Voting with Correlated Information*

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Abstract

We show that in large elections where there is correlated information and the possibility, however small, of misinformation (i.e. that information is non-informative), information aggregation fails if voters have a non-zero, potentially negligible, idiosyncratic bias towards either party. The mechanism in play is that if a voter is pivotal, then the posterior on information is that the most likely event is that information is non-informative, regardless of how its prior probability might have been. Thus, a voter is better off voting following the bias even if it is arbitrarily small.

JEL Classification: C72, D72.

Keywords: Correlation; Elections; Information aggregation; Misinformation.

1 Introduction

Information correlation in elections is endemic, whether because voters consult the same sources of information (newspapers, TV channels, websites, etc.) or because these sources of information themselves gather their information from the same news agencies (Associated Press (US), Press Association (UK), Reuters, etc.). The purpose of this paper is to study information aggregation in elections where there is information correlation.

We consider an election where voters choose between two candidates such that the most appropriate candidate is not known. Voters each have access to information in the form of a signal that is, conditionally on the appropriate candidate, correlated across voters. On top of

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that, voters have an idiosyncratic bias towards either candidate, and thus value candidates based on both which one is the most appropriate one and the voters' own bias.

We find that even if the bias is arbitrarily small, then regardless of the correlation across signals, if there is the possibility, however small, of misinformation (i.e., there is a chance that players' signals are not informative), then information aggregation fails in large elections. That is, correlation with an arbitrarily small possibility of misinformation coupled with an arbitrarily small bias stops information aggregation, allowing the least appropriate candidate to win the election with probability 1. None of these two factors by themselves make information aggregation fail.

The key to the result is the following. In elections, rational voters behave as if pivotal, i.e., as if their vote determined the outcome of the election. Thus, in simple majority elections if voters vote following their signal (or informatively as in Austen-Smith and Banks (1996)), then signals in the population are split 50/50 between both candidates. If signals are correlated and there is the possibility of misinformation, then misinformation is the most likely event by an exploding factor on the number of voters, however small its prior probability is. This means that, conditional on being pivotal, a voter learns that with probability approaching 1 his own signal, and that of the other voters, is not informative, and thus is better off voting following is own bias however small such bias may be.

Following the literature on voting with correlated information, an assumption we make about correlation of information is that of exchangeability, first introduced in statistics by Johnson (1924). In our context, exchangeability means that the identity or labelling of voters does not matter. Using exchangeability, de Finnetti (1997) shows that in settings with a sequence of correlated Bernoulli random variables, then there is an underlying random variable such that conditional on this variable the sequence of Bernoulli random variables is iid. Our main result shows that conditional on a voter being pivotal when all other voters vote following their signal this random variable is such that all Bernoulli signals have a 50% probability of pointing towards either candidate, and are thus not informative. This means that the bias alone determines the behaviour of the voters.

Previous work focusing on correlation information but when voters ignore such correlation can be found in Levia and Razin (2015) (see also De Marzo et al (2003), Glaeser and Sunstein (2009) and Ortoleva and Snowberg (2015)). They show that correlation neglect can improve information aggregation in some settings. In our paper, without correlation of information there is information aggregation if voter bias is sufficiently low. Therefore, correlation, even if negligible, causes information aggregation to fail.

This paper contributes to the literature on information aggregation in elections (Austen-

Smith and Banks (1996) and Feddersend and Pessendorfer (1996), see also Mengel and Rivas (2017) and references therein) focusing on the largely unexplored case of correlated information. The closest work to ours is that of Mandler (2011), who presents a setting with correlated signals and exchangeability and finds that information aggregation fails. The difference between Mandler (2011) and our paper is that we make no assumption about the particular correlation on signals other than allowing for misinformation. Mandler (2011), on the other hand, considers the case where the iid distribution of signal qualities obtained from applying de Finetti (1995) have a particular slope (similar to what is found on Acemoglu et al (2016)). That is, Mandler (2011) imposes requirements on the behaviour of the underlying random variable that governs the distribution of the Bernoulli signals, whereas we only require that it's domain includes, with an arbitrarily small probability, an arbitrarily small interval around 1/2.

