare Max Fines	76	60.0	1.71**	1.3	30

an individual in a session constitutes an observation
t-test of difference from theoretical prediction: ***=1% , **=5%, *=10%

Table 3: Estimation of Cutpoints

cutpoints and predicted cutpoints is statistically significant in all treatments.[21] Furthermore, each of the three mobilization treatments have cutpoints that are significantly lower than the baseline treatment but not significantly different from each other.

As mentioned, we varied the order of the implementation of the treatments in our experiments so as to identify the existence of possible order effects. We find no evidence of statistically significant differences in cutpoints for treatments conducted in different orders. Comparing the differences in average cutpoints for the efficiency maximizing lottery after the baseline and before the welfare maximizing fines yields a t-statistic of -0.75. A test for differences in cutpoints in the welfare maximizing fines treatment conducted after the efficiency maximizing lottery and before the welfare maximizing lottery treatments corresponds to a t-statistic of 0.61.

There is considerable individual heterogeneity in individual thresholds in all of the treatments. Figure 4 shows the empirical distribution function of estimated cutpoints for all of our treatments. While there are few classification errors for the average subject, most subjects are well classified; 65% can be classified with at most one error.

that subjects only consider their own decisions and not the actions of others. The optimal threshold for a single person casting a vote can be calculated to be 0.6. The baseline threshold of 0.71 observed in our experiment is substantially higher than this naive benchmark.

[21] We also consider thresholds over the last five periods only, to allow for the possibility that it takes some time for subjects to understand the optimal strategy. When we consider only the last five periods, cutpoints are still statistically significantly lower than the theoretical predictions and are similar to those reported here.

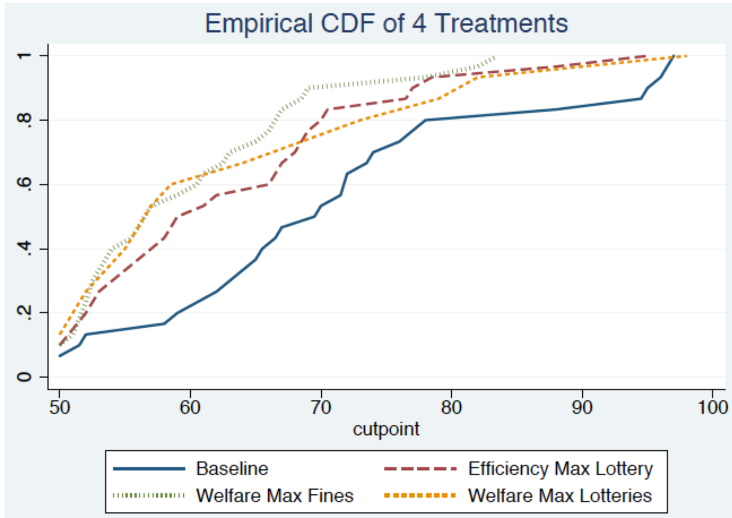


Figure 4: Empirical Distribution Functions

Blank Ballots: In some countries, blank ballots are quite common. When introducing lotteries or fines, one may worry about the incentives to cast blank (or foul) ballots. While interesting from a theoretical point of view, we stress that we tailored our experimental design so that the identified equilibrium behavior would remain an equilibrium even if submitting blank ballots were allowed. That is, the expected size of the lottery prize (in equilibrium) does not surpass the voting cost. Since subjects vote excessively, the incentives to cast a blank ballot are even lower when using the experimental turnout levels.

To summarize, there are three important insights that emerge when comparing the theoretical predictions regarding individual behavior and our experimental observations. First, subjects appear to be using strategies that are similar to threshold strategies. Second, comparative statics follow through: institutions designed to increase participation achieve that goal. Third, however, the levels of participation are significantly greater than those predicted by the theory, and exhibit significant variance across individuals.

