Modeling the Evolution of Ideological Landscapes Through Opinion Dynamics

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Abstract This paper explores the possibilities to explain the stylized facts of empirically observed ideological landscapes through the bounded confidence model of opinion dynamics. Empirically, left–right self-placements are often not normally distributed but have multiple peaks (e.g., extreme-left-center-right-extreme). Some stylized facts are extracted from histograms from the European Social Survey. In the bounded confidence model, agents repeatedly adjust their ideological position in their ideological neighborhood. As an extension of the classical model, agents sometimes completely reassess their opinion depending on their ideological openness and their propensity for reassessment, respectively. Simulations show that this leads to the emergence of clustered ideological landscapes similar to the ones observed empirically. However, not all stylized facts of real world ideological landscapes can be reproduced with the model.

Changes in the model parameters show that the ideological landscapes are susceptible to interesting slow and abrupt changes. A long term goal is to integrate models of opinion dynamics into the classical spatial model of electoral competition as a dynamic element taking into account that voters themselves shape the political landscape by adjusting their positions and preferences through interaction.

Keywords Continuous opinion dynamics • Bounded confidence • European social survey • Stylized facts • Homophile adaptation • Random reconsideration • Consensus • Polarization • Plurality

1 Introduction

Voters' ideological preferences are the basis of electoral behavior in spatial models of electoral competition. This holds for the classical rational choice model of Downs [3] as well as for agent-based models of multidimensional and multiparty competition [8, 11, 12]. In these models parties or candidates follow optimizing

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or satisficing strategies and heuristics to win as many voters as possible, while the voters have stable never changing preferences on which basis they vote non-strategically for the party which manifesto is closest to their ideological ideal point. Thus, only the choice of a party is modeled not the choice of the preferences of voters. Laver [11, p. 280] acknowledges that "Almost all observers of real politics believe voter preferences to evolve dynamically in response to the development of political competition, yet static models of party competition find this type of feedback difficult to handle." This paper shall serve as a first attempt to model dynamics of voter preferences based on opinion dynamics between voters.

Opinions are subjective statements which summarize and communicate emotions, attitudes, beliefs, and values to others. Thus, on the one hand, opinions are a manifestation of individual preferences because of their summarizing nature. On the other hand, opinions can trigger changes of opinions of others because they are an act of communication. While political science has a large literature on the mechanism of opinion formation within the individual and how it can be shaped towards public opinion through mass media and political communication [see, e.g., 7, 23], not so much attention has been spent to study systemic effects triggered by the mechanisms of interaction between voters.

In this context, systemic effects are effects which are triggered by behavior on the individual level but which go beyond the scope of the individual. Thus, we look at the evolution of the landscape of opinions based on local interaction to detect possible hidden driving forces which shape the evolution of opinion landscapes. We do this partly instead of studying in detail the individual process of opinion formation for contextual information or the aggregation of public opinion from individual opinions.

One suitable model is the bounded confidence model of continuous opinion dynamics [1, 9, 10, 21]. The model triggered a large stream of literature within the scientific communities of social simulation and the physics of socio-economic systems [see 13]. This paper is to explore the usability of the model as a model of preference formation of many agents in ideology spaces based on some stylized facts of ideological landscapes based on left-right self-placements in different countries in the European Social Survey (ESS).

The paper is organized as follows. First, empirical opinion landscapes will be presented and stylized facts will be derived. Second, the bounded confidence model of continuous opinion dynamics will be presented. Third, the main dynamics triggered on the level of opinion landscapes will be shown. Fourth, the matching between empirical landscapes and modeling results will be discussed.

2 Opinion Landscapes: Empirical Observations

We use data from the European Social Survey (ESS rounds 1–6) to get a glimpse of opinion landscapes and their characteristics. Figure 1 shows the left–right ideology landscapes of France and Sweden over all available ESS rounds from 2002 to 2012.

