Diffusion and Spatial Equilibrium of a Social Norm: Voting Participation in the United States, 1920-2008

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Abstract

Social conformity can spread social norms and behaviors through a society. This research examines such a process geographically and over time for voting, which is strongly influenced by the norm that citizens should vote. A mathematical model for the spread of voting participation under the influence of social conformity is developed based on the diffusion equation, and predictions are tested with spatial analysis of state-level voter turnout in American presidential elections from 1920 to 2008. Results show that voter turnout has converged to a stable equilibrium in its geographical distribution across the states—but it is an equilibrium that results in persistent differences at the state level. Turnout increases about one percentage point with each degree of latitude.

keywords: social norm; voter turnout; social conformity; spatial model; equilibrium; diffusion

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1. Introduction

This research examines the spatial or geographical diffusion of voting participation in the United States, which is strongly influenced by conformity with the social norm that good citizens should vote. Why should this concern us? First, the spatial dimension adds an important factor in understanding turnout; in particular, it helps explain regional differences and their persistence in spite of increasing homogeneity of American society. Diffusion of a social norm can lead to an equilibrium geographically that is not a uniform distribution. Second, the results will show that one may have to take geographic location explicitly into account when explaining social norm-related behavior in a population. Another goal of this research is to show that population-level data analysis can lead to new understandings about social norms that might be very difficult to reach through individual or group analysis.

People often conform their behavior to a widely accepted social norm (Cialdini, 1993; Coleman, 2007a). It also happens that when people see or learn about others' behavior, they may begin to act like them because of their propensity for social conformity. As Cialdini reports, people are increasingly likely to conform to others as the proportion of other people doing something increases. Even the thought that relatively more people are doing something is enough to prompt conformist behavior in many individuals. This is a self-limiting process, however, as not everyone can be brought into conformity; some people are more prone to conformity than others. Conformity is not the only mechanism for social diffusion; ideas can spread when people get information through personal contact and by learning from others, directly or through mass media. But only conformity directly involves the diffusion of behavior patterns within large social groups and populations.

Conformity is greatly affected by nonconscious cognitive processes.[1] People's conformity with a social norm can occur without their conscious awareness, and they may attribute their behavior to other reasons. Individuals may correctly see that social conformity affects others' behavior while holding the illusion that their own behavior is not affected by social influence (Pronin, Berger, and Moluki, 2007). People will conform in private situations as well as in public and change their attitudes and preferences to conform to others. Social sanctions are not necessary to ensure conformity with a social norm, which is the situation with voting in the United States.

Studies on social conformity point to the importance of spatial effects. The willingness of people to comply with social norms, such as voting, recycling, obeying laws, or giving to charity, can vary significantly from place to place (Coleman, 2007a). In a natural social

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[1] See Coleman (2007a) for a review of the research.

context the influence of conformity on an individual is related to the distance from other people as well as to the relative number of people who may express a position or behavior. The joint influence of a group increases with a power function of the number (usually an exponent of about 0.5), but decreases approximately with the square of the distance to the individual (Nowak and Vallacher, 1998: 225).

Voting in a national election is a good case to study the diffusion of a norm because the duty to vote is an important and widely recognized social norm and a presidential election has a strong priming effect. Not everyone may vote because of this norm, but the correspondence is close enough that as we track voting participation, we are also tracking the prevalence of the norm. If voter turnout increases in an area, for example, people who are prone to conformity will be more likely to vote, regardless of the reason for the initial increase in turnout. In this respect, one can say there has been a spread of the norm among the population.

Considerable research backs up the fact that people vote mainly because of the widely held norm that good citizens should vote (Blais, 2000), and social pressure or information about others' voting behavior can increase voting participation (Knack, 1992; Gerber, Green, and Larimer, 2008; Gerber and Rogers, 2009). Much of this research has been at the individual level, but conformity operates at individual, group, and societal levels (Cialdini, 1993), so one would expect to see a spatial effect on political behavior at higher levels of aggregation, such as neighborhoods, counties, states, or nationally. Political research also demonstrates that interaction between people can spread political attitudes and behavior through a local population (Kenny, 1992; Mutz, 1992 and 2002; Huckfeldt and Sprague, 1995; McClurg, 2003).

The impact of social conformity extends across different social behaviors or norms, strengthening its community-wide effect. This happens when conformity with one norm or behavior spills over to bring people into conformity with other norms (Cialdini, Reno, and Kallgren, 1990.) People collectively tend to behave with a consistent degree of conformity in different situations, such as voting, abstaining from committing crimes, giving to charity, and answering the census. Knack and Kropf (1998) show this at the county level and Coleman (2002, 2007a) at state and county levels. Coleman (2002, 2004, 2007a, 2010) also shows that conformity with the voting norm can spill over to affect voting for political parties; this is observable at the state level in the United States and at the national level in smaller countries, such as Germany. So the diffusion of voting participation can lead to a corresponding diffusion of behavior on related social norms—the one reinforcing another.

A growing number of studies demonstrate spatial effects in political behavior over larger areas. One example is when voters change their voting choice to align with the local party majority in a constituency, as research on British voters shows (MacAllister et al., 2001). Tam Cho and Rudolph (2008) analyze political activities of individuals in and around large American cities. They conclude that a part of the spatial pattern of behavior around cities is consistent with a diffusion model and cannot be reduced to socio-demographic differences in the population. Other spatial analyses showing broad regional or community effects, all with aggregate data, concern voter turnout in Italy (Shin, 2001; Shin and Agnew, 2007), the Nazi vote in Germany in 1930 (O'Loughlin, Flint, and Anselin, 1994), realignment in the New Deal (Darmofal, 2008), and voting in Buenos Aires, Argentina (Calvo and Escolar, 2003). One also sees spatial effects at larger geographic scales in the diffusion or contagion of homicide rates (Cohen and Tita, 1999; Messner, et al., 1999); in collective violence such as riots (Myers, 2000); and in the negative association of lynching rates across Southern counties of the United States (Tolnay, Deane, and Beck, 1996). Such evidence points toward a social diffusion process.

