INSTITUTO TECNOLÓGICO AUTÓNOMO DE MÉXICO

CENTRO DE INVESTIGACIÓN ECONÓMICA

Discussion Paper Series

Rational Ignorance and Voting Behavior

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October 2005
Discussion Paper 05-05

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M E X I C O

RATIONAL IGNORANCE AND VOTING BEHAVIOR

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ABSTRACT. We model a two-alternative election in which voters may acquire information about which is the best alternative for all voters. Voters differ in their cost of acquiring information. We show that as the number of voters increases, the fraction of voters who acquire information declines to zero. However, if the support of the cost distribution is not bounded away from zero, there is an equilibrium with some information acquisition for arbitrarily large electorates. This equilibrium dominates in terms of welfare any equilibrium without information acquisition–even though generally there is too little information acquisition with respect to an optimal strategy profile.

Keywords: *JEL* D72.

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Date: First Version: September 20th 2005, This Version: October 10, 2005.

Several useful conversations with Helios Herrera are gratefully acknowledged.

1. INTRODUCTION

Ever since proposed by Joseph Schumpeter [10] (very colorfully) and Anthony Downs [1] (in more subdued terms), the "rational ignorance hypothesis" has been part of the received wisdom in social sciences. In modern language, a weak version of the hypothesis proposed by Schumpeter and Downs would be that, since either acquiring information or processing publicly available information is costly for voters, and the impact of any voter on the outcome of a large election is presumably negligible, individual voters will generally chose to remain uninformed. A strong version would extract the implication that the outcome of large elections will not generally reflect the preferences of voters, insofar as discovering which of the alternatives is best for each voter is costly. In this paper, we propose a simple model of information acquisition in large elections that is consistent with the weak version but disproves the strong version of the rational ignorance hypothesis.

In the model, voters have heterogenous costs of acquiring information. In large elections, only those voters with very small costs will be willing to acquire information. The reason is that we focus on symmetric strategies, and the probability of being decisive declines to zero for any sequence of symmetric strategies. Thus, if the support of the distribution of information costs is bounded away from zero, there will not be an equilibrium with information acquisition for large enough electorates. However, if the support is not bounded away from zero, and any asymmetry in prior beliefs is moderate, there will be an equilibrium for arbitrarily large electorates in which a small fraction of voters decides to acquire information. Moreover, the expected utility of voters in this equilibrium will be larger than the expected utility of voters in any equilibria without information acquisition. Intuitively, even though the fraction of informed voters declines to zero as the electorate grows large, the probability that the informed voters are decisive does not decline to zero. This implies that there is at least partially successful information aggregation for arbitrarily large electorates. The condition for fully successful information aggregation (that is, for choosing the best alternative for voters with limit probability one) is very stringent, though: fully successful information aggregation requires the density of the distribution of individual costs to be unbounded at zero.

Though the model makes a number of simplifying assumptions–such as common preferences and the focus on symmetric strategy profiles–we believe that the two most important implications of the model: (1) Only a small fraction of voters are informed, and (2) Informed voters have a disproportioned impact on the outcome of the election, are likely to hold in a wide class of models of elections.

The issue of information acquisition in elections have been recently the object of some attention in the economic literature, though the literature has focused generally on voting in committees rather than large elections. (See e.g. the survey by Gerling *et al.* [5].) Mukhopadhaya [8] and Persico [9], for instance, consider a setting in which committee members have identical costs of acquiring information. With identical costs, there is a maximum number of voters that can acquire information in equilibrium. Moreover, there is no symmetric equilibrium with information acquisition for a large enough electorate.

Information acquisition in large elections has been considered in Martinelli [7], a predecessor of this paper. In Martinelli [7], voters are identical, as opposed to this paper, but can choose the quality of the information they acquire, with the cost being a convex function of quality. (At least) partially successful information aggregation in that setting is possible if the marginal cost of information quality is zero when the quality is lowest. The model in Martinelli [7] predicts that in equilibria with information acquisition, *every* voter will be nearly uninformed, and the aggregate cost information acquisition will decline to zero when information aggregation is more successful. The model in this paper, *per contra*, predicts that there will be a minority of voters with much better information than the rest, and that the aggregate cost of information acquisition will grow unboundedly when information aggregation is more successful. To the extent that the predictions of this paper are more realistic, heterogeneity in the voters' costs of acquiring and processing information seems to be a necessary ingredient for satisfactory models of information in elections.

Information acquisition in large elections has also been considered by Feddersen and Sandroni [4], in the context of their ethical voter model [3]. The ethical voter model of Feddersen and Sandroni [4] predicts that a significant fraction of the electorate will acquire *independent* information and that the fraction of informed voters may decrease with the quality of information. More realistically perhaps, the pivotal voter model of this paper predicts that only a vanishing fraction of the electorate acquire information, and that the fraction of informed voters increases with the quality of information, since a higher quality increases the individual incentive to acquire information. We leave for the last section of this paper a few remarks on the thorny (at least for pivotal voter models) issue of voter participation in large elections.

2. THE MODEL

We analyze an election with two alternatives, A and B. There are $2n+1$ voters ($i = 1, \dots, 2n+1$). A voter's utility depends on the chosen alternative

$d \in \{A, B\}$, the state $z \in \{z_A, z_B\}$, and on whether the voter acquires information or not. Acquiring information has an idiosyncratic utility cost given by c_i, so the utility of voter i can be written as $U(d,z) - c_i$ if the voter acquires information and as $U(d,z)$ if the voter does not acquire information.

At the beginning of time, nature selects the state. The prior probability of state A is $p \in [1/2, 1)$; that is, if there is any asymmetry in prior beliefs, it favors state z_A. Voters are uncertain about the realization of the state. After the realization of the state, nature selects the cost of information for each voter. We assume that the cost of information is independently and identically distributed across voters according to a distribution function F. F is strictly increasing and continuously differentiable over some interval $(\underline{c}, \overline{c})$ such that $0 \leq \underline{c} < \overline{c}$, with $F(\underline{c}) = 0$ and $F(\overline{c}) = 1$. Each voter learns her own cost of acquiring information but not the cost of information for other voters. After learning the cost of information, each voter must decide wether to acquire information or not. Each voter then receives a signal $s \in \{s_A, s_B\}$, the "opinion" of voter i. If a voter acquires information, the probability of receiving signal s_A in state z_A is equal to the probability of receiving signal s_B in state z_B and is given by $1/2 + q$, where $q \in (0, 1/2)$. If a voter acquires no information the probability of each signal is 1/2 regardless of the state. Signals are private information.