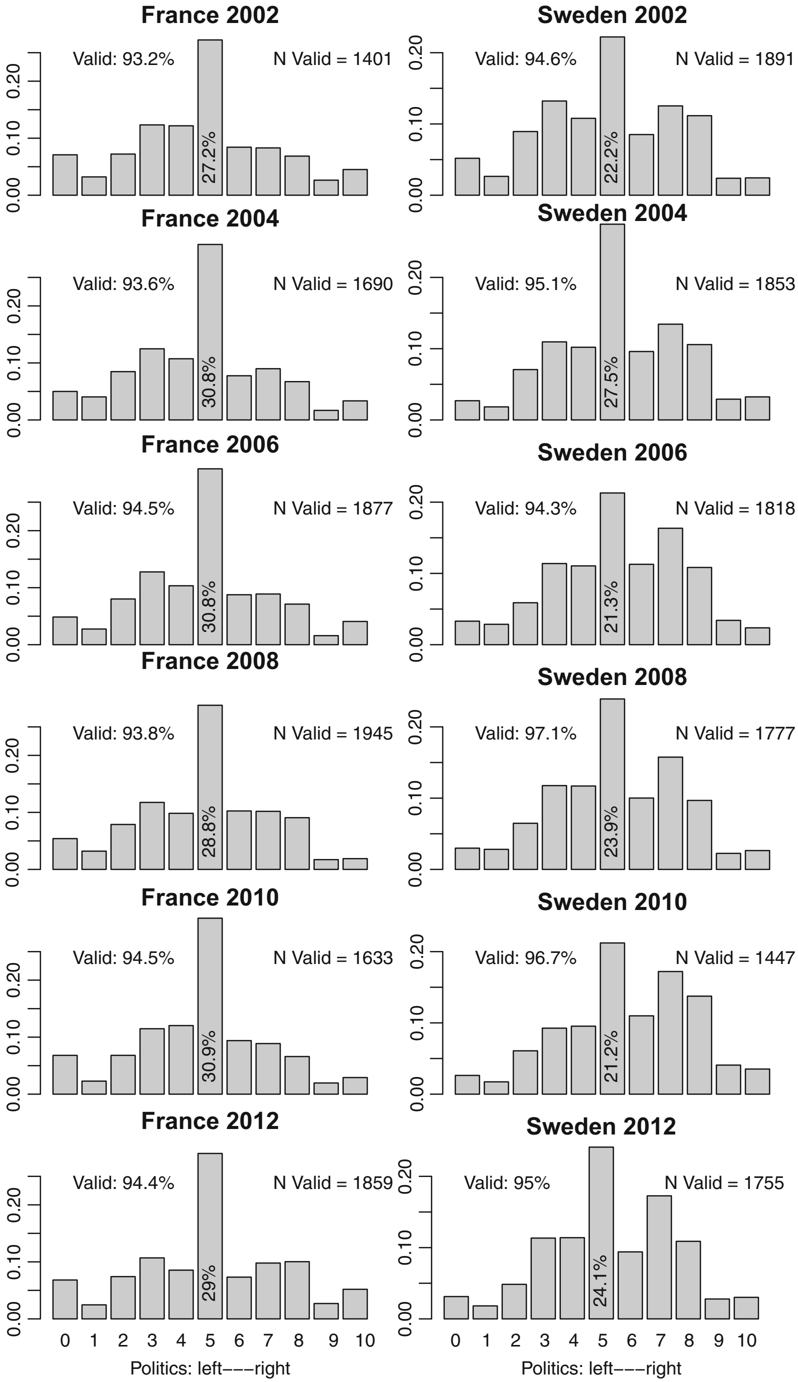

Fig. 1 Time evolution of opinion landscapes of the left–right scale from ESS 2002–2012

Answering the survey, people self-place themselves on a left–right scale with 11 grades ranging from zero (left) to ten (right). Shown are weighted histograms over the full samples per country in rounds. Individuals were weighted using the design weights delivered with the ESS dataset. This corrects for biases of the sampling design. Accompanying each opinion landscape, the percentage of valid answers and the number of valid answers is reported. Valid answers typically exclude "Refusal," "Don't know," and "No answer."

