Nonequilibrium dynamics in a three-state opinion-formation model with stochastic extreme switches

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(Received 15 July 2022; accepted 3 November 2022; published 28 November 2022)

We investigate the nonequilibrium dynamics of a three-state kinetic exchange model of opinion formation, where switches between extreme states are possible, depending on the value of a parameter q. The mean field dynamical equations are derived and analyzed for any q. The fate of the system under the evolutionary rules used in S. Biswas *et al.* [Physica A **391**, 3257 (2012)] shows that it is dependent on the value of q and the initial state in general. For $q = 1$, which allows the extreme switches maximally, a quasiconservation in the dynamics is obtained which renders it equivalent to the voter model. For general q values, a "frozen" disordered fixed point is obtained which acts as an attractor for all initially disordered states. For other initial states, the order parameter grows with time t as $\exp[\alpha(q)t]$ where $\alpha = \frac{1-q}{3-q}$ for $q \neq 1$ and follows a power law behavior for $q = 1$. Numerical simulations using a fully connected agent-based model provide additional results like the system size dependence of the exit probability and consensus times that further accentuate the different behavior of the model for $q = 1$ and $q \neq 1$. The results are compared with the nonequilibrium phenomena in other well-known dynamical systems.

DOI: 10.1103/PhysRevE.106.054311

I. INTRODUCTION

One of the main motivations in studying nonequilibrium phenomena is to check what kind of steady states can be reached using different initial conditions. In the well-known Ising-Glauber model at zero temperature, on lattices or networks, several studies have been made to show that the steady states may not be the equilibrium steady states [1–14]. Exit probability, a quantity related to the type of final state reached from an initially biased state, has also been studied extensively in recent times in spin and opinion-formation models [15–26]. In systems with more than two states, several other interesting features, like the two-stage ordering process, have been noted [26]. In addition, how a system evolves to a stable state starting from an unstable fixed point is also a matter of interest [27].

Opinion dynamics models relevant to social phenomena have received extensive attention recently [28–31]. These models typically show a rich nonequilibrium behavior. Usually, the opinion of an agent is updated following the interaction with other individuals; sometimes the influence of media is also incorporated. In the numerous models studied so far, the interaction and the choice of the interacting agent(s) play crucial roles. The simplest models involve binary opinions typically represented by 0,1 or ± 1. The voter model [32,33], in which an agent just copies the opinion of another randomly picked up agent, is one of the simplest and earliest opinion dynamics models. Later, models involving more complexities have been constructed [29,30]. The binary models obviously cannot capture all the intricacies of the real world. Hence, models with three or more opinion states as well as continuous values of opinions have been considered in the recent past. The voter model can be generalized with a larger number of states easily [34] while other multistate models which involve the effect of more neighbors have also been considered [35,36]. In comparison to the simple binary-state models, here the opinions are not merely flipped but can change in more than one possible way. We focus our attention on the so-called kinetic exchange models where pairwise interactions are considered at each step [37]. However, these models generally have some restrictions. In particular, in the kinetic exchange models most recently studied with three discrete opinion states quantified by -1, 0, and 1 (assumed to represent e.g., left, central, and right ideologies), a transition from 1 to -1 or vice versa (i.e., an extreme switch of opinion) is not allowed to the best of our knowledge [38–42]. Also, in many other similar three-state models such a restriction is imposed [43–49]. However, human behavior being complex and unpredictable, such switches cannot be completely ruled out. In fact, there are real-world examples where even political cadres or leaders shift their allegiance to parties with totally opposite principles [50,51]. The reasons may be associated with immediate gains and selfish interests, lack of strong ideological beliefs, etc. We consider a model for opinion dynamics where extreme switches are allowed to happen and see how the dynamics are affected by this. It may be added here that for the multistate voter model or Potts-type models, such extreme switches can take place; however, in the relevant studies, the effect of such switches has not been the issue of interest specifically [34–36].

In this article, we have considered a kinetic exchange model of opinion dynamics with three states, with the possibility of switching between extreme opinions. In the mean field approach, the equations for the time derivatives are set