The election takes place after voters receive their signals. A voter can either vote for A or vote for B. (That is, there are no abstentions.) The alternative with most votes is chosen.

We assume

$$U(A, z_A) - U(B, z_A) = U(B, z_B) - U(A, z_B) = r > 0.$$

That is, A is the "right" alternative in state z_A and B is the "right" alternative in state z_B.

After describing the environment, we turn now to the description of strategies and the definition of equilibrium in the model. An *action* is as a triple (x, v_A, v_B), where $x \in \{0, 1\}$ specifies whether to voter acquires information or not, $v_A \in \{A, B\}$ specifies which alternative to vote for after receiving signal s_A, and $v_B \in \{A, B\}$ specifies which alternative to vote for after receiving signal s_B. A *strategy* for voter i is a (measurable) mapping

$$\sigma_i(c_i) : (\underline{c}, \overline{c}) \to \{0, 1\} \times \{A, B\} \times \{A, B\},$$

specifying an action for every realization of the cost c_i. (For simplicity, we omit considering strategies that allow for randomizing over actions.) An *equilibrium* $\overline{\sigma}$ ($\sigma_i = \sigma$ for all i) is a symmetric Nash equilibrium. An *equilibrium with information acquisition* is an equilibrium such that the distribution over actions (induced by the distribution of costs and by the equilibrium mapping) assigns positive probability to the set of actions with $x = 1$.

Obviously, there are at least two equilibria without information acquisition: for every voter to adopt the action $(0,A,A)$ for every realization of the cost of information, and for every voter to adopt the action $(0,B,B)$ for every realization of the cost of information. In either case, the probability that a single voter is decisive is zero, so it is a best response to acquire no information and vote for the alternative favored by every other voter. We focus on equilibria with information acquisition in the remainder of the paper.

3. The Equilibria with Information Acquisition

3.1. **Cutoffs and wedges.** Theorem 1 below shows that equilibria with information acquisition for arbitrarily large electorates must be characterized by a cutoff c^n such that voters acquire information (and vote according to the information received) only if their idiosyncratic cost falls below the cutoff, and by a "wedge" $w^n \geq 0$, such that uninformed voters vote for the alternative favored by prior beliefs with probability $1/2 + w_n$.

We have

Theorem 1. *There is some $\underline{n}$ such that for $n \geq \underline{n}$ a mapping σ^n is an equilibrium with information acquisition if and only if the probability distribution over actions induced by σ^n and F satisfies*

$$\Pr[\sigma^n(c_i) = (1,A,B)|c_i < c^n] = 1$$

and

$$\Pr[\sigma^n(c_i) = (0,A,A)|c_i > c^n] - \Pr[\sigma^n(c_i) = (0,B,B)|c_i > c^n] = 2w^n,$$

where $(c^n, w^n) \in (\underline{c}, \overline{c}] \times [0, 1/2)$ satisfies

$$2\binom{2n}{n}\left(1/4 - (qF(c^n) + w^n(1-F(c^n)))^2\right)^n pqr = c^n, \tag{1}$$

$$2\binom{2n}{n}\left(1/4 - (qF(c^n) - w^n(1-F(c^n)))^2\right)^n (1-p)qr = c^n. \tag{2}$$

To provide some intuition, note that, if $p = 1/2$, equations 1 and 2 admit a unique solution, given by $w^n = 0$ and

$$\left[\binom{2n}{n}\left(1/4 - q^2F(c^n)^2\right)^n\right] qr = c^n.$$

The term in brackets is equal to the probability of a voter being decisive in either state, i.e. the probability that n other voters vote for A and n other voters vote for B. The left-hand side is equal to the gain of acquiring information; that is, the probability of being decisive multiplied by the precision gain q and the utility gain r. Thus, if $p = 1/2$, (i) uninformed voters vote for A or for B with the same probability and (ii) the marginal informed voter equates the gain of acquiring information with the cost of information.

If $p > 1/2$, the equilibrium with information acquisition requires that uninformed voters vote with larger probability for A than for B (i.e. the wedge w_n is positive) so that the probabilities of states z_A and z_B, conditional on the voter being pivotal, are equal to each other, in order to keep uninformed voters willing to randomize in the first place. This implies that the probability of being decisive, multiplied by the prior probability, is the same in both states. The indifference condition for the marginal informed voter equates the sum of the probabilities of being decisive in either state, weighted by the prior probabilities, multiplied by the precision gain q and the utility gain r, to the cost of information. This indifference condition can be written substituting the probability of being decisive in state z_A times the prior probability of state z_A times two for the sum of the weighted probabilities, as in equation 1, or substituting the probability of being decisive in state z_B times the prior probability of state z_B times two for the sum of the weighted probabilities, as in equation 2.

Proof of Theorem 1. For any given symmetric mapping σ, let $t^{\sigma}(z)$ be the probability with which each voter votes for alternative A in state z as induced by the mapping σ. Let

$$P^{\sigma}(\text{piv}|z) = \binom{2n}{n}(t^{\sigma}(z))^n(1-t^{\sigma}(z))^n$$

denote the probability that a single voter is decisive in state z as induced by the mapping σ. Note that

$$P^{\sigma}(\text{piv}|z) \leq \binom{2n}{n}2^{2n};$$

in particular, as n increases the probability of being decisive converges uniformly to zero for any sequence of symmetric strategy mappings.

Consider a symmetric strategy mapping with information acquisition σ and a voter who has acquired information and has received the signal s_A. For this voter, the posterior probability of state z_A, conditional on being decisive and on receiving signal s_A, is

$$\frac{P^{\sigma}(\text{piv}|z_A)(1/2+q)p}{P^{\sigma}(\text{piv}|z_A)(1/2+q)p + P^{\sigma}(\text{piv}|z_B)(1/2-q)(1-p)}.$$

It is easy to see that the voter will prefer to vote for A if

$$(1/2+q)P^{\sigma}(\text{piv}|z_A)p > (1/2-q)P^{\sigma}(\text{piv}|z_B)(1-p);$$

that is, the voter prefers to vote for A if the posterior probability of state z_A, conditional on being pivotal and on receiving signal s_A, is larger than the posterior probability of state z_B.