Looking at the empirical opinion landscapes the following **stylized facts** can be extracted:

1. Distributions never visually fit any "standard distribution." It is far from being uniform or normal distributed.
2. The largest peak is always at the center (bin 5). It almost always exceeds neighboring peaks by far giving a "non-continuous" impression.
3. Multiple peaks are almost ubiquitous.
4. Very often extremal peaks exist on both sides. The next-to-extremal bins 1 and 9 are almost always lower than both of their neighboring bins.
5. Peaks at 3 (moderately left) and 7 (moderately right) are frequent. The next-to-center bins at 4 and 6 are often low compared to both of their neighbors. There seems to be a tendency that moderate left and moderate right clusters might form. Especially on the right wing the peak of the cluster might also lie at 8 instead of 7 (e.g., Israel or France 2012).
6. The "shape" of landscapes away from the center and the extremes often has a "smooth" look without abrupt jumps giving the impression that a smooth continuous curve underlies the bins.

Looking at the evolution of opinion landscapes over time shows that opinion landscapes usually change slowly over time. Focusing on the off-center moderate left and right clusters around the bins 3 and 7 shows some tendencies of movement. Clusters might slightly drift—sometimes to the left, sometimes to the right. Sometimes the whole opinion landscape seems to drift in some direction (e.g., Sweden seems to drift slightly to the right). Sometimes the left and the right clusters seem to drift in different directions (e.g., France 2010 seems to have left and right clusters closer to the center than in 2004 as well as in 2012).

Two conclusions can be drawn from these stylized facts. First, empirical opinion landscapes do not follow simple distributions, in particular they are not at all close to be normally distributed. Second, empirical opinion landscapes nevertheless show some smoothness which points to some process which structures them in typical clustered shapes which are not random or externally triggered.

How do these non-simple but structured opinion landscapes evolve? Numerous factors might of course play a role. For example, there might be psychological reason why certain opinions are more attractive than others (e.g., the central or the extremal bins). In this paper we will focus on reasons which might lie in the interaction and adaptation of individuals. In the following section we will look at the bounded confidence model of opinion dynamics which produces clustered opinion landscapes.

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As a side note, multimodality of ideological landscapes has also been used by the father of the spatial model [3, Fig. 8] as an explanation why two parties might not fully converge to the median voter's position and as a reason for the emergence of new parties at newly evolving modes.

3 Bounded Confidence Model of Continuous Opinion Dynamics

Model Definition Let us consider a society of N agents in which agent i is characterized by an *ideological position* x_i (also called *opinion* in the following) in the range [0,1] which is subject to change over time while the agent communicates with others. All agents are further equipped with a homogeneous *bound of confidence* ε also from the range [0,1] which is not subject to change but determines the maximal ideological distance to others which an agent is willing to take into account to revise its ideological position. Thus, the ideological positions of all agents at time t form the vector $x(t) \in [0, 1]^N$ which defines an opinion landscape. As ideological position changes over time, $x(t)$ is the dynamic variable of the model of opinion dynamics, while the bound of confidence ε is a static variable. The bound of confidence somehow models homophily, which is the tendency to interact positively only with agents which are similar to oneself [6, 18].

We consider agents to change their ideological positions because of two processes: *homophile adaptation* and *random reconsideration*.

Homophile Adaptation Consider that at each time step an agent i meets another agent j picked at random and interacts with it only when their distance in opinion is less than its bound of confidence $|x_i(t) - x_j(t)| < \varepsilon$. If agent j is close enough agent i changes its ideological position to the average of the two positions $x_i(t + 1) = (x_i(t) + x_j(t))/2$. If agent j is too far away agent i's position remains unchanged $x_i(t + 1) = x_i(t)$.

Reconsideration Sometimes agents reconsider their ideological position from scratch. Each agent reconsiders its ideological position at each time step with probability p (which is thought to be small, e.g., $p = 0.1$). When an agent reassesses its ideological position it chooses a random value from the interval [0, 1] with equal probability independently of the positions of others. Thus, the agent's new opinion is sampled from a uniform distribution. The parameter p is the second global static parameter of the model.

To start a run of the model each agent starts with a step of reconsideration to setup the initial ideological positions.