2. Diffusion Models

Diffusion models can be very complicated, but here a number of simplifying assumptions are made. The type of social diffusion discussed is that caused by the effect of social influence on individual behavior, with the effect aggregated to a larger population and geographic scale. Influence models have been widely used in social and economic analysis (Bartholomew, 1982). They divide between individual-based models and population models. Among individual models one can largely distinguish among those built up using social networks or lattices (Young, 1999; Morris, 2000; Valente, 2005; Barash, 2011); models of individual decision making in a social field (Granovetter, 1978; Helbing, 1998; Brock and Durlauf, 2001); cellular automata models (Nowak and Vallacher, 1998); and models adapted from statistical physics (extensively reviewed by Castellano, Fortunato and Loreto, 2009).

Individual- or agent-based models face severe challenges (Castellano, Fortunato and Loreto, 2009): the need for realistic micro-level models of behavior, the problem of inferring macroscopic phenomena from the microscopic dynamics, and the compatibility of results with empirical evidence. In their critique, they write, "Very little attention has been paid to a stringent quantitative validation of models and theoretical results" (p. 3). A review of individual-based models in ecology reveals similar findings; Grimm (1999) concludes that such models will never lead to theories at the population level. With respect to this analysis, a principal weakness of the models is that, being essentially theoretical in nature, they rarely make a direct connection with an actual geographical area where they might be tested, that is, where distance and location matter.

This analysis concerns aggregated voting participation or turnout, which is measured on a continuous scale in a model of diffusion at the population level. The most familiar population diffusion model is the gravity model, in which the flow between regions is proportional to the product of their populations and inversely related to the distance between them. But gravity models make no assumptions about individual behavior or social interaction, which is an inherent limitation in the model, and they quickly reach their limit of practicality as the number of interacting regions increases. They are not suitable for a studying continuous change across an area. In contrast, the model for social diffusion here is based on a continuous diffusion model of physics as applied, for example, to the flow of heat across a conducting surface.

In the basic mathematical model for diffusion (Eq. 1), the rate of change in time t of a function $u(x,y,t)$ equals the sum of the second partial derivatives with respect to the spatial coordinates (latitude and longitude) multiplied by an undetermined constant C. In this analysis, u is voter turnout, as defined below. Equation (1), also known as the heat equation, is a model for a diffusion process that applies to aggregate statistical properties, and likewise it is the aggregate statistical character of a population that concerns us here.

$$u_t = C\,(u_{xx} + u_{yy}) \quad (1)$$

The social model assumes: (1) that norms can be spread spatially by social conformity; (2) that internal or external forces for diffusion apart from social conformity are relatively minor or negligible; and (3) that social conformity as a cognitive process is relatively constant during the period of analysis and not discontinuous geographically; that is, people are much the same everywhere but may change their behavior in response to local situations.

At equilibrium, when the time derivative $u_t = 0$, equation (1) becomes the Laplace equation (2)

$$0 = u_{xx} + u_{yy} \quad (2)$$

Instead of trying to apply the diffusion equation (1) directly to state turnout data, the analysis takes an easier research path, which is borne out by the results. The analysis makes successive cross-sectional tests over a series of elections to verify whether the country is approaching or has reached a spatial equilibrium in turnout as represented by the Laplace equation (2).

To test for a Laplace equation model, one can make use of the general characteristics of a solution to the equation. Partial differential equations can be very difficult to solve analytically, so it is common to solve them numerically by approximating them with a discrete lattice model and simulating the model with a computer (Hoffman, 1992). As an approximation to this, one can represent a country by a large number of small geographic areas much like an enormous chess board or lattice; each geographic unit is identified by a point at its geographical center. Assume that voter turnout u is known for each small area. Let each area be identified by its x_i and y_j location on the (x,y) geographical coordinates of the lattice with i counting lattice points from left to right and j from top to bottom. A small unit at (x_i,y_j) has four neighbors (x_i,y_{j+1}), (x_{i+1},y_j), (x_i,y_{j-1}), and (x_{i-1},y_j). Consider next how people in the center unit are influenced by turnout in the neighboring units. To reach a numerical solution, a rule is needed to describe how each unit will change in response to values in the neighboring states. By the Nowak and Vallacher (1998) model and Cialdini's (1993) research, influence is proportional to the relative frequency of people in neighboring units who are expected to vote. The neighboring units are equidistant from the center, so distance is not a factor. What might be the net result on voter turnout in the center unit? Suppose that two of the neighboring units have turnout 50% and two have 70%. One would expect people in the center who are closer to the 50% neighbors to shift their voting behavior in that direction, while voters closer to the 70% areas would tend that way. So a commonsense prediction would be that turnout in the center would tend toward the average, 60%. For the moment consider as a working hypothesis that turnout in the center unit will approximately tend toward the average of turnout in the neighboring units. The analysis subsequently will try to validate this hypothesis.

More formally, let us express the idea that because of the influence of social conformity each unit becomes more like its neighbors, with the turnout at (x_i, y_j) tending toward the average of the turnout in the four neighbors. The units might have any turnout values initially. One can extrapolate what will happen in this arrangement by a mental or computer simulation. At each iteration one successively replaces the turnout value at each point by the average turnout of its four neighbors. That is, at each turn for every point let

$$u(x_i,y_j) = \tfrac{1}{4}\ [\ u(x_i,y_{j+1}) + u(x_{i+1},y_j) + u(x_i,y_{j-1}) + u(x_{i-1},y_j)\ ]$$

This is called a relaxation process. If one does this simulation the result is that after some large number of iterations all units end up with the same turnout value. But this would be an unrealistic outcome; it does not square with reality. With one additional hypothesis, however, this becomes an interesting and realistic model, namely, that turnout values in the units on the geographic boundary of the country (or lattice) do not change, or at least change very little in relation to change in the interior. This seems reasonable because each boundary unit interacts with two neighbors that are also boundary units but with only one interior unit, and change in the interior propagates slowly toward the boundary. The analysis subsequently will check how realistic this hypothesis is.