Another related paper is Ladha (1993), who analyses correlated information with exchangeable signals but with non-strategic voters. Ladha (1993) finds that information aggregation holds.

The rest of the paper is organized as follows. Section 2 presents the model whereas Section 3 present our main results. Finally, section 4 concludes the paper.

2 The Model

There is a pool of infinitely many potential voters, each voter i characterized with a bias $b_i \in \mathbb{R}$ drawn from some distribution such that $P(b_i \neq 0) > 0$ for all i. A subset $N + 1 \geq 2$, with N even, of them have to decide between two candidates $c \in \{0, 1\}$ by simultaneously casting a vote for either candidate. The candidate that the receives the most votes wins the election where in case of a tie the winner is determined by the toss of a fair coin.

There is a state of nature that can take two values $s \in \{0, 1\}$ both equally likely a priori. The utility of each voter i when candidate c wins the election and the state is s is given by

$$u_i(c, s) \quad = \quad cs + (1 - c)(1 - s) + (2c - 1)b_i$$

Thus, the voter receives one unit of utility whenever the winner of the election coincides with the state of nature plus a bias dependent payoff. If $b_i < 0$, then voter i receives $-b_i$ if candidate 0 wins and b_i if candidate 1 wins. On the other hand, if $b_i > 0$, then voter i receives b_i if candidate 1 wins and $-b_i$ if candidate 0 wins.

Before the election, each voter i receives a signal $\theta_i \in \{0, 1\}$ with quality $q_i \in [0, 1]$ such that

$$P(\theta_i = s|s) \quad = \quad q_i.$$

Each voter observes his own signal but ignores the quality of such signal. Given the state of nature, signals and signal qualities received by different voters are correlated. The fact that signals and signal qualities are correlated is common knowledge. Thus, before voting each voter knows his own signal but ignores his signal quality, and he also knows the fact that signals and qualities are correlated and how. However, he ignores the state of nature, the signals received by other voters, and the quality of such signals.

We assume that the signals received by voters are anonymous, i.e., they do not depend on the particular identity of the voter. This implies that the signals received by each player are *exchangeable* (Johnson (1924)):

Definition 1 (Exchangeability). *A sequence of signals $\{\theta_i\}_i^\infty$ is exchangeable if for any finite number of voters $N+1$ and any two sequences of voters $j_1, \ldots, j_{N+1}$ and $k_1, \ldots, k_{N+1}$ we have that*

$$P\left(\theta_{j_1}, \ldots, \theta_{j_{N+1}}\right) \quad = \quad P\left(\theta_{k_1}, \ldots, \theta_{k_{N+1}}\right)$$

According to de Finetti's theorem, exchangeability implies that there exist some random variable q with probability distribution f such that given the value of q the distribution of signals $\{\theta_i\}$ conditional on the state s and on q is iid, and for all i we have $P(\theta_i = s|s, q) = q$.

We assume that correlation between signals is such that it is possible that de Finetti's density distribution f is non-vanishing in any right-neighbourhood of $\frac{1}{2}$. That is, there is a non-zero probability that signals are all non-informative. We refer to this by saying that misinformation is possible.

Assumption 1 (Misinformation). *There exists a $\kappa > 0$ and a $\delta > 0$ such that for all $\alpha < \delta$ we have that $\inf_{q \in \left[\frac{1}{2}, \frac{1}{2}+\alpha\right)} f(q) \geq \kappa$.*

A strategy for each voter is a map $v : \{0, 1\} \times \mathbb{R} \rightarrow \{0, 1\}$ where $v(\theta_i, b_i)$ is the action of voter i who receives signal θ_i and has a bias b_i. Note that we are assuming symmetric strategies. Finally, for simplicity, assume that if a voter is indifferent between voting for party 0 or party 1 he votes for party 1.