This model resembles the bounded confidence model proposed by Krause [10] and Deffuant et al. [1] independently from each other. Both models differ in their communication regime [20]. Here, we concentrate on the communication regime of Deffuant et al. [1] where agents only engage in pairwise interaction as described.

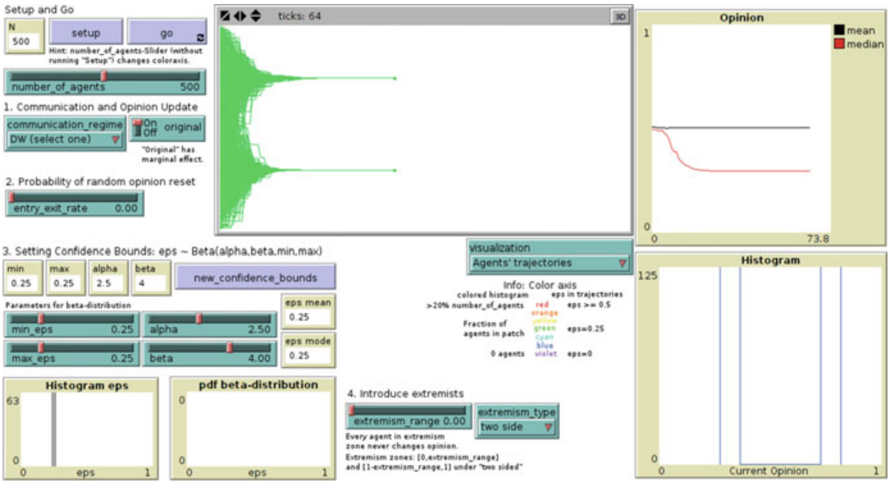

Fig. 2 Full screen of the Netlogo model of Lorenz [16]. A run is shown for 500 agents with homogeneous bound of confidence $\varepsilon = 0.25$ and without reconsideration ($p = 0$)

Originally, the model was formulated without the process of reconsideration, which was introduced as noise by Pineda et al. [19]. It is called uniformly distributed opinion noise by Mäs et al. [17]. Several other modifications of the models such as multidimensional opinion spaces [14], heterogeneous bounds of confidence [15], relative agreement, and extremism [2] were introduced and analyzed.

The version with pairwise communication and random reconsideration (and some other options) is implemented in Netlogo [22] for easy use [16]. This version is used in the following to produce the following figures.

Figure 2 shows the full screen of the Netlogo model (in a slightly changed design compared to [16]). The main panel in the upper center shows the trajectories of opinions up to the current time step (here $t = 64$) moving from left to right. For longer runs this panel turns into a "rolling" display showing only the latest time steps. The interface (left-hand side and bottom of the screen) includes besides the core controls on for the number of agents and the "setup" and "go" buttons the following functions:

1. controls for the communication regime. In this paper "DW (select one)" with original "On."
2. a slider to set the probability of reconsideration p.
3. a module to initialize random distributions of heterogeneous bounds of confidence, not used here.
4. options to introduce extremists, not used here.

On the right-hand side of the model screen there are two observers which accompany the central panel of trajectories. The top panel shows the evolution of the mean and the median opinion over the full time the simulation has been running.

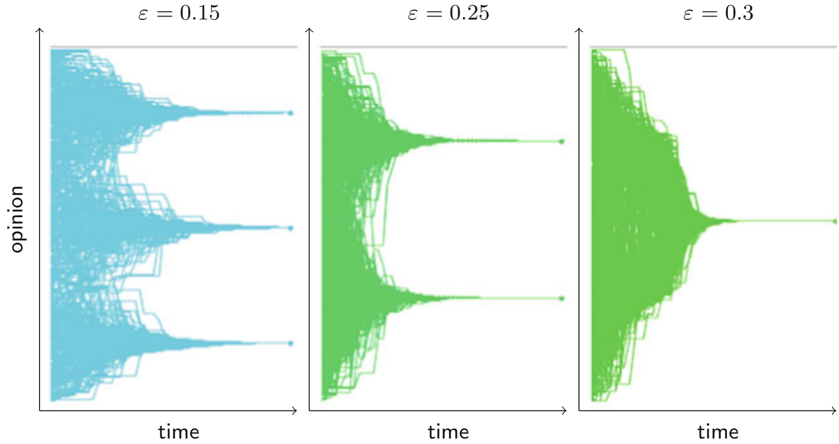

Fig. 3 Trajectories for $N = 500$ agents with homogeneous ε without reconsideration leading to plurality (*left*, $\varepsilon = 0.15$), polarization (*center*, $\varepsilon = 0.25$), and consensus (*right*, $\varepsilon = 0.3$)