What can one say about the result of this revised relaxation process after a very large number of iterations? As it turns out, it is not necessary to simulate this on a computer to know the general form of the result. No matter what the initial turnout values are, or the boundary values, this model leads to a distribution of turnout values across the country or lattice that is unique and depends only on the values on the boundary. If the simulation continues until no further change occurs—the steady state—the final distribution of turnout values fits a mathematical function $u(x,y)$ known as a harmonic or potential function (Garabedian, 1964: 458ff); that is, one can solve a Laplace equation numerically by a computer simulation of the type just described (Garabedian, 1964: 485ff).[2] It is this type of function that interests us, not the actual turnout values. Such a function is always a solution of the Laplace equation (2).

A harmonic function has unique properties (Kellogg, 1953): (1) The product of a harmonic function multiplied by a constant is harmonic (scale invariance), as is the sum or difference of two such functions. (2) It is invariant—still harmonic—under translation or rotation of the axes. (3) The function over an area is completely determined by the

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[2] The Laplace equation is solved by approximation with its Taylor expansion to a difference equation that, by rearranging terms, is exactly the equation used in this model. The boundary must be fairly smooth.

values on the boundary; the solution is unique. (4) A harmonic function over a closed, bounded area takes on its maximum and minimum values only on the boundary of the area (if it is not a constant). (5) If a function is harmonic over an area, the value at the center of any circle within the area equals the arithmetic average value of the function around the circle. This implies that averages around concentric circles are equal. The converse is also true. If the averages around all circles equal the values at their centers, the function is harmonic. Note also that the property of scale invariance implies that the size of the units of analysis should not matter much.

The research plan is to conduct a series of tests of this model on state-level turnout data in American presidential elections. There is ample research indicating that voter turnout does vary widely by state, and that conformity has an effect on turnout at the state level. The first test in the analysis will verify that there is a spatial dependence or autocorrelation of turnout values in neighboring states, which is a necessary condition to pursue the diffusion hypothesis. This test can also refute the possibility that the spatial turnout distribution is random. The second test is that the geographical distribution of turnout is a harmonic function. Additional tests use properties of harmonic functions as supplementary checks on the validity of the model. One can examine approximately whether average turnout values around concentric circles are equal, and whether the maximum and minimum turnouts are in border states. These hypotheses would be satisfied trivially if the distribution of turnout were constant, so this situation must be ruled out as well. As it turns out, only one type of harmonic function needs to be tested in this analysis--a linear function of latitude and/or longitude, which is a plane. Ideally one would test this possibility statistically against all non-harmonic function alternatives. This is not possible, but the analysis tests a broad class of alternatives to the harmonic function with quadratic equations, such as $u(x,y) = a x^2 + b x + c$. If the geographic distribution fits such a model in x or y, which represents a curved surface, it is not harmonic. The analysis is limited to testing these hypotheses with areal data of high granularity, however.

3. Spatial Analysis

The field of spatial analysis has developed greatly in recent years, adding more sophisticated statistical methods to earlier geographic, map-based analysis (Haining 2003). Because of the complexity of spatial analysis, however, it remains mainly a method of exploratory data analysis. This analysis uses the geographical software GeoDa 0.9.5 developed primarily by Luc Anselin, who pioneered many of the methods used in spatial analysis (Anselin, L., Sybari, I., and Kho, Y., 2006). GeoDa is available at no charge via the Internet from Arizona State University (http://geodacenter.asu.edu). GeoDa follows the ArcView standard for geometric area data files developed by ESRI, Inc. To construct a map and analyze the corresponding data, three different files are required: a shape file that describes the geometry of each unit, an index file, and a data file in dBase format. It is burdensome to construct these files, but fortunately many such files already exist and are available online without charge. Shapefiles at the state level for the United States are widely available through the Internet; this analysis uses files from Idaho State University's open-source MapWindow (http://www.mapwindow.org). Only the contiguous 48 states are included in this analysis.

The working hypotheses of this spatial analysis are that distance matters and that being closer means a having a stronger effect, which is in accord with research on social conformity. If spatial dependence is present, one expects to see an association or correlation between neighboring areas on the same behavioral dimension. The definition of correlation depends, however, on how one defines neighborhood and the type of distance measure used. So the concept of correlation is more complex than the analogous application in time-series or bivariate analysis. Because spatial dependence weakens with increasing distance from a location, the analysis must focus on areas or regions around a location where one might reasonably find a strong autocorrelation. For each areal unit one identifies its nearest neighboring units where one would expect to see the strongest spatial autocorrelation. In this analysis the neighbors of a state are the states that share a common border with it (but not just a vertex); this is called rook contiguity by analogy with chess. Because of the great differences in sizes of the states, this works better than using a distance metric such as miles to identify neighbors. Under this definition of neighbors, the spatial lag for a state is the average turnout in the bordering states. The spatial autocorrelation for states is the correlation between their turnout and their spatial lag.

With geographically based data at hand and neighborhoods identified, one can move on to investigate spatial autocorrelation. A spatial autocorrelation may refer to an attribute of an entire country, or it may refer to regions within a country. One might also observe a spatial autocorrelation in the absence of a true diffusion effect, perhaps because each geographical unit had been simultaneously affected by a remote influence, or because of random chance events or historical circumstances. In any case, an analysis must first determine that an observed spatial autocorrelation is not random but statistically significant (Ward and Gleditsch, 2008).