3 Results

When a voter decides whether to vote for 0 or 1, he compares the payoff he obtains under these two actions given the actions of all other voters. However, a voter can influence his own payoff only when his vote can change the outcome of the election (i.e., he is pivotal). This can happen if and only if candidates 0 and 1 are tied when counting the votes of the other N

voters. Thus, a voter is pivotal if and only if exactly $\frac{N}{2}$ voters vote for 0 and $\frac{N}{2}$ voters vote for 1. Let $\pi(s)$ be the probability that a voter is pivotal when the state of nature is given by s. Note that in an abuse of notation we are omitting the strategies of the other N voters as an argument in π, this should not cause any confusion.

The expected increase in utility of voter i when he votes for candidate 0 as opposed to candidate 1 when he receives signal θ_i is given by

$$\Delta u_i(\theta_i) = P(\text{pivotal}|\theta_i)\left[P(s=0|\text{ pivotal } \cup \theta_i) - P(s=1|\text{ pivotal } \cup \theta_i) - 2b_i\right]. \quad (1)$$

Since $P(s=1|\text{ pivotal } \cup \theta_i) = 1 - P(s=0|\text{ pivotal } \cup \theta_i)$ we have that a voter votes for 0 if and only if

$$\Delta u_i(\theta_i) \propto P(s=0|\text{ pivotal } \cup \theta_i) - \frac{1}{2} - b_i \geq 0.$$

If $\theta_i = 0$ we have $P(s=0|\text{ pivotal } \cup \theta_i) = P(\theta_i = s|\text{ pivotal } \cup \theta_i)$. Moreover, if $\theta_i = 1$, then $P(s=0|\text{ pivotal } \cup \theta_i) = P(\theta_i \neq s|\text{ pivotal } \cup \theta_i) = 1 - P(\theta_i = s|\text{ pivotal } \cup \theta_i)$. Thus, the term $P(\theta_i = s|\text{ pivotal } \cup \theta_i)$, i.e. the probability that the voter's signal is correct given the event that he is pivotal, contains all the information we need to determine how such voter behaves given the bias.

We say that a voter votes *informatively* if his votes coincides with his signal. A voter votes *following is bias* if he votes 0 whenever $b > 0$ and votes 1 whenever $b < 0$, irrespective of the signal he receives.

Our first result establishes that if voters vote informatively, then conditional on being pivotal, the probability that a voter's signal is correct tends to $\frac{1}{2}$ as the number of voters N increases.

Lemma 1. *If all voters other than i vote informatively, then for all $\varepsilon > 0$ there exists a N such that*

$$P(\theta_i = s|\text{ pivotal } \cup \theta_i) \in \left(\frac{1}{2} - \varepsilon, \frac{1}{2} + \varepsilon\right)$$

Proof. Since the signals of voters are exchangeable, then By de Finetti's theorem and using Bayes rule we have that there exists a distribution function F with density f such that

$$\begin{aligned} P(\theta_i = s|\text{ pivotal } \cup \theta_i) &= \frac{\int_0^1 q^{\frac{N}{2}+1}(1-q)^{\frac{N}{2}} f(q)\mathrm{d}q}{\int_0^1 q^{\frac{N}{2}}(1-q)^{\frac{N}{2}} f(q)\mathrm{d}q} \\ &= \frac{\int_0^1 q\,(4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q}{\int_0^1 (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q}. \end{aligned}$$

Fix any $\rho \in (0, \frac{1}{2})$ and define the set $A_\rho = \{q \in [0,1] \setminus \left[\frac{1}{2}-\rho, \frac{1}{2}+\rho\right]\}$. We have that