The bottom panel shows the histogram of the current opinions in eleven equidistant bins, resembling the discretization of empirical opinion landscapes from the ESS.

Model Dynamics Let us first look at homogeneous bounds of confidence without random reconsideration.

Bound of Confidence ε Large bounds of confidence (approximately $\varepsilon > 0.27$) lead to *consensus*. Intermediate bounds of confidence (approximately $0.18 < \varepsilon < 0.27$) lead to *polarization* into two equally large opinion clusters, one moderately left-wing and one moderately right-wing. Small bounds of confidence ($\varepsilon < 0.18$) lead to *plurality* of three or more clusters. Figure 3 shows trajectories for different bounds of confidence to demonstrate consensus, polarization, and plurality. The dynamical process towards stable polarization over time runs as follows: (1) Starting with initially uniformly distributed opinions, central agents (with opinions more than ε away from the boundary) are equally likely to find a close enough communication partner at either side. Extremal agents close to the boundary of the opinion space instead can only find close enough communication partners slightly more central. Thus they will move closer to the center, but at most $\varepsilon/2$ as they ignore others when they are farther than ε away. (2) After a few time steps this leads to a slightly higher concentration of agents in the region $[\varepsilon/2, \varepsilon]$ and the opposing region on the other side of the opinion space. The concentration of agents remains the same in the center and declined at the extremes. Now, an agent between the center and ε has a higher chance to find a close enough communication partner at the other side of the center because the concentration of agents is higher there. Thus, it is more likely that it moves from the center towards the region of higher concentration. The same happens on the other side of the opinion space. (3) Regions of slightly higher concentration quickly gain higher concentration through this kind of attraction. Regions of high concentration finally converge to opinion clusters which have a distance of about 2ε.

Similar arguments explain the evolution of more clusters for lower bounds of confidence. Of course, the random initial conditions and the random selection of communication partners can lead to different outcomes, but even for relatively low numbers of agents the separation between consensus and polarization as attractive final opinion landscapes is quite sharp at the critical value $\varepsilon = 0.27$. This means that random influence decides which of the two attractive landscapes will be reached when the bound of confidence is at such a critical value. When the bound of confidence is far away from a critical value it is almost sure that always the same pattern of clustered opinion landscape is reached.

The typical locations bifurcating at the critical values into more and more clusters are shown in a bifurcation diagram in [13]. Note that in this study we ignore minor clusters of minimal size which structurally emerge at the extremes and between the major clusters, because they usually contain only zero to two agents in the sample sizes we use.

From a political science perspective the view on the mean and the median opinion is interesting (see upper right panel in the model's full screen in Fig. 2). In uniformly distributed opinions mean and median are of course almost the same. Interestingly, in the ε range of polarization the median quickly starts to deviate from the mean when opinion dynamics starts. The mean remains almost central but due to the depopulation of the center the median finally ends up to be in one of the two off-central clusters far away from the compromising position in the center. Which of the two clusters ends up slightly larger than the other is subject to random fluctuation.

In summary, the model with homogeneous bounds of confidence and without reconsideration is thus able to produce clustered opinion landscapes, but they are way to clustered to match the empirical opinion landscapes from the ESS.

Random Reconsideration with Probability *p* The introduction of random individual reconsideration of opinions with probability p blurs the peakedness of clusters such that they visually come closer to the opinion landscapes observed empirically in the ESS data. Random reconsideration also triggers slight movements of clusters.