5.2 Efficiency and Welfare Comparisons

As we have seen, experimental subjects exhibit excessive participation relative to the theoretical predictions across treatments. We next examine the implications of subjects' behavior on efficiency

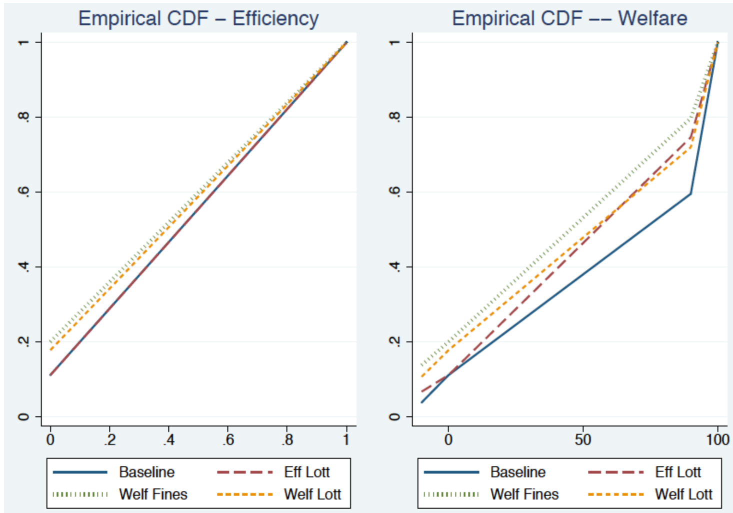


Figure 5: Empirical Cumulative Distribution of Efficiency and Welfare

and welfare across treatments.

Specifically, we inspect the effect of the treatments on efficiency – the share of correct decisions, and welfare – the average payoff of subjects accounting for the cost associated with voting (but not accounting for fine or lottery payments). Figure 5 depicts the empirical distribution of efficiency and welfare across treatments. We see that the Baseline treatment stochastically dominates all other treatments in terms of efficiency. Furthermore, both lottery treatments stochastically dominate the fines treatment in terms of efficiency. We see a similar pattern when we consider welfare. The highest levels of welfare are in the baseline treatment and welfare in all treatments stochastically dominates welfare in the fines treatment.

To gain some intuition on the driving forces behind these results, consider Figure 1 again. The maximal welfare was achieved when participation rates were at $p^{\max} = 0.76$. Recall that subjects' mean threshold under the baseline treatment is 0.71, implying excessive voting relative to the theoretical threshold prediction of 0.87. Importantly, this observed threshold is much closer to the optimal threshold $p^{\max}$ than the equilibrium level and so welfare levels under the baseline treatment are high. This tendency to over-vote shifts subjects to a threshold between 0.63 and 0.60 in the welfare maximizing lottery or fine treatments, respectively, thereby shifting the electorate to the region in which there is excessive voting relative to the optimum.

	Efficiency (Correct Wheel Chosen)		Welfare (Payoffs Exc Lottery)	
	Random Effects Probit		Random Effects	
Efficiency Max Lottery	0.000	-0.052	-1.814	-4.532
	(0.025)	(0.062)	(2.388)	(4.910)
Welfare Max Lottery	-0.074**	-0.039	-7.942	-2.225
	(0.034)	(0.074)	(2.864)	(6.013)
Fines	-0.095***	-0.233***	-11.059***	-19.700***
	(0.027)	(0.068)	(2.339)	(4.910)
Efficiency Max Lottery X Period		-0.004		-0.294
		(0.004)		(0.382)
Welfare Max Lottery X Period		-0.013*		-1.349**
		(0.005)		(0.540)
Fines X Period		-0.003		0.446
		(0.003)		(0.382)
Period		-0.010**		-0.634*
		(0.004)		(0.382)
Accuracy	0.002***	0.002***	0.038	0.039
	(0.001)	(0.001)	(0.062)	(0.062)
Intercept			-80.849***	-85.861***
			(4.925)	(5.804)
Observations	1575	1575	1575	1575
Mean of Dependent Variable	0.859	0.862		
Coefficiencts of Random Effects Probit represent marginal effects				
***=1% , **=5%, *=10%				

Table 4: Regression Estimates of Efficiency and Welfare

To summarize, while behavior follows in nature the benchmark theoretical model, particularly in terms of the use of threshold strategies, as well as in the comparative statics observed, aggregate outcomes diverge from those suggested by the benchmark model. Indeed, efficiency and welfare are affected by the precise *levels* of participation, not only by the responses individuals exhibit toward information accuracy or participation instruments. Ultimately, the baseline treatment without any inducement through lotteries or fines generates the highest levels of efficiency and welfare per individual.