$$\begin{aligned} P(\theta_i = s | \text{ pivotal } \cup \theta_i) &= \frac{\int_0^1 q\,(4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q}{\int_0^1 (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q} \\ &= \frac{\int_{\frac{1}{2}-\rho}^{\frac{1}{2}+\rho} q\,(4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q + \int_{A_\rho} q\,(4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q}{\int_{\frac{1}{2}-\rho}^{\frac{1}{2}+\rho} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q + \int_{A_\rho} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q} \\ &\leq \frac{\int_{\frac{1}{2}-\rho}^{\frac{1}{2}+\rho} q\,(4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q}{\int_{\frac{1}{2}-\rho}^{\frac{1}{2}+\rho} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q} + \frac{\int_{A_\rho} q\,(4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q}{\int_{\frac{1}{2}-\rho}^{\frac{1}{2}+\rho} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q} \\ &\leq \left(\frac{1}{2}+\rho\right) + \frac{\int_{A_\rho} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q}{\int_{\frac{1}{2}-\rho}^{\frac{1}{2}+\rho} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q}. \end{aligned}$$

Notice now that for all $q \in [0,1]$ the expression $q(1-q)$ has a maximum at $q = \frac{1}{2}$, is symmetric around this point, and is monotonically increasing for $q < \frac{1}{2}$ and decreasing for $q > \frac{1}{2}$. Furthermore, define $f(\underline{q}) = \sup_{q \in \left(0, \frac{1}{2}-\rho\right)} f(q)$ and $f(\bar{q}) = \sup_{q \in \left(\frac{1}{2}+\rho, 1\right)} f(q)$, and also $f(\hat{q}) = \max\{f(\underline{q}), f(\bar{q})\}$. Given this, we have

$$\begin{aligned} \int_{A_\rho} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q &= \int_0^{\frac{1}{2}-\rho} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q + \int_{\frac{1}{2}+\rho}^{1} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q \\ &\leq \left[\frac{1}{2}-\rho\right]\left[4\left(\frac{1}{2}-\rho\right)\left(\frac{1}{2}+\rho\right)\right]^{\frac{N}{2}} f(\underline{q}) \\ &\quad + \left[1-\left(\frac{1}{2}+\rho\right)\right]\left[4\left(\frac{1}{2}+\rho\right)\left(\frac{1}{2}-\rho\right)\right]^{\frac{N}{2}} f(\bar{q}) \\ &\leq \left[\frac{1}{2}-\rho\right]\left(1-4\rho^2\right)^{\frac{N}{2}} f(\underline{q}) + \left[\frac{1}{2}-\rho\right]\left[1-\rho^2\right]^{\frac{N}{2}} f(\bar{q}) \\ &\leq [1-2\rho]\left(1-4\rho^2\right)^{\frac{N}{2}} f(\hat{q}). \end{aligned}$$

Similarly, using Assumption 1 there exists a $\kappa > 0$ and $\delta > 0$ such that for any $\alpha < \delta$ if we define $f(\tilde{q}) = \inf_{q \in \left(\frac{1}{2}, \frac{1}{2}+\alpha\right)} f(q)$ we have that $f(\tilde{q}) \geq \kappa$ and thus is non-zero, and

$$\begin{aligned} \int_{\frac{1}{2}-\rho}^{\frac{1}{2}+\rho} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q &\geq \int_{\frac{1}{2}}^{\frac{1}{2}+\rho} (4q(1-q))^{\frac{N}{2}} f(q)\mathrm{d}q \\ &\geq f(\tilde{q}) \int_{\frac{1}{2}}^{\frac{1}{2}+\rho} (4q(1-q))^{\frac{N}{2}} \mathrm{d}q \\ &\geq f(\tilde{q}) \int_{\frac{1}{2}}^{\frac{1}{2}+\rho^2} (4q(1-q))^{\frac{N}{2}} \mathrm{d}q \\ &\geq \rho^2 \left(1-4\rho^4\right)^{\frac{N}{2}} f(\tilde{q}). \end{aligned}$$

Therefore, we have

$$\frac{\int_{A_\rho}(4q(1-q))^{\frac{N}{2}}f(q)\mathrm{d}q}{\int_{\frac{1}{2}-\rho}^{\frac{1}{2}+\rho}(4q(1-q))^{\frac{N}{2}}f(q)\mathrm{d}q} \leq \frac{[1-2\rho]\left(1-4\rho^2\right)^{\frac{N}{2}}f(\hat{q})}{\rho^2\left(1-4\rho^4\right)^{\frac{N}{2}}f(\tilde{q})}$$

$$\leq \frac{(1-2\rho)\,f(\hat{q})}{\rho^2 f(\tilde{q})}\left(\frac{1-4\rho^2}{1-4\rho^4}\right)^{\frac{N}{2}}.$$