We claim that this inequality above necessarily holds if σ is an equilibrium mapping. To see this suppose that

$$(1/2+q)P^{\sigma}(\text{piv}|z_A)p \leq (1/2-q)P^{\sigma}(\text{piv}|z_B)(1-p).$$

Then adopting the action $(0,B,B)$ with probability one (and saving the cost of information acquisition) would yield more utility to any voter than the strategy σ, since the voter would strictly prefer to vote for B in case or receiving signal s_B and would be at best indifferent between A and B in case of receiving signal s_A. A similar argument shows that

$$(1/2+q)P^{\sigma}(\text{piv}|z_B)(1-p) > (1/2-q)P^{\sigma}(\text{piv}|z_A)p.$$

Therefore, in any equilibrium with information acquisition, voters who acquire information vote for A if they receive the signal s_A and for B if they receive the signal s_B.

It is easy to see that if a voter finds advantageous to acquire information for any realization of the cost in a given interval, the voter will find advantageous to acquire information for any realization of the cost in a lower interval. Thus, if σ is an equilibrium with information acquisition, there is a cutoff c^{σ} such that for the voter will acquire information for almost every realization of c_i such that $c_i < c^{\sigma}$, and will not acquire information for almost every other realization of c_i. Thus,

$$\Pr[\sigma(c_i) = (1,A,B)|c_i < c^{\sigma}] = 1.$$

Let v^{σ} be the probability with which uninformed voters vote for A; that is

$$\Pr[\sigma^n(c_i) = (0,A,A)|c_i > c^{\sigma}] + \tfrac{1}{2}\Pr[\sigma^n(c_i) = (0,A,B)|c_i > c^{\sigma}] \\ + \tfrac{1}{2}\Pr[\sigma^n(c_i) = (0,B,A)|c_i > c^{\sigma}] = v^{\sigma}.$$

From this definition and the previous arguments it follows that

$$t^{\sigma}(z_A) = (1-F(c^{\sigma}))v^{\sigma} + F(c^{\sigma})(1/2+q).$$

Let

$$w^{\sigma} = v^{\sigma} - 1/2$$

or equivalently

$$\Pr[\sigma^n(c_i) = (0,A,A)|c_i > c^n] - \Pr[\sigma^n(c_i) = (0,B,B)|c_i > c^n] = 2w^{\sigma}.$$

Then

$$t^{\sigma}(z_A) = 1/2 + (1-F(c^{\sigma})w^{\sigma} + F(c^{\sigma})q$$

and

$$1 - t^{\sigma}(z_A) = 1/2 - (1-F(c^{\sigma})w^{\sigma} + F(c^{\sigma})q.$$

Thus,

$$P^{\sigma}(\text{piv}|z_A) = \binom{2n}{n}\left(1/4 - (qF(c^{\sigma}) + w^{\sigma}(1-F(c^{\sigma})))^2\right)^n, \tag{3}$$

and, by similar arguments,

$$P^{\sigma}(\text{piv}|z_B) = \binom{2n}{n}\left(1/4 - (qF(c^{\sigma}) - w^{\sigma}(1-F(c^{\sigma})))^2\right)^n. \tag{4}$$

We can now calculate the gain of acquiring information as

$$(pP^{\sigma}(\text{piv}|z_A) + (1-p)P^{\sigma}(\text{piv}|z_B))\,qr.$$

From the previous calculations it follows that an equilibrium with information acquisition with $c^{\sigma} = \overline{c}$ requires

$$\binom{2n}{n}\left(1/4 - q^2\right)^n qr \geq \overline{c}.$$

However, the left-hand side of this equation converges uniformly to zero, so that an equilibrium in which voters acquire information with probability one is impossible for large n. Thus, $c^{\sigma} < \underline{c}$. Moreover, it must satisfy the indifference condition

$$(pP^{\sigma}(\text{piv}|z_A) + (1-p)P^{\sigma}(\text{piv}|z_B))\,qr = c^{\sigma}. \tag{5}$$

We claim that if σ is an equilibrium with information acquisition and $c^{\sigma} < \underline{c}$ (so that voters are uninformed with positive probability) then

$$pP^{\sigma}(\text{piv}|z_A) = (1-p)P^{\sigma}(\text{piv}|z_B); \tag{6}$$

that is, uninformed voters are indifferent between voting for A and voting for B. For if, say, $pP^{\sigma}(\text{piv}|z_A) > (1-p)P^{\sigma}(\text{piv}|z_B)$; then every uninformed voter would have an incentive to vote for A. But then, taking into account the behavior of informed voters, we obtain $P^{\sigma}(\text{piv}|z_A) < P^{\sigma}(\text{piv}|z_B)$, a contradiction.

Putting together equations 3, 4, 5 and 6 we obtain that equations 1 and 2 in the statement of the theorem are necessary and sufficient for the symmetric strategy σ (with $c^{\sigma} = c^n$ and $w^{\sigma} = w^n$) to be an equilibrium with information acquisition for large n. □

3.2. **Existence.** Theorem 2 below shows that there are equilibria with information acquisition for arbitrarily large electorates only if $\underline{c} = 0$. Since the left-hand side of equations 1 and 2 converge uniformly to zero for large n, the cutoff c^n must converge to zero along any sequence of equilibria with information acquisition.

If $\underline{c} = 0$, we define $f(0) = \lim_{c\downarrow 0} F'(c)$. If $F'(c)$ grows unboundedly as c approaches zero, we use the convention $f(0) = \infty$. Intuitively, $f(0)$ plays an important role with respect to information aggregation in large elections because the cutoff c^n converges to zero along any sequence of equilibria with information acquisition. Also, if $\underline{c} = 0$, we let $\overline{p}$ be the solution to

$$\frac{p}{1-p} = \exp(64(1-p)^2 r^2 q^4 f(0)^2/\pi).$$

Note that $\overline{p} = 1/2$ if $f(0) = 0$ and $\overline{p} = 1$ if $f(0) = \infty$, and moreover $\overline{p}$ is strictly increasing in $f(0)$ in between. If $1/2 \leq p < \overline{p}$, the asymmetry in prior beliefs is "moderate" which allows for the existence of equilibria with information acquisition. Intuitively, if the asymmetry in prior beliefs is not moderate, it becomes impossible to make uninformed votes indifferent between the two alternatives while at the same time providing incentives to some voters to acquire information.