In Table 4 we consider estimations of efficiency and welfare. Since efficiency and welfare can vary in each period, we allow for some variance introduced at the level of the individual decision maker in a treatment by estimating a random effects probit for the probability of making the right decision (efficiency) and a random effects model for payoffs (welfare). In all models, we control for randomness introduced by the draws of signal accuracy by including the control *Accuracy* that represents the probability of a correct signal. Overall, these estimates confirm that the Baseline treatment provides the greatest efficiency and welfare, though the Efficiency Maximizing Lottery also displays efficiency and welfare close to the baseline and not statistically different from its theoretical predictions. The

	(Voted)
	Random Effects Probit
Accuracy	0.015***
	(0.001)
Efficiency Max Lottery	0.187**
	(0.060)
Welfare Max Lottery	0.138*
	(0.066)
Fines	0.234***
	(0.053)
Period	-0.025*
	(0.010)
Reinforce Learning	0.000
	(0.000)
# Voted in Last Period	-0.010
	(0.013)
Observations	1575
Mean of Dependent Variable	0.715
Coefficiencts represent marginal effects	
***=1% , **=5%, *=10%	

Table 5: Participation over Time

fines treatment has the lowest levels of efficiency and welfare. We see little evidence for efficiency and welfare outcomes changing significantly throughout the course of the experiment.

5.3 Dynamics

Since subjects take part in more than one treatment and many periods of decision making, we consider the possibility that some dynamic factors influence subjects' decisions about whether to vote in Table 5. Coefficients represent marginal effects of a random effects probit regression. The dependent variable is a binary variable describing whether an individual voted. We control for signal accuracy with the variable Accuracy and find that a 1% increase in the accuracy of information makes a subject 1.5% more likely to vote, consistent with our observations regarding strategic behavior above.

We study how subject behavior differs over time by considering a variable *Period* that indicates the period in which the decision was made. We see that subjects are less likely to vote in later periods, decreasing the probability of voting by 2.3% in each period. we construct a variable designed to test whether subjects' behavior is consistent with reinforcement learning, or the theory that subjects tend to repeat behaviors that yield higher payoffs: The variable *Reinforce Learning* is equal to the sum of payoffs in all previous periods in which the subject voted. We do not see meaningful evidence of this kind of learning in our experiment. Last, we consider the role of the number of subjects voting in the last period, *# Voted Last Period* and see that when more people voted in the last period, individuals are less likely to vote in the current period, though the effect is not significant.

6. Conclusions

The current paper provides a model that sheds light on the important trade-offs involved in inducing greater participation. On the one hand, more participation implies more information utilized to determine the collective decision. On the other hand, more participation means that the average voter is less informed. We illustrate the generality of environments under which greater participation, by means of commonly used fines or lottery prizes, leads to potentially greater welfare and efficiency. Namely, for small groups, both fines and lotteries can be effective in increasing welfare and efficiency. For large groups, however, lotteries are more potent in eliminating wrong collective choices.

We test our benchmark model using an array of laboratory experiments. Our results generate several insights. First, subjects' behavior follows theoretical predictions in spirit. Subjects exhibit selective participation: they roughly use threshold strategies so that they vote only when their information accuracy is sufficiently high. Second, comparative statics implied by the theory are followed in the data. In particular, the introduction of abstention fines or participation lottery prizes are effective in getting out the vote. Nonetheless, precise levels of voting do not match the theoretical predictions. In fact, across all treatments, subjects vote more often than theory predicts. Consequently, the theoretical welfare and efficiency implications are not met in full by the data. Specifically, the baseline treatment in which no fines or lottery prizes are present generates very good relative results. Nonetheless, lotteries do provide significant improvements over fines, despite the latter being more commonly utilized.

