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Adoption of innovations with contrarian agents and repentance

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HIGHLIGHTS

- Data of adoption of innovations provide evidences of a complex behavior.
- A key factor of the model is the idiosyncratic resistance to change.
- Social influence is included by favoring the adoption or acting against it.
- The inclusion of repentance generates a rich landscape including cycles.

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ABSTRACT

The dynamics of adoption of innovations is an important subject in many fields and areas, like technological development, industrial processes, social behavior, fashion or marketing. The number of adopters of a new technology generally increases following a kind of logistic function. However, empirical data provide evidences that this behavior may be more complex, as many factors influence the decision to adopt an innovation. On the one hand, although some individuals are inclined to adopt an innovation if many people do the same, there are others who act in the opposite direction, trying to differentiate from the "herd". People who prefer to behave like the others are called mimetic, whereas individuals who resist adopting new products, the stronger the greater the number of adopters, are named contrarians. Besides, in the real world new adopters may have second thoughts and change their decisions accordingly. In this contribution we include this possibility by means of repentance, a feature which was absent in previous models. The model of adoption of an innovation has all the ingredients of a previous version, in which the agents decision to adopt depends on the appeal of the novelty, the inertia or resistance to adopt it, and the social interactions with other agents, but now agents can repent and turn back to the old technology. We present analytic calculations and numerical simulations to determine the conditions for the establishment of the new technology. The inclusion of repentance can modify the balance between the global incentive to adopt and the number of contrarians who prevent full adoption, generating a rich landscape of temporal evolution that includes cycles of adoption.

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1. Introduction

Innovation is at the core of the changing in living conditions all along the human history. It is also one of the main driving forces of sustainable economical development in modern societies. However, even when innovations may represent a clear improvement over existing technologies, its adoption is not guaranteed because it depends on other factors that can restrain the adoption process, like the individual resistance or a high price. Besides, the adoption may be boosted by means of advertising or interpersonal influence. Rogers [1] was the first one to address theoretically the problem of innovation adoption, as early as 1962. In his qualitatively description, he claims that adoption curves are S-shaped (logistic) as a function of time: there are few early adopters, and only when their number becomes larger than a threshold, adoption develops up to a saturation point.

Systems of heterogeneous interacting individuals are complex systems whose properties have been studied in the contexts of economics (see [2–4] and references therein), criminality [5], game theory [6], and in many other social and biological systems. It has been shown that when the individuals are mimetic, i.e. they choose to imitate the behavior of the others (also called herding or congregator behavior), the possible equilibria have well known properties [7,8]. If some individuals do not exhibit a mimetic behavior, adoption dynamics is more involved, but also more interesting. Such individuals, called *contrarians*, have been described in different contexts in the literature. Galam [9] introduced contrarian agents in voter models, in such a way that they adopt opinions that are systematically opposite to the one of the majority of their neighbors. Subsequent extensions of this 2-state model explain the global balance between the two competing opinions observed in some real situations, in cases where the number of contrarians exceeds a threshold value [10,11]. Other possibilities have been proposed more recently by Crokidakis et al. [12], where agents can have either positive (mimetic) or negative (contrarian) interaction with a given probability, and by Masuda [13], who considered different models in which the decision of each contrarian depends on its neighborhood (made of contrarians and/or mimetics).

With or without contrarians, the time evolution of the fraction of adopters is a Markov chain: $n(t+1) = \mathcal{F}(n(t))$. The fixed points attractors of the dynamics satisfy $n = \mathcal{F}(n)$. However, as demonstrated by Goles et al. [14], systems with interacting binary agents evolve toward fixed points only when the interactions are *symmetric* and positive. Negative symmetric interactions may lead either to fixed points or to cycles of length 2, depending on details of the dynamics and on the initial state. These results rely on the existence of an energy function that is a decreasing (more rigorously, non-increasing) function of time under the system's dynamics. However, a system with contrarians does not necessarily have an underlying energy function, because the interactions between mimetic agents and contrarian agents are not symmetric. Being an individual property, contrarians have negative interactions with all other agents. Thus, interactions between contrarians are symmetric – both being negative – but interactions between a contrarian and a mimetic agent are anti-symmetric. Consequently, the existence of fixed points is not guaranteed.

The dynamics of adoption in models with only mimetic individuals has been studied a long time ago by Bass [7], in which was probably the first mathematical, however phenomenological, formulation of the problem. Later, Phan et al. [15] studied the problem in different types of networks, showing that the fraction of adopters increases with time through avalanches that depend on the underlying network structure. Moreover, the fraction of adopters at equilibrium in the absence of contrarians has been obtained analytically in [16] for a uniform distribution of the resistance to adopt and small values of the interaction weights. Numerical results have been obtained when contrarians are included: in the context of innovation the most important consequence of the inclusion of contrarians is the non-trivial restraining effect on the adoption curves, i.e, a small fraction of contrarians produce a large reduction on the final fraction of adopters [16].

All these models are suitable for situations where users cannot change their decisions, such as the case of expensive technologies. But there are other situations, as for example the choice of an operating system, a software, or an internet supplier, where the decision can be revised periodically. In such cases, adopters may change their minds and abandon the innovation. In this article we investigate that possibility on a society where individuals exhibit a mimetic or contrarian behavior (kept fixed during the whole adoption process), but they can repent for their decisions, going back to a non-adopter state. We study this model using analytical and numerical approaches, and considering different distributions of the idiosyncratic resistance to adopt.

We explore the parameters space by comparing the results of simulations with a mean field analytic approach, analyzing the phase diagram of the system for different proportions of mimetics and contrarians. The paper is organized as follows: In Section 1 we present the model, in Section 2 we consider a uniform distribution of the resistance to adopt (analytically and numerically), and in Section 3 we analyze the case of a logistic distribution. Conclusions are presented in Section 4.

2. The model of adoption with social interactions

A "microscopic" model of adoption dynamics has been proposed recently by some of us [16]. The model considers heterogeneous idiosyncratic individuals in the presence of advertising. For the sake of clearness we show below the payoff (P) function that every agent evaluates, adopting the novelty if its value is positive:

$$P = A - R_i + J_i n, \tag{1}$$

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