We have

Theorem 2. *(i) If $\underline{c} = 0$, $f(0) > 0$ and $p < \overline{p}$, there there is some $\underline{n}$ such that for $n \geq \underline{n}$ there is an equilibrium with information acquisition.*
(ii) If either $\underline{c} > 0$ or $\underline{c} = 0$, $f(0) > 0$ and $p > \overline{p}$, there is some $\overline{n}$ such that for $n \geq \overline{n}$ there is no equilibrium with information acquisition.

Proof. Lemma 2(i) and (ii) in the Appendix shows that if $f(0) > 0$ and $p < \overline{p}$, then the system given by equations 1 and 2 has a solution for n large enough satisfying $qF(c^n)/(1-F(c^n)) \geq w^n$. An example of equilibrium with information acquisition is the following mapping

$$\sigma(c_i) = \begin{cases} (1,A,B) & \text{if } c_i \leq c^n \\ (0,A,A) & \text{if } c^n < c_i \leq c^* \\ (0,B,B) & \text{if } c_i > c^* \end{cases},$$

where c^* solves $F(c^*) = F(c^n)/2 + 1/2 + w_n$, and (c^n, w^n) is a solution to equations 1 and 2. (Note that $qF(c^n)/(1-F(c^n)) \geq w^n$ implies that w^n must converge to zero, so c^* is well-defined.) Part (i) of the theorem follows from Theorem 1.

Lemma 2 (iii) in the Appendix shows that if $\underline{c} = 0$, $f(0) > 0$ and $p > \overline{p}$, there is some $\overline{n}$ such that for $n \geq \overline{n}$ there is no solution to equations 1 and 2. Similarly, since the left-hand side of equations 1 and 2 converges uniformly to zero as n goes to infinity, it follows that there cannot be a solution to equations 1 and 2n for n large enough if $\underline{c} > 0$. Part (ii) of the theorem follows from Theorem 1. □

Theorem 2 tells us whether there are or there are not equilibria with information acquisition in every possible circumstance except if either (1) $\underline{c} = 0$ and $p = \overline{p}$ or (2) $\underline{c} = 0$, $f(0) = 0$ and $p > \overline{p}$. The first exception is unimportant to the extent that it is a knife-edge case in relation to prior beliefs. With respect to the second exception, the analysis in the next section shows that *if* there are equilibria with information acquisition under those circumstances, in the limit they are payoff-equivalent to the equilibrium in which nobody acquires information and voters vote for the alternative favored by prior beliefs.

4. Information Aggregation

In this section and the remainder of the paper we assume $\underline{c} = 0$. Let $P^{\sigma}(A|z_A)$ and $P^{\sigma}(B|z_B)$ be, respectively, the probability of choosing alternative A in state z_A and the probability of choosing alternative B in state z_B for a given strategy profile σ. In this section we investigate the limit of the probabilities $P^{\sigma_n}(A|z_A)$ and $P^{\sigma_n}(B|z_B)$ as n grows large along a sequence of equilibrium profiles with information acquisition.

If $0 < f(0) < \infty$ and $p < \overline{p}$, we define $(k^*, h^*) \in [0, \infty)^2$ to be the solution to

$$k \exp\left(4(k+h)^2\right) = 2\pi^{-1/2} q^2 r f(0) p, \tag{7}$$

$$k \exp\left(4(k-h)^2\right) = 2\pi^{-1/2} q^2 r f(0)(1-p) \tag{8}$$

satisfying $h \leq k$. Lemma 1(i) in the Appendix shows that such a solution exists and is unique. As shown by Lemma 2(i), k^* and h^* represent respectively the limit of the bias of voters toward the right alternative $(qF(c^n))$ and the limit of the bias toward the alternative favored by prior beliefs $(w^n(1-F(c^n)))$, both multiplied by $\sqrt{n}$. The term $\sqrt{n}$ is important because of the central limit theorem.

Let Φ denote the standard normal distribution function. We have

Theorem 3. *(i) If $0 < f(0) < \infty$ and $p < \overline{p}$, there is a sequence σ_n of equilibria with information acquisition such that along that sequence*

$$P^{\sigma_n}(A|z_A) \to \Phi(2\sqrt{2}(k^* + h^*)) \text{ and } P^{\sigma_n}(B|z_B) \to \Phi(2\sqrt{2}(k^* - h^*)).$$

(ii) If $f(0) = \infty$, then along any sequence σ_n of equilibria with information acquisition

$$P^{\sigma_n}(A|z_A) \to 1 \text{ and } P^{\sigma_n}(B|z_B) \to 1.$$

(iii) If $f(0) = 0$ and $p > 1/2$, then along any sequence σ_n of equilibria with information acquisition

$$P^{\sigma_n}(A|z_A) \to 1 \text{ and } P^{\sigma_n}(B|z_B) \to 0.$$

Theorem 3(i) states a result for a given sequence of equilibria and not for all sequences of equilibria with information acquisition. More generally, we can say that along any sequence of equilibria with information acquisition such that $P^{\sigma_n}(A|z_A)$ and $P^{\sigma_n}(B|z_B)$ converge,

$$P^{\sigma_n}(A|z_A) \to \Phi(2\sqrt{2}(k' + h')) \text{ and } P^{\sigma_n}(B|z_B) \to \Phi(2\sqrt{2}(k' - h'))$$

for some solution (k',h') to equations 7 and 8. We do not state the theorem in terms of every sequence of equilibria with information acquisition because, if $p < \overline{p}$ and $0 < f(0) < \infty$, equations 7 and 8 admit a solution such that $k < h$, i.e. an equilibrium in which there is more bias toward the alternative favored by prior beliefs than toward the right alternative.

If $p = 1/2$, equations 7 and 8 do admit a unique solution. We have $h^* = 0$ and k^* given by

$$k^* \exp\left(4k^{*2}\right) = \pi^{-1/2} q^2 r f(0).$$

If $f(0) > 0$, we get $k^* > 0$. Thus, if $p = 1/2$ and $f(0) > 0$, the limit probability of choosing the right alternative is strictly larger than 1/2 in either state along any sequence of equilibria with information acquisition.