Figure 4 shows three example trajectories in heatmap visualization and a snapshot of the histogram. As can be inferred from the trajectories, the histogram fluctuates but keeps its typical shape. The values $\varepsilon = 0.15, 0.25, 0.3$ are taken from Fig. 3 and the values $p = 0.12, 0.2, 0.09$ are chosen in an attempt to visually match some characteristics of ESS opinion landscapes. The matching will be discussed in the final section.

Finally, it shall be demonstrated how the model with random reconsideration reacts close to critical values of the bound of confidence. Without randomness the critical bound of confidence between polarization and consensus is $\varepsilon = 0.27$. Figure 5 shows snapshots from the model running with $\varepsilon = 0.28$ and a probability of random reconsideration $p = 0.09$.

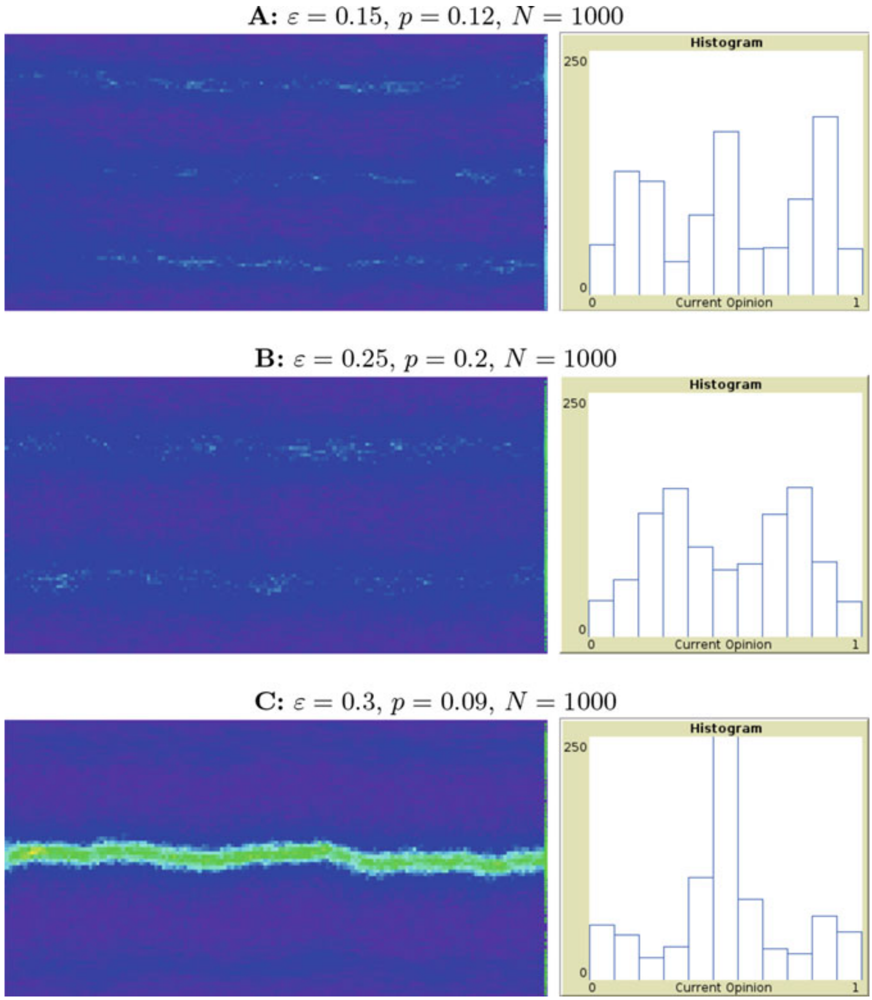

Fig. 4 Trajectories of $N = 1000$ agents with closed-minded (**a**), open-minded (**c**), and intermediate bounds of confidence (**b**) and different probabilities of random reconsideration p. The bounds of confidence are the same as in Fig. 3

The snapshots show that two meta-stable states exist—a polarized one with two clusters and a consensual one with a central clusters which position moves considerably in the central range. The system switches between these states through rare random events. The transition from polarization appears to be a slow one (panel top right) through a random drift of the central cluster and the evolution of the second cluster in the other half of the opinion space. In contrast, the transition from polarization to consensus is rather abruptly triggered by a random fluctuation which suddenly builds a critical mass to connect the two sides.