4. Results

The analysis begins with an examination of the spatial distribution of voter turnout in eight presidential elections: 1920, 1940, 1960, 1968, 1980, 1992, 2000, and 2008. Voter turnout is based on the voting-age population in the 48 contiguous states. The hypothesis that the state turnout distribution is a harmonic function of location is tested on these elections. The purpose of using widely spaced elections is to allow a basic consideration of change over time, while giving more attention to recent elections. The other two hypotheses about harmonic function averages and locations of extrema, being less complex statistically, are tested on all elections from 1920 to 2008. As stated previously, for this analysis the neighbors around each state are defined as the set of states that have a boundary in common with it. It is a gross approximation of the lattice model discussed earlier but is sufficient to test the model. In the U.S. this identification of neighbors leads to different numbers for the states. The most common number of neighbors is four, and forty states have between three and six states sharing a border. (The exact arrangement of neighbors does not affect the solution to the Laplace equation, though it may affect the rate of convergence to a solution in a numerical analysis.)

A cursory examination of state-level turnout shows that, typically, low turnout values are in the South and high values in the North. Compared to earlier elections, however, 2008 shows a slight shift of low turnout states toward the Southwest from the South, the traditional location. Spatial autocorrelation for the entire country is assessed with Moran's *I*, a test of spatial dependence among neighboring states that will indicate whether the spatial distribution is random or not. As with Pearson's correlation, Moran's *I* can be positive or negative, with the customary range [-1,1]; a value close to zero implies no autocorrelation. It is based on the aggregate of autocorrelations in the neighborhoods of all states. When states with above average turnout are neighbors of states that also have above average turnout, the *I* value increases; the same holds when below average turnout states border other low turnout states. In 1920, for example, $I = 0.55$ ($p < .0001$), indicating a substantial and statistically significant spatial autocorrelation across the country. The significance level of a Moran's *I* estimate is determined by a permutation test (repeated 999 times) (Efron and Tibshirani, 1998). Results in Table 1 show that in all eight elections of the analysis the U.S. definitely has significant spatial autocorrelation of voter turnout in neighboring states that is not random. This meets the necessary criterion for a possible diffusion process at the state level.

4.1 Harmonic function hypothesis

The nonrandom, north-south gradient in the turnout suggests modeling the state turnout distribution as a function of latitude and, perhaps, longitude. The map shapefile contains information on the longitude and latitude points of the polygon vertices used to map each state. From these points GeoDa can compute the centroid, which is the latitude-longitude location of the geometric center of gravity of the state. This location is used in the analysis. A linear function of latitude or longitude, representing a plane surface, is a solution of the Laplace equation and a harmonic function, so it is a good first test of whether the geographical distribution is a harmonic function. Table 2 shows the results of linear regression of turnout against latitude and longitude at the state centroid, but longitude is not statistically significant except in 2008. GeoDa estimates spatial regression models with a maximum likelihood procedure because OLS regression can lead to biased coefficient estimates when there is spatial autocorrelation.

Each regression model after 1920 explains about half the variance in state turnout (Table 2). As a function of latitude, turnout increases more slowly after 1960 than in earlier elections; that is the geographical gradient is less steep. In fact, latitude coefficients in 1980, 1992, and 2000 are close to equality, within a margin of error, and only somewhat less in 2008. From 1980, turnout increases about one percentage point with each degree of latitude. Checking for curvature with a quadratic model, however, one finds better models (with errors) for 1920 and 1940.

$$\text{1920 turnout} = -457\ (117) + 24.1\ (6.1)\ \text{latitude} - 0.281\ (0.088)\ \text{latitude}^2$$
$$\text{1940 turnout} = -470\ (134) + 24.5\ (7.0)\ \text{latitude} - 0.275\ (0.089)\ \text{latitude}^2$$

For 1920, R square = 0.51, and the fitted quadratic surface has a maximum at about latitude 43 degrees (the latitude of Madison, Wisconsin); for 1940, R square = 0.56.

The regression analysis thus shows that a plane dependent only on latitude fits the turnout data well in elections from 1960 to 2000 but not so well in 1920 and 1940 when the distribution fits a convex quadratic surface; in 2008 a plane also fits but with both latitude and longitude significant. Because a plane is a harmonic function, all the elections except 1920 and 1940, satisfy the first diffusion hypothesis. This leads to the inference that as a result of diffusion, the distribution of turnout has changed over time to approximate an equilibrium from 1960 on.

Table 2 also indicates whether spatial lag or spatial error correlations remain significant when turnout is modeled as a function of latitude and longitude; this is assessed with a Lagrange multiplier (LM) test (Ward and Gleditsch, 2008). If significant, the spatial lag test suggests a possible bias in the estimation of the coefficient, a missing covariate, or other regression problems. In 1920 and 1940, for example, the test indicates a problem, because a quadratic regression model fits better. From 1968 on, however, latitude and longitude completely determine the spatial lag; it is no longer significant in the regression model except marginally for 1992. The spatial error term is not significant in 1960 and is of marginal significance in elections in 1992 and after, when its possible impact on the estimated model, if any, is slight. When turnout varies linearly with latitude or longitude it also supports the hypothesis that, in the steady state, turnout in the center unit is approximately the average of values in neighboring units. Of course, precision is limited by the granularity in state-level location data.

Because of the possibility of omitted covariates and to gain more information on the diffusion process, the 1992 election was reanalyzed with a regression on latitude, adding variables related to education and income--factors known from prior research to affect turnout (e.g., Wolfinger and Rosenstone, 1980)--as well as population and population density, which might bear on social diffusion. Results are in the Appendix. Of the additional factors, education, represented by average SAT scores, is the strongest, but latitude remains by far the most important explanatory variable overall; other variables have marginal significance. Region (Northeast, Midwest, South, and West) is not significant as a factor in the model, indicating that the relationship between latitude and turnout is not simply a regional effect. The fact that variables other than location may be significant in 1992 or other elections does not diminish the importance of the diffusion process, but differences among the states can create bumps in the spatial distribution. In any event, the aim is not to find the best socioeconomic model for every election but to identify whether there is a geographical equilibrium in turnout that has persisted over time.

