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Kinetic models of collective decision-making in the presence of equality bias

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HIGHLIGHTS

- Novel kinetic models for the influence of the competence in the evolution of decisions in multi-agent systems.
- The evolution of the competence depends on a social background in which individuals grow and on the possibility to learn from the more competent ones.
- The hypothesis of equality bias induces the agents to behave in the same way as if they were as good, or as bad, as their partner, leading to suboptimal collective decisions.
- Numerical experiments based on Monte Carlo techniques for the Boltzmann equation in the quasi-invariant scaling.

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ABSTRACT

We introduce and discuss kinetic models describing the influence of the competence in the evolution of decisions in a multi-agent system. The original exchange mechanism, which is based on the human tendency to compromise and change opinion through self-thinking, is here modified to include the role of the agents' competence. In particular, we take into account the agents' tendency to behave in the same way as if they were as good, or as bad, as their partner: the so-called *equality bias*. This occurred in a situation where a wide gap separated the competence of group members. We discuss the main properties of the kinetic models and numerically investigate some examples of collective decision under the influence of the equality bias. The results confirm that the equality bias leads the group to suboptimal decisions.

1. Introduction

The fallibility of human judgement is evident in our everyday life, especially regarding our self-evaluation ability. Several tests have been designed in cognitive psychology and clinical research in order to find an experimental evidence for this phenomenon, see Refs. [1–4] and the references therein, showing that subjects are in general overconfident about the correctness of their belief. This lack in *metacognition*, i.e. the self-assessment of our own knowledge skills, goes hand in hand with the grade of competence of each subject.

The correlation between *competence* and *metacognitive skills* is somehow double and might be summarized in the following sentence: "the same knowledge that underlies the ability to produce correct judgement is also the knowledge that underlies the ability to recognize correct judgement" [5]. Here the authors found a systematic bias of the most incompetent

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agents on their metacognition than the most experts; behavior which is usually known as *Dunning–Kruger effect*. In other words, incompetence not only bring people to poor choices but also disable to recognize that these are wrong or improvable. Further, the overconfidence of the novices emerges together with the under-confidence of highly competent individuals which tend to negatively estimate their skills.

This coupled deviation from an objective self-evaluation of personal abilities has been recently investigated in Ref. [6], where authors asked how people deal with individual differences in competence, in the context of a collective perceptual decision-making task, developing a metric for estimating how participants weight their partner's opinion relative to their own. Empirical experiments, replicated across three slightly different countries as Denmark, Iran, and China, show how participants assigned nearly equal weights to each other's opinions regardless of the real differences in their competence. This *equality bias*, whereby people behave as if they are as good or as bad as their partner, is particularly costly for a group when a competence gap separates its members.

Drawing inspiration from these recent results, we propose a multi-agent model which takes into account the influence of competence during the formation of a collective decision [7,8]. After the seminal models for wealth/opinion exchange for a multi-agent system introduced in Refs. [9–11] some recent works considered additional parameters to quantify the personal knowledge or conviction [7,8,12,13] or constrained versions of these models [14–16]. For example, individuals with high conviction are resistant to change opinion, and can play the role of leaders [13,16]. In Ref. [17] there exists a threshold conviction beyond of which one of the two choices provided to the individuals prevails, spontaneously breaking the existing symmetry of the initial set-up.

More precisely, we introduce a binary exchange mechanism for opinion and competence deriving a kinetic equation of Boltzmann-type [8,7,10,14,16,18,19]. The binary collision terms for competence and opinion describe different processes:

- the competence evolution depends on a social background in which individuals grow and on the possibility for less competent agents to learn from the more competent ones;
- the opinion dynamics depend by a competence based compromise process which includes an equality bias effect and change of opinion through self-thinking;
- agents are driven toward an a-priori correct choice in dependence on their competence grade.

In order to derive a nonlinear equation of Boltzmann-type for the joint evolution of competence and opinion in the limit of a large number of interacting agents, we resort to the principles of classical kinetic theory (we refer to the recent monograph [18] for an introduction to the subject). Furthermore, to simplify the study of the asymptotic behavior of the model, we obtain a Fokker–Planck approximation of the dynamic in the so-called quasi-invariant scaling.

The rest of the paper is organized as follows, in Section 2 we introduce the binary interaction model for competence and opinion. We discuss the competence-based interactions between agents formulating a definition of collective optimal decision which is coherent with the experimental setting of Ref. [6]. Then the equality bias function is introduced acting as a modification of the effective competence into perceived competence. In Section 3 we derive the Boltzmann-type model and study the evolution of the moments under some specific assumptions. The Fokker–Planck approximation is then obtained in Section 4, and we derive the stationary marginal density of the competence variable. Finally in Section 5 we present several numerical experiments which show that the model is capable to describe correctly the decision-making process based on agents' competence and to include the equality bias effects. The latter, as expected, drive the system toward suboptimal decisions.

2. Modeling opinion and competence

In this section we discuss the modeling of opinion dynamics through binary exchanges, the analogous of dyadic interaction in the reference experimental literature [6,20]. The mathematical approach follows several recent works on alignment processes in socio-economical dynamics [7,8,10,13,18,19,21–23].

2.1. Evolution of competence

It is evident that one of the main factors playing a role is the social background in which an individual grows and lives, then it is natural to assume that competence is, in part, inherited from the environment. Moreover, we clearly have the possibility to improve specific competences during interactions with more competent agents.

Similarly to the works [7,8,18] we describe the evolution of the competence of an individual in terms of a scalar variable $x \in X$, where $X \subset \mathbb{R}^+$. Let $z \in \mathbb{R}^+$ be the degree of competence achieved from the background in each interaction; in what follows we will always suppose that $C(z)$ is a distribution with bounded mean

$$\int_{\mathbb{R}^+} C(z)\mathrm{d}z = 1, \qquad \int_{\mathbb{R}^+} zC(z)\mathrm{d}z = m_B. \tag{2.1}$$

We define the new amount of competence after a binary interaction between two agents with competence x and x_* as follows

$$\begin{cases} x' = (1-\lambda(x))x + \lambda_C(x)x_* + \lambda_B(x)z + \kappa x \\ x'_* = (1-\lambda(x_*))x_* + \lambda_C(x_*)x + \lambda_B(x_*)z + \kappa x_*, \end{cases} \tag{2.2}$$