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Awareness, persuasion, and adoption: Enriching the Bass model

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HIGHLIGHTS

- We build a stochastic model to monitor awareness and adoption in innovation diffusion.
- We consider many interacting actors with own connectivity and taste for innovation.
- Actors decide when it is worth to adopt according to a micro-founded decision process.
- Two sufficient statistics describe macro awareness and adoption curves.
- Features such as delayed adoptions and non-monotonicity of the adoption are detected.

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ABSTRACT

In the context of diffusion of innovations, we propose a probabilistic model based on interacting populations connected through new communication channels. The potential adopters are heterogeneous in the connectivity levels and in their taste for innovation. The proposed framework can model the different stages of the adoption dynamics. In particular, the adoption curve is the result of a micro-founded decision process following the awareness phase. Eventually, we recover stylized facts pointed out by the extant literature in the field, such as delayed adoptions and non-monotonic adoption curves.

1. Introduction

The *diffusion of innovations* explains how new ideas, products, or practices spread in a population. It is one of the most discussed topics in the field of behavioral science, including anthropology, sociology, and management science. Two milestones widely recognized in this field are the models developed by Refs. [1,2]. The former identifies different steps through which the innovation decision process develops (knowledge, persuasion, decision, adoption, and confirmation) and different adopter categories as ideal types, i.e., innovators (venturesome), early adopters (respectable), early majority (deliberate), late majority (skeptical), and laggards (traditional). The latter proposes an analytical model for the timing of the initial purchase of new products; the author assumes that the population consists of "innovators", who typically adopt early, independently of the others, and "imitators", who are influenced in their choice by the media and by the number of previous buyers.

New social media and, more generally, communication outlooks in the present digital era call for a revision of the classical framework *à la* Bass. In the context of diffusion of innovations, communication plays a crucial role, as participants create and share information with one another to reach a mutual understanding [1] that is able to foster the process itself. We believe, in particular, that some minimal features must be included: (i) heterogeneous *connection degrees* influencing awareness;

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(ii) a *multilevel diffusion mechanism* recalling the original Rogers' diffusion stages; (iii) *behavioral motives* such as imitation and persuasion, driving the decision process; (iv) *fragmentation* of the population of potential adopters.

The aim of this paper is to provide a general but tractable framework that encompasses all these ingredients. Our main result is a closed-form equation for two distinct (but coupled) processes describing the time evolution of *awareness* and *adoption*. These equations are derived relying on large deviation techniques, as the limit of aggregate statistics describing a population of interacting agents. In this respect, our approach is inspired by Schelling's *Micromotives and Macrobehavior* (1978). Indeed, we first implement the single-agent decision process, where characteristics such as connectivity degree, private willingness to adopt, and imitation propensity are considered. Second, we choose appropriate state variables, identifying, at the micro level, *awareness* (knowledge) and *adoption*, and we study their time evolution, depending on agents' characteristics. Finally, a convergence result over the population size, i.e., when the number of actors grows to infinity, provides the awareness and the adoption dynamics at the macro level.

The power of our methodology can be illustrated by means of a significant application (see Section 4 for more details). Consider a very simplified world consisting in four subpopulations of homogeneous agents: *innovator hubs*, *innovator non-hubs*, *follower hubs*, and *follower non-hubs*. In doing so, we are accounting for both connectivity and taste for innovation (these characters are rarely disentangled in previous studies). Our model provides closed-form equations for the awareness/adoption curves related to the four subpopulations. Eventually, we are able to generate delayed adoptions compared to awareness trends as well as atypical (non-monotonic) adoption curves. These features, although already documented in empirical works (see Refs. [3,4]), have not yet been explained by a rigorous and micro-founded model.

The paper is organized as follows. Connectivity, the behavioral rationale of possible adopters, and the two-stage diffusion mechanism are introduced in Section 2. In Section 3, we find the asymptotic aggregate awareness and adoption dynamics. Section 4 describes in detail the baseline example pointed out above. In Section 5, we provide a short review of recent literature, and we conclude. The Appendix contains all proofs.

2. Awareness and adoption

Our setting assumes that an innovative product/service is launched through a new communication channel such as a social network. Nowadays, social media are increasingly common in the marketing mix chosen to sustain the launch of a new product/service. We consider a population of N actors linked within the network. They form the population of possible adopters.

To summarize information concerning agents' characteristics, we define *identity vectors* as follows.

Definition 1 (*Identity Vector*)**.** Let $\theta_i = (\beta_i, p_i, q_i)$, for $i = 1, \ldots, N$, be the identity vector of actor i, where

- $\beta_i \geq 0$ measures the connection degree (connectivity);
- $p_i \geq 0$ represents the propensity to adopt (innovation coefficient);
- $q_i \geq 0$ represents the propensity to conform (imitation coefficient).

We assume that θ_i, $i = 1, \ldots, N$, are independent and identically distributed (i.i.d.), with distribution η^θ.

The identity vector collects the basic parameters that are useful for representing in a simple way the features pointed out above (network structure and behavioral motives behind the adoption). We will see in what follows how these parameters are used in order to characterize the awareness process and the decision problem behind adoption.

We aim at monitoring a *two-stage diffusion process*: awareness and adoption. Awareness shows whether an actor has been reached by the information. Being aware represents a necessary step for the agent to consider the possibility of adopting the innovation: awareness must precede adoption. We, now, describe the two-level diffusion process on a time window $[0, T]$ (possibly $T = +\infty$).

Definition 2 (*Awareness and Adoption Processes*)**.** We define the awareness and the adoption processes, respectively $\mathbf{x} = \{(x_1(t), \ldots, x_N(t)),\ t \in [0, T]\}$ and $\mathbf{y} = \{(y_1(t), \ldots, y_N(t)),\ t \in [0, T]\}$, where the following hold.

$$\begin{cases} x_i(t) = 1 & \text{if agent } i \text{ has been reached by the information by } t; \\ x_i(t) = 0 & \text{otherwise.} \end{cases}$$

$$\begin{cases} y_i(t) = 1 & \text{if agent } i \text{ has adopted by } t; \\ y_i(t) = 0 & \text{otherwise.} \end{cases}$$

We are interested in studying the joint evolution of $(\mathbf{x}, \mathbf{y})$, based on characteristics of the agents and of the network. In particular, we consider suitable *transition intensities*[1] for the awareness and the adoption processes, taking into account the whole network structure and the behavioral motives driving the adoption process of the single agents.

[1] Transition intensities are the rates of probability of having a jump in one component of a jump process. For instance, the transition intensity $\lambda_i^x(t)$ for process $\mathbf{x}$ at time t is defined as

$$\lambda_i^x(t) = \lim_{h \to 0} \frac{1}{h} \mathbb{P}(x_i(t+h) \neq x_i(t) \,|\, \mathbf{x}(t), \mathbf{y}(t), \theta_i).$$