4.2 Mean-value hypothesis.

The second hypothesis test for harmonic functions is that the average values around concentric circles are equal and are equal to the value at the center. As an approximation, the analysis divides the states into two groups: those on the boundary or border and those in the interior. Here 30 states are identified as boundary states and 18 as interior states. (Boundary states are: WA, OR, CA, AZ, NM, TX, LA, MS, AL, FL, GA, SC, NC, VA, MD, DE, NJ, NY, CT, RI, MA, VT, ME, OH, MI, WI, MN, IL, ND, MT. Interior states: ID, NV, UT, CO, WY, SD, OK, AR, IA, IN, KY, WV, TN, NH, PA, NE, KS, MO.) States where the national border length is very short in relation to interior border length, are classified as interior states. This results in Idaho, Indiana, and Pennsylvania being interior states.

The harmonic property suggests that to an approximation the average value of turnout in the boundary states should equal the average in the interior states. This is tested with a t-test for every election from 1920 to 2008.

The trend from 1920 to 2008 is strongly toward equality of means as seen in Figures 1 and 2. Of the 23 elections in the analysis, the boundary and interior means are equal (the null hypothesis is not rejected) in 15, at a significance level of $p = .05$. (T-tests were adjusted for unequal variance but not corrected for multiple tests.) Elections with statistical rejection of equal means run from 1920 to 1936 and 1952 to 1960. But in the ten elections from 1972 on, the difference between mean boundary and interior turnout is consistently less than 2 percentage points and is 1 point or less in six elections.

As seen in Figure 2, which plots the trend in the difference in means between boundary and interior states, there is a remarkably consistent convergence of the difference to zero. The trend is strongly linear:

$$\text{Difference in Mean Turnout Percentages} = 374\ (20) - 0.19\ (0.01)\ \text{Year}$$

For variable Year, the 95% CI = [-0.21, -0.17] and R square = 0.94. So the difference in turnout between boundary and interior averages has decreased at a rate of about 0.2 percentage points per year or 0.8 points per election. The strong linearity of the change, meaning a constant rate of change, is a remarkable sign of the gradual and persistent effect of social diffusion.

4.3 Maximum and minimum hypothesis.

The third hypothesis test of a harmonic function is that the maximum and minimum are on the boundary. Over almost all the elections the minimum has been on the boundary, namely in a southern state. The maximum has been less often on the boundary, but from 1976 it has been in Minnesota or Maine, both on the northern border. Utah or Idaho (interior states) had the top values in elections from 1944 to 1968. From 1976 on, the minimum was in South Carolina five times, Texas twice, and once each in Nevada and Arizona; all but Nevada are on the border. So eight of the nine elections from 1976 to 2008 satisfy the hypothesis for both maximum and minimum. The chance of either the maximum or minimum being on the boundary in a given election is 30/48 = 0.625 if all combinations are equally likely. By the binomial distribution the probability of exactly one missed prediction of 18 for the nine elections from 1976 is p = 0.002. So the analysis confirms the hypothesis for the group of elections from 1976, which agrees with the other results that the country has gradually converged toward a harmonic distribution and equilibrium from 1920 to 1968 and beyond.

4.4 Stability of boundary values

A final test is whether the boundary values are stable, which was hypothesized when developing the lattice model. Figure 1 indicates that average boundary values stabilized in the 1950s; and analysis shows no linear trend for average turnout in the boundary states from 1952 to 2008 (p = .11). But over this period the average turnout of interior states was decreasing (linear slope = - 0.27, p = .0003). The average turnout in boundary states was 55%, and it remained in a narrow range with 95% CI [53.0-57.1].

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Analysis shows that the geographic distribution of turnout across the states has increasingly approximated a harmonic function, namely a plane, with the results closest to prediction from about 1980 and with turnout increasing about one percentage point for each degree of latitude. Over half the variation in state turnout rates in each election analyzed from 1960 to 2000 can be accounted for by the latitudes of the states; in 2008 latitude and longitude account for slightly less than half the variation. Variation in turnout also has decreased greatly, the standard deviation of state turnout falling from 18 in 1920, to 6.6 in 1980, to 6.4 in 2000.

The steady convergence of average interior and boundary turnout values for at least 80 years tells of a diffusion process that has been little affected by either short-term political and economic changes or by long-term generational changes. In essence the U.S. has undergone a slow averaging or smoothing of turnout across its territory, as assumed in the lattice model of social diffusion, and in accord with the presumed effect of social conformity on the voting norm. In spite of that, however, the country as a whole has maintained a substantial north-south gradient in state turnout levels indicative of a spatial equilibrium.

One might ask whether some other social process could have produced the observed results. Clearly, there has be a great increase in homogeneity in American society over this time period, and voting reforms have eliminated the discrimination of early years. Mass media, migration, and economic development have reduced regional diversity. Such factors undoubtedly account for much of the reduction in state-level variation in voter turnout and have caused some smoothing of the geographical distribution. But the harmonic-function characteristic of the distribution has remained quantitatively about the same since the 1980s in spite of many changes in American society over this period. Furthermore, statistical tests of the model, including tests for remaining spatial lag and the auxiliary regression analysis of 1992, do not indicate any serious problems with specification or estimation of the model.