The experimental results suggest that institutions designed to encourage participation are effective in doing so. However, they do not all improve upon collective decisions and should be carefully examined before implementation. In particular, lotteries may be a useful instrument for collective choice environments.

From a methodological point of view, while our model fares rather well in predicting individual *patterns* of participation, it does not do very well in predicting precise *levels*. It is levels of participation that influence the ultimate welfare and efficiency of institutions. Thus, our study suggests the potential value of incorporating modifications to our benchmark model in order to predict the relative performance of institutions. This might be particularly important for political elections, where social forces such as civic duties might act to induce individuals to turn out. There are several models that could help explain high rates of voting that would be natural channels for future research in this context, both theoretical and empirical. To mention a few examples, moral voting (as suggested by Feddersen and Sandroni, 2006 and Feddersen, Gailmard, and Sandroni, 2009) in which costs are effectively reduced for some voters who benefit from voting in a particular (socially beneficial) way, voting with the winner or with the majority (a-la Callander, 2008, see also Agranov, Goeree, Romero, and Yariv, 2015), some form of loss aversion (Kahneman and Tversky, 1979) through which the cost of implementing the less preferred alternatives is enhanced psychologically, or altruistic voting, may be potential mechanisms.

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7. Appendix – Proofs

We focus on symmetric equilibria in which agents use identical thresholds for both signals ρ and β (existence is guaranteed). For every $p \in [1/2, 1]$ and for each $i = 1, \dots, 2n+1$ define the random variable $V_i^n(p)$ as follows:

$$V_i^n(p) = \begin{cases} 1 & \text{with prob.} \quad r(p) \equiv \int_p^1 sf(s)\,ds \\ 0 & \qquad\qquad\; F(p) \\ -1 & \qquad\qquad\; w(p) \equiv \int_p^1 (1-s) f(s)\,ds \end{cases}$$

Suppose that agent i votes according to her signal if the accuracy q_i is (weakly) greater than p and abstains otherwise. Then $V_i^n(p)$ is equal to 1 if voter i makes the correct decision, i.e., she votes for r in state R and for b in state B. $V_i^n(p)$ is equal to zero if voter i abstains and $V_i^n(p)$ is equal to -1 if she makes the wrong decision.

Notice that

$$\mathbb{E}\left(V_i^n(p)\right) = r(p) - w(p)$$

and

$$Var\left(V_i^n(p)\right) = r(p) + w(p) - \left[r(p) - w(p)\right]^2$$

For every n and every $i = 1, \dots, 2n+1$ we let

$$V^n(p) = \sum_{j=1}^{n} V_j^n(p)$$
$$V_{-i}^n(p) = \sum_{j \neq i} V_j^n(p)$$

Define now

$$E_n(p) = \left(p - \tfrac{1}{2}\right) \Pr\left(V_{-i}^n(p) = 0\right)$$
$$O_n(p) = \tfrac{1}{2}\left[p \Pr\left(V_{-i}^n(p) = -1\right) - (1-p) \Pr\left(V_{-i}^n(p) = 1\right)\right]$$

Suppose that all the agents different from i use the threshold p and the accuracy of i's signal is p. $E_n(p)$ represents i's benefit from voting when the number of agents who vote (not including i) is even (and, thus, the two alternatives *red* and *blue* receive the same number of votes). $O_n(p)$

represents i's benefit (actually loss) from voting when the number of agents who vote (not including i) is odd (and, thus, one alternative receives one vote more than the other alternative). The total benefit from voting (not accounting for the cost c, the fine or the prize) is then

$$D_n(p) = E_n(p) + O_n(p)$$

It is easy to see that for every n, $D_n(1/2) = 0$ and $D_n(1) = 1/2$. Also, $O_n(1/2) = O_n(1) = 0$ and $O_n(p) < 0$ for every $p \in (1/2, 1)$.

