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An agent based multi-optional model for the diffusion of innovations

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HIGHLIGHTS

- Formalism for the study of collective decision among several options is proposed.
- Heterogeneity in the population of potential buyers produces more realistic results.
- Trade-off between improvement and time of launching is analyzed.
- Uncertainty reduces the delay interval in the launching with competitive advantages.
- Saturation time decreases due to the increment of the rewiring probability.

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ABSTRACT

We propose a model for the diffusion of several products competing in a common market based on the generalization of the Ising model of statistical mechanics (Potts model). Using an agent based implementation we analyze two problems: (i) a three options case, i.e. to adopt a product *A*, a product *B*, or non-adoption and (ii) a four option case, i.e. the adoption of product *A*, product *B*, both, or none. In the first case we analyze a launching strategy for one of the two products, which delays its launching with the objective of competing with improvements. Market shares reached by each product are then estimated at market saturation. Finally, simulations are carried out with varying degrees of social network topology, uncertainty, and population homogeneity.

1. Introduction

The process of diffusion of innovations motivated ample academic interest in the sixties, extending until today. A pioneering work has been the one developed by Bass [1]. Originally this model was fitted, with enough precision, to the observational data of adoption rates corresponding to many consumer durable goods, obtaining the cumulative S-curves for the number of adopters, in which fast growth is generated by word of mouth between early and late adopters [2]. Later, the Bass model was extended in its use to other products, for example those related to the telecommunications sector [3]. Many of the innovation diffusion models were inspired by models initially developed for application in different disciplines. The Bass model was not the exception; in that case the analogy was made with epidemic models [4].

The Bass model performs an aggregate description of the behavior of potential decision makers in relation with the adoption or not of an innovation (or technology). In this formulation the set of deciders is assumed to be homogeneous and totally connected, or equivalently, we suppose that each individual is influenced by all remaining decision makers. The basic assumption of the model is that at each point in time, potential buyers are exposed to two kinds of influences: an external influence, in the shape of advertising campaigns carried out by the companies via the mass media; and an internal influence coming from "word-of-mouth" interactions with adopters [5].

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The Bass model has the general advantage of its simple application, constituting a description on a macro level that shows the observed global behavior [6]. However, the lack of detail at a microscopic level turns it into a weak prediction instrument, restricting its application to analogies with similar known products [3].

On the other hand, the study of diffusion models at the micro level has recently intensified, with special focusing on agent based models (ABMs), as is shown, for example, in the review paper by [7]. In general, ABMs involve two complementary causes for innovation adoption: (a) the individual evaluation of the advantages related to the adoption of the new product (or technology) and (b) the imitation of behavior of close contacts which are considered as examples to follow by the decision maker. ABMs have the advantage, compared to macro models, that the introduction of the social networks is possible. Those social networks are the routes for interaction between the elements of the system [8].

In the case of the diffusion of only one new product in a potential market, individuals in ABMs must choose between two alternatives: to adopt or not to adopt. It was found that the social system described before can be obtained by using the analogy with the well-known Ising statistic model [9], which was originally developed in the field of physics to describe the phase transition in ferromagnetic materials [10]. In the physical model the agents represent spins in a regular lattice. Those spins can be in two positions: one in the direction of an external field and the other in the opposite direction. In that model, each agent (ion in the metallic lattice) can be influenced by its neighbors, which generate a local field that induces the orientation of the spin. There are examples in scientific literature in which the Ising model is adapted to modeling the social process of opinion formation [11,12] and others in which the diffusion of technology is studied [13].

In the Ising model, the interaction is limited to the nearest neighbors in a regular array. However, a social process of communication does not necessarily correspond to an interaction with the geographic proximity, so it is necessary to modify the formalism in order to include irregular networks where the notion of nearness is diffuse. Such is the case of the family of networks known as "small world networks" (SWN) described by Watts and Strogatz [14]. The different networks in the family of SWN are obtained by the variation of only one parameter called rewiring probability. The idea is to re-connect the agents, starting from a regular network with a probability which is the parameter mentioned before. A rewiring probability of zero corresponds to a regular network, and a probability of one to a totally random network. For values of probability in the interval [0.003, 0.02], the SWN for a two dimensional network are obtained [15]. SWN have been strongly studied in the scientific literature, observing that they have suitable properties for applications in social communications and other natural phenomena [16].

At this point we have an Ising-like model equipped with a SWN which lets us study the technology diffusion process corresponding to only one product, as was applied in the previous work [13]. However the generalization of this model to more products, whose physical analogy is the Potts model, has been used in a few cases of the social field [17]. The idea of the present work is the exploration of the possibilities of the Potts-like formulation for the analysis of the diffusion process associated to the launching of "M" products in a common market.

The case in which two brands compete for a unique market is analyzed in Ref. [18], by using an agent-based cascade model. Following Refs. [19,20], we can identify two mayor categories of agent-based diffusion models: (a) threshold models, in which agents adopt when a specified minimum number of neighbors have adopted, and (b) cascade models, where the probability of adoption increases with the number of adopters in the neighborhood, with an exponential mathematical dependency.

One contribution of our proposal, considering the two categories given before, is that this formalism could be thought of as a threshold model, but applicable to "M" options, and particularly applied in this paper to systems of three and four options. In the algorithm we propose, adapted from statistical mechanics applications, agents have an implicit threshold that relates to the perceived effective utility of each of the potential choices. This threshold is a function of the differences of utility of the available options, as is shown in Ref. [13]. Moreover, this model can also generate a more stochastic decision process, slightly moving away from the "threshold" category, when uncertainty is considered by varying the temperature parameter.

Yet another contribution of this paper lies in the way agents decide between the available choices, which is embedded in the model. That means that the probability of adoption is dynamically modified in time for each agent, depending of the consumption choices of their particular set of neighbors. This methodology is different from, for example, the ones used by Refs. [21,22], where diffusion is described as a two stage process; first, the units adopt, and then, at each point in time, adopters can decide whether to disadopt, or switch, according to a separate "coin-flip".

The work is organized as follows: Section 2 gives the formalism for "M" options, showing also how the Ising-like ($M = 2$) and the studied cases ($M = 3$ and $M = 4$) can be deduced from it. Section 3 describes the variables of the model, such as: rewiring probability, the utility of each product, the spatial and temporal distribution of early adopters, and the temperature as a measure of uncertainty in the decision. Section 4 gives the details about the implementation of the agent based model. Section 5 shows and performs the analysis of the results obtained. Section 6 summarizes the main conclusions.

2. Formalism for "M" options (Potts-like)

Let us consider a population of N agents, which are identified by Greek indexes, and M possible states, which are identified by Latin indexes, for all the agents. The set of states E is written as: $E = \left\{ \overrightarrow{X}_1, \ldots, \overrightarrow{X}_M \right\}$ with $\overrightarrow{X}_i \in R^M$. For simplicity we choose a canonical basis, then $E = \{(1, 0, \ldots, 0) ; (0, 1, 0, \ldots, 0) ; \ldots ; (0, 0, \ldots, 1)\}$.