5. Discussion

The degree of social conformity with an important norm, such as voting, can vary across both time and geography. As people in one area influence those in the next, and so on, the degree of conformity can change across a landscape, with a general trend toward a smooth transition in behavior from one area to the next. Because conformity is a universal human characteristic one can expect to see this process at work in every society, and a general model of diffusion should be the goal of research. The methods of spatial analysis were developed primarily for exploratory data analysis, however, and they do not help much in developing and testing general theories about spatial diffusion or equilibrium. The model and analysis here add another layer of explanation to what is offered by spatial analysis—a layer more aligned with theory construction and testing.

One can compare the results here with findings about a normative equilibrium in individual-based analyses, including agent-based models. Young (1999) explores how the sizes of networks affect societal dynamics using a network model of individual behavior in a social context. In his model, a society with small, close-knit networks evolves rapidly toward stability with most people having the same behavior. But the model does not speak to persistent geographical differences or to the type of geographical equilibrium seen here. Brock and Durlauf (2001) model conformity in the situation when individuals conform to the mean of a common reference group. In their model, under certain general conditions of utility maximization, there will be at least one equilibrium at the average choice level of the society. Under slightly varied conditions multiple equilibria can occur in the absence of coordination among individuals. This is the situation when social groups with different social norms exist contemporaneously. Brock and Durlauf also discuss how neighborhoods can differ significantly under effects of conformity, but they do not extrapolate from the possibility of different neighborhood equilibrium levels to continuous change over a geographical area, or to a harmonic function type equilibrium. It is hard to see how that would flow naturally from their model.

Agent-based models from statistical physics also have been used extensively to study social interaction and conformity effects (Castellano, Fortunato and Loreto, 2009). For example, such models have been used to show how the distribution of voting might evolve in a hypothetical society from an initial distribution of voters and nonvoters. The agents are placed on lattice (similar to the procedure used here) and interaction between neighboring agents is specified. What happens next is followed through a computer simulation. Too many variations of this model have been analyzed to summarize them succinctly, but their shared weakness is the lack of applicability to an actual geographical area where they might be tested empirically.

In contrast to the difficulties of individual-level models in explaining population behavior geographically, the model here succeeds by making interesting predictions that can be tested and confirmed, while not being so obvious as to make them trivial; this should be a goal of social science models generally (Coleman, 2007b). In other words, the results point much more strongly to a diffusion process as predicted by the model than to any alternative explanation. And the results give a new perspective on the spatial distribution of social-norm related behavior, which may fit other social norms as well. It does not overcome the problem of directly linking micro- and macro-level behavior. But the model here is based on strong evidence from multiple research studies that many people vote because of the injunctive social norm that citizens should vote or because of the perception that others are voting. The results also suggest that the population-level model is quite robust to variation in individual behavior and changes in the electorate, considering how varied individual voting behavior has been across the states and over time and from one generation of voters to the next. Indeed this is exactly the value of a population model based on aggregate statistical properties.

The goal here is not to explain voter turnout but to examine how social diffusion of a norm may have affected voter turnout geographically. Nevertheless, one can see immediately from these results that studies of voting behavior will possibly have to include spatial lags and geographical location, which has not been common practice. In general, one must be open to the possibility that location is pertinent to conformity with social norms.

Another important finding is the very slow, exceptionally steady rate of change in voting participation over time in the U.S., as average turnout in interior states converged toward that of the boundary states, and the country as a whole began to show the characteristics of a steady-state conclusion to a diffusion process. The diffusion model did not fit the U.S. in 1920 or 1940 but the overall state distribution starts to fit by 1960 as a plane function of latitude and gradually other characteristics of a harmonic function become evident. Clearly, the degree of conformity with the social norm of voting does not change easily. There are situations when conformist change can diffuse rapidly through a society; fashions, fads, and crime waves are examples. But in the U.S. elections one sees a diffusion process in voting participation that has taken several generations and 80 years or more to reach its current, nearly harmonic distribution close to a steady state. This also means that the turnout distribution is not going to change much from now on. Local bumps might get smoothed out, but the north-south gradient is likely to remain mostly as it is for the foreseeable future. The geographical distribution appears to have reached a relatively stable equilibrium distribution, but this does not imply uniformity across the country.

References

Anselin, L., Sybari, I., and Kho, Y. 2006. GeoDa: An introduction to spatial data analysis. Geographical Analysis 38: 5-22.

Barash, V. 2011. The Dynamics of Social Contagion. Doctoral Dissertation. Cornell University.

Bartholomew, D.J. 1982. Stochastic Models for Social Processes. NY: Wiley.

Blais, A. 2000. To Vote or Not to Vote: The Merits and Limits of Rational Choice Theory. Pittsburgh, PA: University of Pittsburgh Press.

Brock, W.A. and Durlauf, S.N. 2001. Discrete choices with social interactions. The Review of Economic Studies, 68: 235-260.

Calvo, E., and Escolar, M. 2003. The local voter: A geographically weighted approach to ecological inference. American Journal of Political Science 47: 189-204.

Castellano, C., Fortunato, S. and Loreto, V. 2009. Statistical physics of social dynamics. Rev. Mod. Phys. 81: 591-656.

Cialdini, R.B. 1993. Influence: Science and Practice. 3rd ed. N.Y.: Harper Collins.

Cialdini, R.B., Reno, R.R., and Kallgren, C.A. 1990. A focus theory of normative conduct: Recycling the concept of norms to reduce littering in public places. Journal of Personality and Social Psychology 58: 1015-1026.

Cohen, J. and Tita, G. 1999. Diffusion in homicide: Exploring a general method for detecting spatial diffusion processes. Journal of Quantitative Criminology 15: 451-493.

Coleman, S. 2002. A test for the effect of social conformity on crime rates using voter turnout. Sociological Quarterly 43: 257-276.

Coleman, S. 2004. The effect of social conformity on collective voting behavior. Political Analysis 12: 76-96.