Lemma 1. *Consider the benchmark model ($f = m = 0$). For any sequence of equilibrium thresholds $\{p_n\}_{n=1}^{\infty}$, we have $\lim_{n\to\infty} p_n = 1$.*

Proof. Any equilibrium threshold p_n must satisfy $D_n(p_n) = c$. Thus,

$$E_n(p_n) = \left(p_n - \frac{1}{2}\right) \Pr\left(V_{-i}^n(p_n) = 0\right) = c - O_n(p_n) \geqslant c \tag{1}$$

We now show that for every $p \in [1/2, 1]$ and every $n \geqslant 1$

$$\Pr\left(V_{-i}^n(p) = 0\right) \geqslant \Pr\left(V_{-i}^{n+1}(p) = 0\right) \tag{2}$$

To see why inequality 2 holds, notice that

$$\Pr\left(V_{-i}^n(p) = 0\right) = \sum_{k=0}^{n} \tbinom{2n}{2k} (1 - F(p))^{2k} F(p)^{2n-2k} \tbinom{2k}{k} \left(\tfrac{r(p)}{1-F(p)}\right)^k \left(\tfrac{w(p)}{1-F(p)}\right)^k$$

where we use the convention $\binom{0}{0} = 1$. It is easy to check that for every $k \geqslant 0$ and for every p

$$\binom{2k}{k} \left(\frac{r(p)}{1-F(p)}\right)^k \left(\frac{w(p)}{1-F(p)}\right)^k \geqslant \binom{2k+2}{k+1} \left(\frac{r(p)}{1-F(p)}\right)^{k+1} \left(\frac{w(p)}{1-F(p)}\right)^{k+1} \tag{3}$$

Also, given $n \geqslant 1$ and p, there exists $\bar{k} = 0, \ldots, n$ such that

$$\binom{2n}{2k} (1 - F(p))^{2k} F(p)^{2n-2k} \geqslant \binom{2n+2}{2k} (1 - F(p))^{2k} F(p)^{2n+2-2k} \tag{4}$$

if and only if $k \leqslant \bar{k}$ (clearly, the inequality is strict for $k = 0$). Inequality (2) follows immediately from inequalities (3) and (4).

Fix $\varepsilon \in (0, 1/2)$ and consider the functions $E_1(\cdot), \ldots, E_n(\cdot), \ldots$ defined over the interval $[1/2, 1-\varepsilon]$. It follows from inequality (2) that for every $p \in [1/2, 1-\varepsilon]$,

$$E_1(p) \geqslant E_2(p) \geqslant \ldots \geqslant E_n(p) \geqslant \ldots$$

Moreover, the sequence of functions $\{E_n(\cdot)\}_{n=1}^{\infty}$ converges pointwise to $\hat{E}(\cdot)$, where $\hat{E}(\cdot)$ denotes the function, defined over the interval $[1/2, 1-\varepsilon]$, which is constant and equal to zero. It then follows from Dini's theorem that $\{E_n(\cdot)\}_{n=1}^{\infty}$ converges uniformly to $\hat{E}(\cdot)$. This and inequality (1) imply that there exists $\bar{n}$ such that $p_n > 1-\varepsilon$ for every $n > \bar{n}$. ■

Proof of Proposition 2.

Given an equilibrium threshold p_n, $\Pr(W, n, p_n)$ denotes the probability that the final decision is wrong. A lower bound for this probability can be computed as follows:

$$\Pr(W, n, p_n) \geqslant \frac{1}{2}F(p_n)\Pr\left(V_{-i}^{n}(p_n) = 0\right) \geqslant \frac{1}{2}F(p_n)\frac{c}{\left(p_n - \frac{1}{2}\right)}$$

The first inequality follows from the fact that a sufficient condition for a wrong decision to take place is that the following three events occur: (i) one voter, say i, abstains; (ii) the two alternatives receive the same number of votes when i abstains, i.e., $V_{-i}^{n}(p_n) = 0$; and (iii) the tie is broken in favor of the incorrect alternative. The second inequality follows from (1).