Proof of Theorem 3. Suppose that the state is z_A. Given the equilibrium strategy described in Theorem 1, the event of a given voter voting for A in state z_A corresponds to a Bernoulli trial with probability of success

$$(1 - F(c^n))(1/2 + w^n) + F(c^n)(1/2 + q)$$

or equivalently

$$1/2 + (F(c^n)q + (1 - F(c^n))w^n).$$

For $n = 1, 2, \ldots$ and $i = 1, \cdots, 2n+1$ define the random variables

$$V_i^n = \begin{cases} 1/2 - (F(c^n)q + (1 - F(c^n))w^n) & \text{if voter } i \text{ votes for } A, \\ -1/2 - (F(c^n)q + (1 - F(c^n))w^n) & \text{if voter } i \text{ votes for } B. \end{cases}$$

For each n, the random variables V_i^n are iid. Moreover,

$$\begin{aligned} &E(V_i^n) = 0, \\ &E((V_i^n)^2) = 1/4 - (F(c^n)q + (1 - F(c^n))w^n)^2, \quad \text{and} \\ &E(|V_i^n|^3) = 1/8 - 2(F(c^n)q + (1 - F(c^n))w^n)^4. \end{aligned}$$

Let F_n stand for the distribution of the normalized sum

$$(V_1^n + \cdots + V_{2n+1}^n) / \sqrt{E((V_i^n)^2)(2n+1)}.$$

Note that A loses the election if it obtains n or fewer votes, that is, if

$$V_1^n + \cdots + V_{2n+1}^n + (2n+1)(1/2 + F(c^n)q + (1 - F(c^n))w^n) \leq n$$

or equivalently

$$V_1^n + \cdots + V_{2n+1}^n \leq -1/2 - (2n+1)(F(c^n)q + (1 - F(c^n))w^n).$$

Then, the probability of A winning the election is $1 - F_n(J_n)$, where

$$J_n = \frac{-1/2 - (2n+1)(F(c^n)q + (1 - F(c^n))w^n)}{\sqrt{E((V_i^n)^2)(2n+1)}}.$$

Using an approximate version of the central limit theorem for finite samples, the Berry-Esseen theorem (see Durrett [2], p. 106), we have that, for all x,

$$|F_n(x) - \Phi(x)| \leq \frac{3E(|V_i^n|^3)}{E((V_i^n)^2)^{3/2}\sqrt{2n+1}}.$$

The right-hand side of the equation above converges to zero as n goes to infinity, so we obtain an increasingly good approximation using the normal distribution even though the distribution of V_i^n changes with n. Thus,

$$\lim_{n\to\infty} |F_n(J_n) - \Phi(J_n)| = 0.$$

Suppose now that $0 < f(0) < \infty$ and $p < \overline{p}$. From Lemma 2(i) in the Appendix we have that there is a sequence of equilibria with information acquisition such that along this sequence, as n increases,

$$qF(c^n)n^{1/2} \to k^* \quad \text{and} \quad w_n n^{1/2} \to h^*.$$

Note that k^* and h^* are finite. Using $1 - F(c^n) \to 1$ we get

$$J_n \to -2\sqrt{2}(k^* + h^*).$$

Since Φ is continuous,

$$\lim_{n\to\infty} |\Phi(J_n) - \Phi(-2\sqrt{2}(k^* + h^*))| = 0.$$

Thus, the probability of A winning converges to $1 - \Phi(-2\sqrt{2}(k^* + h^*)) = \Phi(2\sqrt{2}(k^* + h^*))$. (Similar calculations show that if the state is z_B, the probability of B winning the election converges to $\Phi(2\sqrt{2}(k^* - h^*))$.)

Suppose that $f(0) = \infty$. From Lemma 2(ii), along any sequence of equilibria with information acquisition,

$$(qF(c^n) + w_n(1 - F(c^n)))n^{1/2} \to \infty.$$

Then J_n goes to $-\infty$. Thus, for arbitrarily large L, the probability of A winning the election is larger than $1 - F_n(-L)$ for n large enough. Using the normal approximation above we can see that the probability of A winning must go to one. (Similar calculations show that if the state is z_B, the probability of B winning the election converges to 1.)

Suppose finally that $f(0) = 0$. From Lemma 2(iii), along any sequence of equilibria with information acquisition,

$$(qF(c^n) + w_n(1 - F(c^n)))n^{1/2} \to \infty.$$

Then J_n goes to $-\infty$. Thus, for arbitrarily large L, the probability of A winning the election is larger than $1 - F_n(-L)$ for n large enough. Thus, the probability of A winning must go to one. (Note that, from Lemma 2(iii), along any sequence of equilibria with information acquisition,

$$(qF(c^n) - w_n(1 - F(c^n)))n^{1/2} \to -\infty.$$

Similar calculations show that if the state is z_B, the probability of B winning the election converges to zero.) □

5. THE AGGREGATE COST OF INFORMATION

We define the aggregate expected cost of information as

$$(2n+1)\int_0^{c^n} cF'(c)\,dc.$$

We have

Theorem 4. *As the number of voters increases, along the sequence of equilibria described by Theorem 3 the aggregate cost of information acquisition converges to $k^{*2}/(q^2 f(0))$ if $f(0)\in(0,\infty)$, to zero if $f(0)=0$, and it grows unboundedly if $f(0)=\infty$.*

Proof. Using the mean value theorem for $H(c^n)\equiv\int_0^{c^n} cF'(c)\,dc$ we have that the expected aggregate cost of information is

$$(2n+1)\xi^n F'(\xi^n)c^n$$

for some ξ^n between zero and c^n. Rewriting, the expected aggregate cost is

$$\frac{2n+1}{n}\times(c^n n^{1/2})^2\times F'(c^n)\times\frac{\xi^n F'(\xi^n)}{c^n F'(c^n)}. \tag{9}$$

Suppose $f(0)\in(0,\infty)$. Then $qF(c^n)n^{1/2}\to k^*$. Thus, for some sequence $\xi^{n\prime}$ between 0 and c^n, $qF'(\xi^{n\prime})c^n n^{1/2}\to k^*$. It follows that $c^n n^{1/2}\to k^*/(qf(0))$. But then we get that the expression 9 in the limit is equal to

$$2\times(k^*/(qf(0)))^2\times f(0)\times 1,$$

or equivalently $k^{*2}/(q^2 f(0))$.