Coleman, S. 2007a. Popular Delusions: How Social Conformity Molds Society and Politics. Youngstown, NY: Cambria Press.

Coleman, S. 2007b. Testing theories with qualitative and quantitative predictions. European Political Science 5: 124-133.

Coleman, S. 2010. [Коулман, С.] Реформа российской избирательной системы и влияние социальной конформности на голосование и партийную систему: 2007 и

2008 годы [Russian election reform and the effect of social conformity on voting and the party system: 2007 and 2008.] Журнала Новой экономической ассоциации [Journal of the New Economic Association (Moscow)] 5: 72-90. English version at http://www.econorus.org/enjournal.phtml.

Darmofal, D. 2008. The political geography of the New Deal realignment. American Politics Research 36: 934-961.

Efron, B. and Tibshirani, R.J. 1998. An Introduction to the Bootstrap. Baton Rouge, FL: Chapman and Hall.

Garabedian, P.R. 1964. Partial Differential Equations. New York: Wiley.

Gerber, A., Green, D.P., and Larimer, C. 2008. Social pressure and voter turnout: Evidence from a large-scale field experiment. American Political Science Review 102: 33-48.

Gerber, A, and Rogers, T. 2009. Descriptive social norms and motivation to vote: Everybody's voting and so should you. Journal of Politics 71: 178-191.

Granovetter, M. 1978. Threshold models of collective behavior. The American Journal of Sociology 83: 1420-1443

Grimm, V. 1999. Ten years of individual-based modeling in ecology: what have we learned and what could we learn in the future? Ecological Modelling 116:129-148.

Haining, R. 2003. Spatial Data Analysis: Theory and Practice. New York: Cambridge University Press.

Helbing, D. 1998. A mathematical model of the behavior of individuals in a social field. arXiv:cond-mat/9805194v1 [cond-mat.stat-mech].

Hoffman, J.D., 1992. Numerical Methods for Scientists and Engineers. NY: McGraw-Hill.

Huckfeldt, R. and Sprague, J. 1995. Citizens, Politics, and Social Communication: Information and Influence in an Election Campaign. NY: Cambridge University Press.

Kellogg, O. D. 1953. Foundations of Potential Theory. New York: Dover.

Kenny, C. B. 1992. Political participation and effects from the social environment. American Journal of Political Science 36: 259-267.

Knack, S. 1992. Civic norms, social sanctions, and voter turnout. Rationality and Society 4: 133-156.

Knack, S. and Kropf, M.E.. 1998. For shame! The effect of community cooperative context and the probability of voting. Political Psychology 19: 585-599.

MacAllister, I. R., Johnston, R., Pattie, C. Tunstall, J.H., Dorling, D., and Rossiter, D.G.. 2001. Class dealignment and the neighborhood effect: Miller revisited. British Journal of Political Science 31: 41-60.

McClurg, S. D. 2003. Social networks and participation: The role of social interaction in explaining political participation. Political Research Quarterly 56: 449-464.

Messner, S.F., Anselin, L., Baller, R.D., Hawkins, D.F., Deane, G., and Tolnay, S.E.. 1999. The spatial patterning of county homicide rates: An application of exploratory data analysis. Journal of Quantitative Criminology 15: 423-450.

Morris, S. 2000. Contagion. Review of Economic Studies, 67: 57-78.

Mutz, D. 2002. The consequences of cross-cutting networks for political participation. American Journal of Political Science 46: 838-855.

Mutz, D. 1992. Impersonal influence: Effects of representations of public opinion on political attitudes. Political Behavior 14: 89-122.

Myers, D. J. 2000. The diffusion of collective violence: Infectiousness, susceptibility, and mass media networks. The American Journal of Sociology 106: 173-208.

Nowak, A. and Vallacher, R.R. 1998. Dynamical Social Psychology. New York: Guilford Press.

O'Loughlin, J., Flint, C., and Anselin, L. 1994. The geography of the Nazi vote: Context, confession, and class in the Reichstag election of 1930. Annals of the Association of American Geographers 84: 351-380.

Pronin, E., Berger, J., and Moluki, S. 2007. Alone in a crowd of sheep: Asymmetric perceptions of conformity and their Roots in an introspection illusion. Journal of Personality and Social Psychology 92: 585-595.

Shin, M. E. 2001. The politicization of place in Italy. Political Geography 20: 331-352.

Shin, M. E., and Agnew, J. 2007. The geographical dynamics of Italian electoral change. Electoral Studies 26: 287-302.

Tam Cho, W. and Rudolph, T.R. 2008. Emanating political participation: Untangling the spatial structure behind participation. British Journal of Political Science 38: 273-289.

Tolnay, S. E., Deane, G. and Beck, E.M. 1996. Vicarious violence: Spatial effects of Southern lynchings. The American Journal of Sociology 102: 788-815.

Valente, T.W. 2005. Network models and methods for studying the diffusion of innovations. In P.J. Carrington, J. Scott, and S. Wasserman, (Eds.), Models and Methods in Social Network Analysis (pp. 98-116). NY: Cambridge University Press.

Ward, M. and Gleditsch, K. 2008. Spatial Regression Models. Thousand Oaks, CA: Sage.

Wolfinger, R.E. and Rosenstone, S.J. 1980. Who Votes? New Haven: Yale University Press.

Table 1. Moran's *I,* a measure of spatial autocorrelation for the entire country.

Election	**Moran's *I***
1920	0.55
1940	0.72
1960	0.70
1968	0.57
1980	0.53
1992	0.53
2000	0.52
2008	0.41

Note: all elections significant at $p < .001$.