Since $\frac{1-4\rho^2}{1-4\rho^4}<1$ for all $\rho\in(0,\frac{1}{2})$ and all the terms in $\frac{(1-2\rho)f(\hat{q})}{\rho^2 f(\tilde{q})}$ are independent of N, we have that for all δ there exists a N such that

$$\frac{\int_{A_\rho}(4q(1-q))^{\frac{N}{2}}f(q)\mathrm{d}q}{\int_{\frac{1}{2}-\rho}^{\frac{1}{2}+\rho}(4q(1-q))^{\frac{N}{2}}f(q)\mathrm{d}q} < \delta.$$

Thus, we have just shown that given ρ for all $\delta>0$ there exists a N such that

$$P\left(\theta_i=s\right|\text{ pivotal }\cup\theta_i) < \frac{1}{2}+\rho+\delta.$$

Since ρ and δ can be chosen as small as desired, we have that for all $\varepsilon>0$ there exists a N such that

$$P\left(\theta_i=s\right|\text{ pivotal }\cup\theta_i) < \frac{1}{2}+\varepsilon.$$

Finally, proceeding as above it can be shown that for all $\varepsilon>0$ there exists a N such that $P\left(\theta_i=s\right|\text{ pivotal }\cup\theta_i)>\frac{1}{2}-\varepsilon$. □

The intuition behind lemma 1 is the following. Conditional on being pivotal and all other N voters voting informatively, it must be that the split of signals in the population is $\frac{N}{2}$ for candidate 0 and $\frac{N}{2}$ for candidate 1. By de Finetti's theorem there exists a random variable q such that, given the realization of q, all signals are correct with probability q (de Finetti's theorem applied to our setting implies that although signals are correlated, by exchangeability there exists a random variable q such that conditional on q all signals are iid). Given that q is not known but its distribution is, the pivotal voter infers that with a large number of voters if he is pivotal it must be that q is arbitrarily close to $\frac{1}{2}$, as otherwise one of the candidates would have received exponentially (in the number of votes) more votes than the other and the voter would not have been pivotal.

Given lemma 1 we have the following result:

Proposition 1. *If all other voters vote informatively, then if a voter's bias is non-negative, there exits an $\hat{N}$ such that for all $N>\hat{N}$ it is a strictly dominant strategy for this voter to vote following his bias.*

Proof. For any non-negative bias level b_i fix any $\varepsilon > 0$ such that $\varepsilon < |b_i|$. According to the result in lemma 1 and equation (1) we have that if N is large enough

$$\Delta u_i(\theta_i) \quad > \quad P\left(\text{pivotal}|\theta_i\right)\left[-2\varepsilon - 2b_i\right].$$

Hence, if $b_i < 0$, then the voter votes for candidate 0. Similarly,

$$\Delta u_i(\theta_i) \quad < \quad P\left(\text{pivotal}|\theta_i\right)\left[2\varepsilon - 2b_i\right].$$

Which means that if $b_i > 0$, then the voter votes for candidate 1. □

The intuition for the result in proposition 1 is that given lemma 1, when other voters vote informatively a voter has no incentive to vote following his signal if his bias is non-negative. This is because, however small the bias, since the voter's (and other voters') signal contains no information when the voter is pivotal, the only factor affecting the voter's expected payoff is the bias.

Our final result shows that the candidate that does not coincide with the state of nature can win with probability one.