Suppose $f(0)=0$. Then $qF(c^n)n^{1/2}\to 0$. It follows that $c^n n^{1/2}\to 0$. But then we get that the expression 9 in the limit is equal to zero.

Suppose $f(0)=\infty$. Then $qF(c^n)n^{1/2}\to\infty$. It follows that $c^n n^{1/2}\to\infty$. But then we get that the expression 9 grows unboundedly with n. □

6. WELFARE

Since the cutoff c^n declines to zero along any sequence of equilibria with information acquisition, it follows that the average expected cost of information acquisition declines to zero. Thus, if $0<f(0)<\infty$ and $p<\overline{p}$, along the sequence of equilibria described in Theorem 3(i), the expected utility of a voter converges to

$$p\Phi(2\sqrt{2}(k^*+h^*))U(A,z_A)+p(1-\Phi(2\sqrt{2}(k^*+h^*)))U(B,z_A)$$
$$+(1-p)\Phi(2\sqrt{2}(k^*-h^*))U(B,z_B)+(1-p)(1-\Phi(2\sqrt{2}(k^*-h^*)))U(A,z_B).$$

The expected utility of a voter under the best possible equilibrium without information acquisition is

$$pU(A,z_A)+(1-p)U(A,z_B),$$

which corresponds to the symmetric strategy of voting for the alternative favored by prior beliefs no matter what. We claim that the expected utility is larger in the equilibrium with information acquisition, or equivalently,

$$\Phi(2\sqrt{2}(k^*-h^*))/(1-\Phi(2\sqrt{2}(k^*+h^*)))>p/(1-p).$$

To see this, from equations 7 and 8 we can get

$$p/(1-p)=\phi(2\sqrt{2}(k^*-h^*))/\phi(2\sqrt{2}(k^*+h^*)),$$

where ϕ is the standard normal distribution density. Using the symmetry properties of the standard normal distribution, all we need to show is, then,

$$\frac{\Phi(2\sqrt{2}(k^*-h^*))}{\Phi(2\sqrt{2}(-k^*-h^*))}>\frac{\phi(2\sqrt{2}(k^*-h^*))}{\phi(2\sqrt{2}(-k^*-h^*))},$$

which is satisfied because the normal hazard rate is strictly decreasing.

If $f(0)=\infty$, the equilibrium with information acquisition is asymptotically efficient, in the sense that the expected utility of a voter converges to its maximum possible value,

$$pU(A,z_A)+(1-p)U(B,z_B),$$

corresponding to choosing the right alternative with probability one at no (average) cost. If $f(0)<\infty$, however, the equilibrium with information acquisition is not asymptotically efficient. To see this, consider a sequence of symmetric cutoff strategy profiles described for n large enough by $\hat{w}^n=0$ and $\hat{c}^n$ such that $qF(\hat{c}^n)=n^{-0.4}$. Along this sequence of symmetric strategy profiles, the expected utility of a voter converges to its maximum possible value, which is strictly larger than the limit expected utility under any sequence of equilibria.

7. Final Remarks

This paper provides a pivotal voter model with costly information that predicts that only a small fraction of voters acquires information in large elections–a prediction we find entirely acceptable. A pivotal voter model with costly participation in elections will typically predict that only a small fraction of voters will turn out to vote–a prediction at odds with mass participation in large elections seemingly everywhere. A way out of this predicament may be a model that endogenously splits the electorate in leaders and followers, along the lines of Herrera and Martinelli [6]. In that paper, the number of leaders is determined by decisiveness considerations. Electoral turnout, in turn, is determined by the number of leaders and the stochastic attachment of followers to leaders. (The technology used by leaders to mobilize followers to participate in the elections is left as a black-box.) We believe that it is possible to introduce an information acquisition component in a similar leader-follower model of elections, with leaders doing essentially all the independent information acquisition in large elections, and providing information to other voters.

APPENDIX: AUXILIARY LEMMATA

Lemma 1. *(i) If $0 < f(0) < \infty$ and $p \leq \overline{p}$, the system 7 and 8 has a unique solution satisfying $k \geq h$. (ii) If $0 < f(0) < \infty$ and $p > \overline{p}$, the system 7 and 8 does not have a solution.*

Proof. Let

$$\overline{h} = 2\pi^{-1/2} q^2 r f(0)(1-p).$$

Suppose first that $p \leq \overline{p}$ as in part (i) of the Lemma. Let $k_I(h)$ represent the value of k that solves equation 7 for any given $h \in [0, \overline{h}]$. Note that $k_I(h)$ is a continuous and strictly decreasing function of h. Similarly, let $k_{II}(h)$ represent the value of k that solves equation 8 satisfying $k \geq h$ for any given $h \in [0, \overline{h}]$. Note that $k_{II}(h)$ is a continuous and strictly increasing function of h and moreover $k_{II}(h) > h$ if $h < \overline{h}$.

Since $p \geq 1/2$, we have that $k_I(0) \geq k_{II}(0)$. It is easy to calculate $k_{II}(\overline{h}) = \overline{h}$. We claim that $k_I(\overline{h}) \leq \overline{h}$. To see this, evaluating the left-hand side of equation 7 at $k = h = \overline{h}$ we obtain

$$2\pi^{-1/2} q^2 r f(0)(1-p) \exp(64\pi^{-1} q^4 r^2 f(0)^2 (1-p)^2).$$

This expression is larger than the right-hand side of equation 7 whenever

$$\exp(64\pi^{-1} q^4 r^2 f(0)^2 (1-p)^2) \geq \frac{p}{1-p},$$

or equivalently, whenever $p \leq \overline{p}$. Thus $k_I(\overline{h})$ must be smaller or equal to $\overline{h}$.

Using $k_I(0) \geq k_{II}(0)$ and $k_I(\overline{h}) \leq k_{II}(\overline{h})$ we obtain that there is a unique $h^* \in [0, \overline{h}]$ such that $k_I(h^*) = k_{II}(h^*)$. Defining $k^* = k_{II}(h^*)$ we obtain that if $p \leq \overline{p}$ there is a unique solution k^*, h^* to equations 7 and 8 satisfying $k \geq h$.