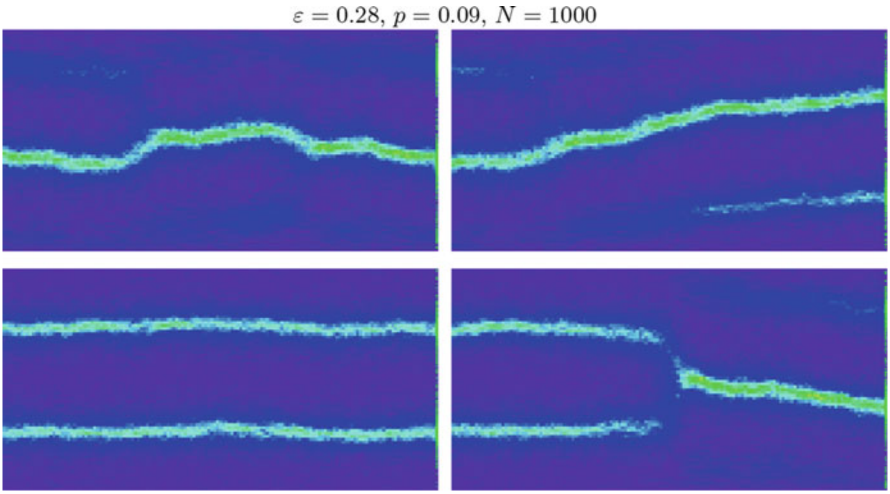

Fig. 5 Trajectories of $N = 1000$ agents with bounds of confidence at a critical value in heat map visualization

4 Discussion

To what extent do opinion landscapes from the model in Fig. 4 match empirical opinion landscapes in Fig. 1? Generally, no model specification seems to be able to reproduce all stylized facts from empirical distributions totally satisfactory. Thus, the development of a parameter fitting procedure is left for future models and the further discussion is exploratory and qualitatively. Nevertheless, the model distributions match the empirically observed distributions visually much better than any specification of a (a, b)-beta distribution. As the model has also only two parameters (ε, p) this is already a small success.

Going along the increasing bounds of confidence from Fig. 4 different stylized facts of empirical distributions are reproduced by the model.

Closed-minded agents (Fig. 4a $\varepsilon = 0.15$): Under a relatively high probability of reconsideration ($p = 0.12$) an opinion landscape with three peaks is produced—a central, a moderate left, and a moderate right cluster as we see it in many empirical landscapes, e.g., in the left–right landscape of Sweden 2002 or Germany's European integration landscape 2012; but empirical landscapes of this type usually also have extremal peaks, the moderate peaks lie a bit closer to the center and never on the bins 1 and 9 and the central peak is much more pronounced.

Intermediate agents (Fig. 4b $\varepsilon = 0.25$): Under a high probability of reconsideration ($p = 0.2$) the opinion landscape is still polarized as for the non-noisy case, but clusters are blurred such that their shape and location at bins 2,3, respectively, 7,8 matches moderate off-center empirical clusters. In this specification a dominant central cluster as observed empirically misses completely. If it would exist it would absorb the moderate clusters quickly. Also extremal peaks as empirically found are missing.

Open-minded agents (Fig. 4c $\varepsilon = 0.3$): Under an intermediate probability of reconsideration ($p = 0.09$) the opinion landscape shows a large central peak as observed empirically, also small peaks at the extremes match the empirical landscapes, although empirical extremal peaks lie more pronounced at 0 and 10 and not on 0,1, respectively, 9,10 as in the model. The weak point here is that empirically we observe much more mass on the bins close to the center.

In conclusion, several stylized facts can be reproduced by this two parameter model much better than classical distributions can, but the model cannot produce a large central peak, and tendencies for small and blurred moderate off-center peaks and small or tiny extremal peaks at the same time in its current form.

Agent-based models for the evolution of ideological landscapes are still in its infancy and it remains to show if they can add interesting insight to political dynamics. At least the possibility for counterfactual analysis at critical values seems promising for studying and understanding self-driven abrupt changes in political landscapes.

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