Table 2. Regression model: turnout % = constant + b_1 * latitude + b_2 * longitude

Year Turnout	**Constant (error)**	**Latitude b_1 (error)**	**Longitude b_2 *(error)***	**R squared**	**Spatial Lag Lagrange Multiplier significance**	**Spatial Error Lagrange Multiplier significance**
1920	-39.9 (17.6)	2.28 (0.44)	ns	0.36	.004	.02
1940	-61.0 (20.0)	3.12 (0.49)	ns	0.46	<.001	.005
1960	-33.5 (12.2)	2.50 (0).31)	ns	0.59	.002	.06
1968	13.9 (6.5)	1.23 (0.16)	ns	0.55	.35	.003
1980	16.7 (5.7)	1.00 (0.14)	ns	0.51	.10	.01
1992	13.2 (6.0)	1.12 (0.15)	ns	0.55	.05	.04
2000	13.1 (5.2)	1.04 (0.13)	ns	0.58	.14	.06
2008	39.2 (7.0)	0.81 (0.15)	0.13 (0.05)	0.45	.40	.05

Note: Latitude and longitude are at the centroids. Longitude not included in the model if not statistically significant (ns). All regressions significant at $p < .0001$.

Figure 1. U.S. elections, 1920-2008, average interior and boundary turnout with LOWESS smoothing.

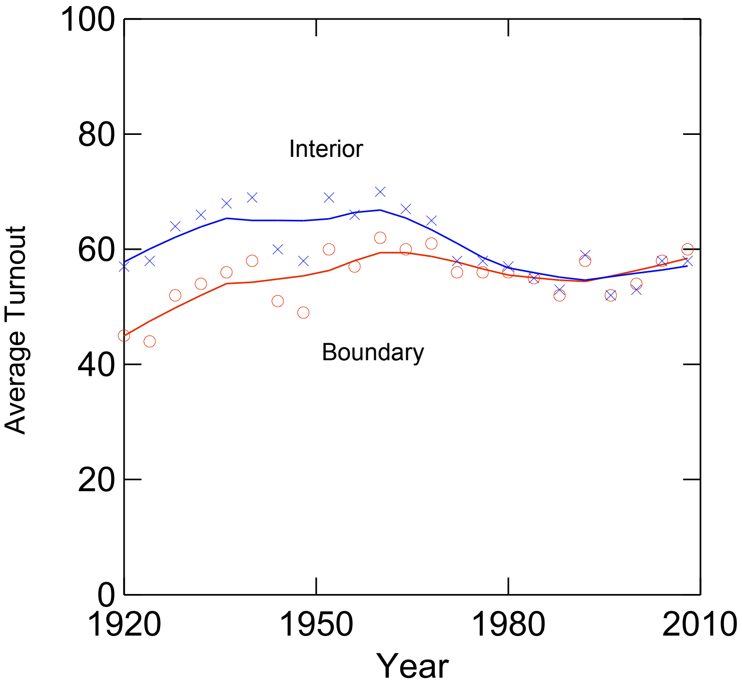
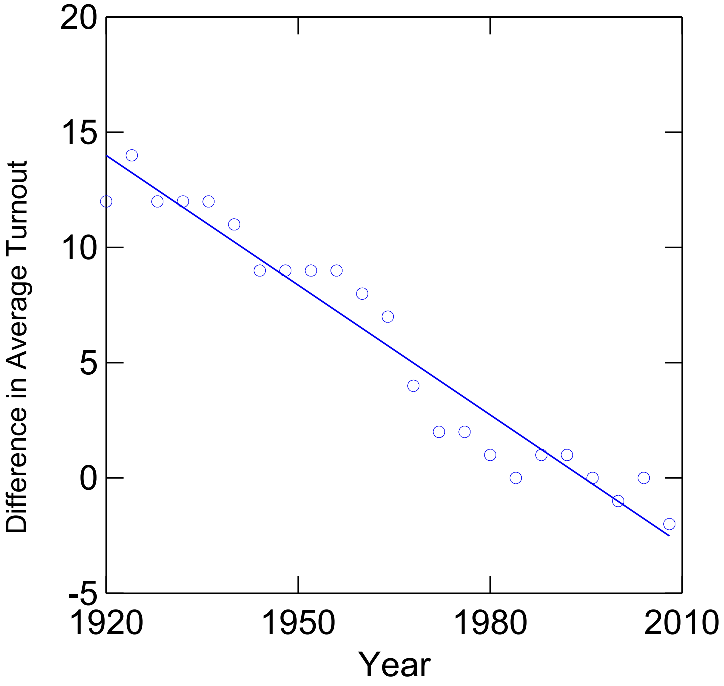


Figure 2. U.S. elections, 1920-2008, difference between average interior state turnout and average boundary state turnout with linear fit.



Appendix

Expanded regression models for U.S. state turnout in 1992 including latitude, socio-economic, and demographic variables from the 1990 U.S. Census.

Variable	**Coefficient**	**Std. Error**	**p**
Constant	-21.4	11.4	.07
Latitude at centroid	0.82	0.14	<.00001
Average Verbal SAT 1992-93	0.083	0.021	.0003
Marriage Rate	- 0.095	0.042	.03
Population 1990	- 0.00026	0.00012	.04
Income	0.00043	0.00018	.02
Pop. Density	- 0.0074	0.0036	.05

N= 48, R square = 0.75, F = 21. Verbal SAT test scores are an indicator of educational achievement among students applying for college, which may reflect the general educational level in the population (source: *Digest of Education Statistics 1995*, International Center for Education Statistics). Latitude is at the centroid. Marriage rate is per 1,000 population. Income is per capita. Population is 1000s. Latitude 95% CI = [0.54, 1.10]. Region (Northeast, Midwest, South, and West) is not statistically significant if included as a factor in an ANOVA model with the covariates. .

Above model with latitude and verbal SAT only.

Variable	**Coefficient**	**Std. Error**	**p**
Constant	-20.9	8.9	.02
Latitude	1.01	0.13	<.00001
Verbal SAT	0.085	0.02	.00004

R square = 0.69, F = 50.