Suppose now that $p > \overline{p}$ as in part (ii) of the Lemma. An argument similar to the previous case proves that, if there is a solution k^*, h^* to equations 7 and 8, it must satisfy $h^* > \overline{h}$. But then, using equation 8, we get $k^* < \overline{h}$. Thus, if there is a solution k^*, h^* to equations 7 and 8, it must satisfy $h^* > k^*$. Suppose there is such a solution. Using equations 7 and 8 we can obtain

$$h^* = \frac{1}{16k^*} \ln\left(\frac{p}{1-p}\right).$$

Substituting back in equation 8 we obtain that k^* must solve

$$k \exp\left(4\left(k - \frac{1}{16k}\ln\left(\frac{p}{1-p}\right)\right)^2\right) = 2\pi^{-1/2} q^2 r f(0)(1-p). \tag{10}$$

Using $h^* > k^*$ we have

$$k^* < \tfrac{1}{4}\sqrt{\ln\left(\tfrac{p}{1-p}\right)}.$$

Note that the left-hand side of equation 10 is strictly decreasing in k for any give k satisfying the constraint above. Thus, equation 10 has a solution if and only if the left-hand side of equation 10 evaluated at

$$k = \frac{1}{4}\sqrt{\ln\left(\frac{p}{1-p}\right)}$$

is smaller than

$$2\pi^{-1/2}q^2 r f(0)(1-p).$$

But this implies $p < \overline{p}$, a contradiction. □

Lemma 2. *(i) If* $\underline{c} = 0$, $0 < f(0) < \infty$ *and* $p < \overline{p}$*, there is some* $\underline{n}$ *such that for* $n \geq \underline{n}$ *there is a solution* (c^n, w^n) *to equations 1 and 2 satisfying* $qF(c^n)/(1-F(c^n)) \geq w^n$ *. Moreover, as n increases,*

$$qF(c^n)n^{1/2} \to k^* \quad \textit{and} \quad w^n n^{1/2} \to h^*,$$

where $(k^*, h^*) \in \Re^2_+$ *is the solution to equations 7 and 8 satisfying* $k \geq h$*.*
(ii) If $\underline{c} = 0$ *and* $f(0) = \infty$*, there is some* $\underline{n}$ *such that for* $n \geq \underline{n}$ *there is a solution* (c^n, w^n) *to equations 1 and 2. Moreover, as n increases, along any sequence of solutions* (c^n, w^n) *to equations 1 and 2,*

$$(qF(c^n) - w^n)n^{1/2} \to \infty.$$

(iii) If $\underline{c} = 0$, $0 < f(0) < \infty$ *and* $p > \overline{p}$*, there is some* $\overline{n}$ *such that for* $n \geq \overline{n}$ *there is no solution to equations 1 and 2.*
(iv) If $\underline{c} = 0$, $f(0) = 0$ *and* $p > \overline{p}$*, then as n increases, along any sequence of solutions* (c^n, w^n) *to equations 1 and 2*

$$qF(c^n)n^{1/2} \to 0 \quad \textit{and} \quad w^n n^{1/2} \to \infty.$$

Proof. Suppose first that $\underline{c} = 0$, $0 < f(0) < \infty$ and $p < \overline{p}$ as in part (i) of the Lemma. Let $\overline{c}^n$ be given by

$$\overline{c}^n = \frac{(2n)!}{2^{2n-1}n!n!}(1-p)qr$$

and let $\overline{w}^n$ be given by

$$\overline{w}^n = \frac{qF(\overline{c}^n)}{1-F(\overline{c}^n)}.$$

Note that $\overline{c}^n$ and $\overline{w}^n$ converge to zero as n grows arbitrarily large. Moreover, using Stirling's formula,

$$\frac{(2n)!}{2^{2n-1}n!n!}n^{1/2} \to 2\pi^{-1/2}.$$

Thus,

$$\overline{c}^n n^{1/2} \to 2\pi^{-1/2}(1-p)qr.$$

Using the mean value theorem for F we have

$$qF(\bar{c}^n)n^{1/2} = \bar{c}^n n^{1/2} F'(\xi)$$

for some ξ between zero and $\bar{c}^n$. Thus,

$$qF(\bar{c}^n)n^{1/2} \to 2\pi^{-1/2}(1-p)qrf(0)$$

and

$$\overline{w}^n n^{1/2} \to 2\pi^{-1/2}(1-p)qrf(0).$$

That is, $qF(\bar{c}^n)n^{1/2} \to \bar{h}$ and $\overline{w}^n n^{1/2} \to \bar{h}$, where $\bar{h}$ is as defined in the proof of Lemma 1.

Now, for any n such that $\overline{w}^n < q$ and such that

$$2\binom{2n}{n}\left(1/4-q^2\right)^n pqr \leq \bar{c},$$

and for any $w \in [0, \overline{w}^n]$, define $c_I^n(w)$ to be the value of c^n that solves equation 1 for $w^n = w$. Note that $c_I^n(w)$ is a continuous and strictly decreasing function of w. Similarly, define $c_{II}^n(w)$ to be the value of c^n that solves equation 2 for $w^n = w$ under the constraint $qF(c^n)/(1-F(c^n)) \geq w^n$. Note that $c_{II}^n(w)$ is a continuous and strictly increasing function of w.

Since $p \geq 1/2$, we have $c_I^n(0) \geq c_{II}^n(0)$. It is easy to calculate $c_{II}^n(\overline{w}^n) = \bar{c}^n$. We claim that for n large enough, $c_I^n(\overline{w}^n) < \bar{c}^n$. Since the left-hand side of equation 1 is decreasing in c^n and the right-hand side is increasing in c^n, we only need to show that the left-hand side of equation 1 is smaller than the left-hand side when evaluated at $c^n = \bar{c}^n$ and $w^n = \overline{w}^n$. That is, after substituting $c^n = \bar{c}^n$ and $w^n = \overline{w}^n$ in equation 1, we need to show that for n large enough

$$\left(1-4\left(qF(\bar{c}^n)+\overline{w}^n(1-F(\bar{c}^n))\right)^2\right)^n < (1-p)/p. \tag{11}$$

Since $\left(qF(\bar{c}^n)+\overline{w}^n(1-F(\bar{c}^n))\right)n^{1/2} \to 2\bar{h}$, the left-hand side of the inequality above converges to $\exp(-4(2\bar{h})^2)$ (see e.g. Durrett [2], Theorem 4.2, p. 94). Thus, we need to show

$$\exp(-16\bar{h}^2) < (1-p)/p.$$

But this inequality is verified whenever $p < \bar{p}$.