Proposition 2. *If the number of voters with positive bias is at least as high as the number of voters with negative bias, then candidate* 1 *wins the election regardless of the state of nature. If the number of voters with negative bias is less than the number of voters with positive bias, then candidate* 0 *wins the election regardless of the state of nature.*

Proof. Define b^m as a bias level such that half the voters have a bias of at most b^m and half the voters have a bias of at least b^m. Note that this value need not be unique. Assume that the number of voters with positive bias is higher than number of voters with negative bias. This implies $b^m > 0$. The proof for the case where the number of voters with positive bias is lower than number of voters with negative bias follows the same logic as what follows and is thus omitted.

From equation (1) we have that the increase in utility from voting to candidate 0 as opposed to voting for candidate 1 is proportional to $P\left(s = 0|\text{ pivotal } \cup \theta_i\right) - \frac{1}{2} - b_i$. Therefore, for any voting strategy employed by other voters we have that there exists a cut-off $b^*(\theta)$ such that if $b_i < b^*(\theta)$, then the voter i votes for 0 and if $b_i \geq b^*(\theta)$, then voter i votes for 1. Note that $b^*(0) \geq b^*(1)$. Note that voters with bias $b_i < b^*(1)$ always vote for 0 regardless the signal they receive, voters with bias $b_i \geq b^*(0)$ always vote for 1 regardless of the signal they receive, whereas voters with bias $b^*(1) \geq b_i < b^*(0)$ vote informatively, i.e. according to their signal.

We now distinguish three cases:

1) If $b^m \geq b^*(0)$, then there are at least half the voters with bias $b_i \geq b^*(0)$. If not exactly half, then this means that candidate 1 always wins, and no voter is ever pivotal, which as above means that if $s = 0$ information aggregation fails. If instead there are equal numbers, then a voter is only ever pivotal if all those with a bias $b_i < b^*(0)$ receive signal 0, which since N is large implies the state is 0 and all voters should vote for 0 regardless of their signal. This contradicts the fact that $b^m > b^*(0)$, i.e. there are voters with bias such that they vote 1.

2) If $b^m < b^*(1)$, then there are at least than half the voters with bias $b_i < b^*(1)$, if not exactly half, then candidate 0 always wins, no voter is ever pivotal, and as above this implies that if $s = 1$ information aggregation fails. If instead there are equal numbers, then a voter is only ever pivotal if all those with a bias $b_i \geq b^*(1)$ receive signal 1, which since N is large implies the state is 1 and all voters should vote for 1 regardless of their signal. This contradicts the fact that $b^m < b^*(1)$, i.e. there are voters with bias such that they vote 0.

3) Finally, consider the case with $b^*(1) \leq b^m < b^*(0)$ and assume there are voters with bias in $(b^m, b^*(0))$ (otherwise proceed as in the case where $b^m > b^*(0)$) and voters with bias $(b^*(1), b^m)$ (otherwise proceed as in the case where $b^m < b^*(1)$). Let N^- be the number of voters with bias $(b^*(1), b^m)$ and N^+ be the number of voters with bias $(b^m, b^*(0))$.

If $\frac{N^+}{N^+ + N^-} > (<) \frac{N^-}{N^+ + N^-}$, then as N becomes large if a voter is pivotal it must be that the state is 0 (1), in which case the best response is to vote 0 (1), thus contradicting the fact that $b^*(1) \geq b^m \geq b^*(0)$.

Finally, if $\frac{N^+}{N^+ + N^-} = \frac{N^-}{N^+ + N^-}$, then the result in lemma 1 can be applied to the population $N^- + N^+$ to show that the posterior on signal quality is arbitrarily close to $\frac{1}{2}$. This means that a voter votes following his bias only, which contradicts the fact that $b^*(1) \geq b^m \geq b^*(0)$. $\square$

4 Conclusions

This paper studies an election where there is correlated information with the possibility of misinformation and voter bias. We find that for any arbitrarily small levels of misinformation and bias information fails to aggregate if the electorate is large enough. The key to the result is that conditional on being pivotal a voter infers that signals are not informative and thus he is better off voting following his bias. The paper contributes to the large literature on information aggregation in large elections by studying the less explored setting where there is correlated information and being novel in the introduction of a small probability of misinformation.

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