Recall from Lemma 1 that p_n converges to 1 as n goes to infinity. Therefore, we have

$$\lim_{n\to\infty} \inf \Pr(W, n, p_n) \geqslant \lim_{n\to\infty} \frac{1}{2}F(p_n)\frac{c}{\left(p_n - \frac{1}{2}\right)} = c \qquad (5)$$

■

Proof of Proposition 3.

Suppose that there is a lottery with prize m. An equilibrium threshold $p_n(m)$ is a solution to the following equation:

$$B_n(p,m) = D_n(p) + L_n(p,m) - c = 0$$

where

$$L_n(p,m) \equiv m\mathbb{E}\left(\sum_{j\neq i}\left(V_j^n(p)\right)^2 + 1\right)^{-1}$$

denotes i's expected prize when she votes and all the other agents use the threshold p.

Fix $z \in (0,c)$ and consider the sequence of elections with prize $m_n = (2n+1)z$ for every n. We choose $p^* \in (1/2, 1)$ so that

$$\frac{z}{1-F(p^*)} - c - \frac{1}{4} > 0$$

Notice that $D_n(p) > -1/4$ for every n and every $p \in [1/2, 1]$. This and the law of large numbers guarantee that there exists $\bar{n}$ such that for every $n \geqslant \bar{n}$

$$B_n(p^*, m_n) > 0$$

Clearly, $B_n(1/2, m_n) < 0$ for every n. Thus, we conclude that for every $n \geqslant \bar{n}$, there exists an equilibrium threshold $p_n(m_n) \in [1/2, p^*)$ satisfying

$$B_n(p_n(m_n), m_n) = 0$$

Now suppose that there are $2n+1$ voters who use the threshold p. The probability $\Pr(W,n,p)$ that the electorate makes the wrong decision is bounded above by

$$\Pr(W,n,p) = \Pr(V^n(p) < 0) + \frac{1}{2}\Pr(V^n(p) = 0) < \Pr(V^n(p) \leqslant 0) \equiv Q(n,p)$$

Our next goal is to approximate $Q(n,p)$ for large n. To do that we need to introduce some additional notation. Let the functions $G : [1/2, 1] \to \mathbb{R}$ and $\gamma : [1/2, 1] \to \mathbb{R}$ be defined by

$$G(p) = -\frac{E(V_i^n(p))}{\sqrt{Var(V_i^n(p))}} = -\frac{r(p) - w(p)}{\sqrt{r(p) + w(p) - [r(p) - w(p)]^2}}$$

and

$$\gamma(p) = \frac{3\mathbb{E}\left(|V_i^n(p) - r(p) + w(p)|^3\right)}{(Var(V_i^n(p)))^{\frac{3}{2}}}$$

We also define $\bar{G} < 0$ and $\bar{\gamma}$ as follows

$$\bar{G} = \max_{p \in \left[\frac{1}{2}, p^*\right]} G(p)$$

$$\bar{\gamma} = \max_{p \in \left[\frac{1}{2}, p^*\right]} \gamma(p)$$

It follows from the Berry-Esseen theorem (Feller, 1971, Volume II, page 542) that

$$\left|Q(n,p) - \Phi\left(G(p)\sqrt{(2n+1)}\right)\right| \leqslant \frac{\gamma(p)}{\sqrt{(2n+1)}}$$

where Φ is the standard normal cumulative distribution function.

For every $n \geqslant \bar{n}$, consider the equilibrium threshold $p_n(m_n) \in [1/2, p^*]$ defined above. The probability $\Pr(W, n, p_n(m_n))$ of making the wrong decision is bounded above by

$$\Pr(W, n, p_n(m_n)) \leqslant \Phi\left(\bar{G}\sqrt{(2n+1)}\right) + \frac{\bar{\gamma}}{\sqrt{(2n+1)}}$$

Clearly, the right hand side of the above inequality converges to zero as n goes to infinity. This conclude the proof of Proposition 3. ■