From $c_I^n(0) \geq c_{II}^n(0)$ and $c_I^n(\overline{w}^n) < c_{II}^n(\overline{w}^n)$ for n large enough we get that there exists a solution (c^n, w^n) to equations 1 and 2 satisfying $qF(c^n)/(1-F(c^n)) \geq w^n$ for n large enough, and it is indeed the unique solution satisfying that constraint. Next, we claim that under the sequence of such solutions, as n increases,

$$qF(c^n)n^{1/2} \to k^* \quad \text{and} \quad w^n n^{1/2} \to h^*,$$

where (k^*,h^*) is the unique solution to equations 7 and 8 satisfying $k \geq h$. To see this, let $k^n = qF(c^n)n^{1/2}$ and $h^n = w^n n^{1/2}$. We can rewrite equations 1 and 2 as

$$\frac{(2n)!n^{1/2}}{2^{2n-1}n!n!}\left(1-4(k^n+h^n(1-F(c^n)))^2/n\right)^n pqr = n^{1/2}F^{-1}(k^n q^{-1} n^{-1/2})$$

and

$$\frac{(2n)!n^{1/2}}{2^{2n-1}n!n!}\left(1-4(k^n-h^n(1-F(c^n)))^2/n\right)^n (1-p)qr = n^{1/2}F^{-1}(k^n q^{-1} n^{-1/2}).$$

Using the mean value theorem for F^{-1} we have

$$n^{1/2}F^{-1}(k^n q^{-1} n^{-1/2}) = k^n (F^{-1})'(\xi_n)/q$$

for some ξ_n between zero and $k^n q^{-1} n^{-1/2}$. Equivalently,

$$n^{1/2}F^{-1}(k^n q^{-1} n^{-1/2}) = \frac{k^n}{qF'(\xi')}$$

for some ξ_n' between zero and c^n. Thus, we can rewrite equations 1 and 2 as

$$\frac{(2n)!n^{1/2}}{2^{2n-1}n!n!}\left(1-4(k^n+h^n(1-F(c^n)))^2/n\right)^n pqr = \frac{k^n}{qF'(\xi')} \tag{12}$$

and

$$\frac{(2n)!n^{1/2}}{2^{2n-1}n!n!}\left(1-4(k^n-h^n(1-F(c^n)))^2/n\right)^n (1-p)qr = \frac{k^n}{qF'(\xi')} \tag{13}$$

for some ξ_n' between zero and c^n. Recall that c^n converges to zero and, using Stirling's formula,

$$\frac{(2n)!n^{1/2}}{n!n!2^{2n}} \to \pi^{-1/2}.$$

Also, if k^n and h^n converge to some finite k and h,

$$\left(1-4(k^n+h^n(1-F(c^n)))^2/n\right)^n \to \exp(-4(k+h)^2)$$

and

$$\left(1-4(k^n-h^n(1-F(c^n)))^2/n\right)^n \to \exp(-4(k-h)^2)$$

(see e.g. Durrett [2], Theorem 4.2, p. 94). It is easy to check that if $0 < f(0) < \infty$, k^n and h^n cannot grow arbitrarily large along any subsequence of solutions (k^n,h^n) to equations 12 and 13. Thus, along any converging subsequence, the limits k and h must satisfy

$$\pi^{-1/2}\exp(-4(h+k)^2) = \frac{k}{qf(0)}$$

and

$$\pi^{-1/2}\exp(-4(h-k)^2) = \frac{k^n}{qf(0)},$$

or equivalently, equations 7 and 8. It follows that $k^n \to k^*$ and $h^n \to h^*$.

Now suppose $\underline{c} = 0$ and $f(0) = \infty$ as in part (ii) of the Lemma. Define $\overline{c}^n$, $\overline{w}^n$, $c_I^n(w)$ and $c_{II}^n(w)$ as in the proof of part (i). Note that now

$$qF(\overline{c}^n)n^{1/2} \to \infty.$$

As in part (i), we can show $c_I^n(0) \geq c_{II}^n(0)$ and $c_I^n(\overline{w}^n) < c_{II}^n(\overline{w}^n)$ for n large enough, so there exists a solution (c^n, w^n) to equations 1 and 2 satisfying $qF(c^n)/(1-F(c^n)) \geq w^n$ for n large enough. (In particular, no upper bound on p is necessary because the left-hand side of equation 11 converges to zero as n goes to infinity.) As in part (i), we obtain equations 12 and 13. Now, however, the right-hand side of both equations converge to zero as n grows arbitrarily large. Thus, both $k^n + h^n$ and $k^n - h^n$ must diverge to infinity.

Suppose $\underline{c} = 0$, $0 < f(0) < \infty$ and $p > \overline{p}$ as in part (iii) of the Lemma. *Assuming* there is a solution (c^n, w^n) to equations 1 and 2, we get that $k^n = qF(c^n)n^{1/2}$ and $h^n = w^n n^{1/2}$ must satisfy the system 7 and 8. But from Lemma 1(ii) we know that the system 7 and 8 has no solution if $p > \overline{p}$.

Finally, suppose $\underline{c} = 0$ and $f(0) = 0$ as in part (iv) of the Lemma. *Assuming* there is a solution (c^n, w^n) to equations 1 and 2, we get that $k^n = qF(c^n)n^{1/2}$ and $h^n = w^n n^{1/2}$ must satisfy equations 12 and 13. Thus, k^n must converge to zero as n grows arbitrarily large; otherwise the right-hand side of both equations converge to infinity while the left-hand side converges to zero. Finally, manipulating equations 12 and 13, we get

$$\frac{\left(1-4(k^n+(1-F(c^n)h^n)^2/n\right)^n}{\left(1-4(k^n-(1-F(c^n)h^n)^2/n\right)^n} = \frac{1-p}{p}.$$

If h^n converges to some h along any subsequence of solutions (c^n, w^n) to equations 1 and 2, then the left-hand side of the equation above converges to $\exp(-4h^2)/\exp(-4h^2) = 1$. But $p > \overline{p}$ implies $p > 1/2$, so the right-hand side of the equation above is strictly smaller than one. $\square$

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