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Exploring associations between micro-level models of innovation diffusion and emerging macro-level adoption patterns

Carlos E. Laciana [a,*], Santiago L. Rovere [a], Guillermo P. Podestá [b]

[a] Grupo de Aplicaciones de Modelos de Agentes (GAMA), Facultad de Ingeniería, Universidad de Buenos Aires, Avenida Las Heras 2214, Ciudad Autónoma de Buenos Aires, C1127AAR, Argentina

[b] Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149-1098, USA

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ABSTRACT

A micro-level agent-based model of innovation diffusion was developed that explicitly combines (a) an individual's perception of the advantages or relative utility derived from adoption, and (b) social influence from members of the individual's social network. The micro-model was used to simulate macro-level diffusion patterns emerging from different configurations of micro-model parameters. Micro-level simulation results matched very closely the adoption patterns predicted by the widely-used Bass macro-level model (Bass, 1969 [1]). For a portion of the $p-q$ domain, results from micro-simulations were consistent with aggregate-level adoption patterns reported in the literature. Induced Bass macro-level parameters p and q responded to changes in micro-parameters: (1) p increased with the number of innovators and with the rate at which innovators are introduced; (2) q increased with the probability of rewiring in small-world networks, as the characteristic path length decreases; and (3) an increase in the overall perceived utility of an innovation caused a corresponding increase in induced p and q values. Understanding micro to macro linkages can inform the design and assessment of marketing interventions on micro-variables – or processes related to them – to enhance adoption of future products or technologies.

1. Introduction

The rapid pace of technological innovation and its importance to the global economy has focused the attention of academia and industry on understanding the processes and drivers behind the diffusion and adoption of innovations [2]. Innovations are defined here as a new product, a new process, a new technology, or even a new organizational form. In turn, the spread of an innovation in a market is termed "diffusion". From the marketing perspective, it is important to understand how marketing communication efforts and social influence from previous adopters may affect the adoption decisions of consumers and, consequently, the diffusion of a new product. The wealth of research into modeling and forecasting the diffusion of innovations is impressive; recent reviews of diffusion models can be found in Refs. [3–5].

The diffusion of innovations may be approached from two alternative perspectives: the macroscopic and microscopic. At the macro level, an entire market is examined to identify or forecast how many customers will eventually adopt an innovation (the market size), and when they will adopt (the time path of adoption). Many macro-level studies of innovation diffusion are rooted on the influential work of Bass [1] described in more detail in the next section. Macroscopic models

* Corresponding author. Tel.: +54 11 4514 3016; fax: +54 11 4514 3016.
E-mail address: clacian@fi.uba.ar (C.E. Laciana).

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provide parsimonious and analytically tractable ways to look at a whole market and interpret its behavior. A related advantage is their use of market-level data – often more available than individual-level data – to forecast sales [6]. On the other hand, macro-models do not provide insight about the processes that determine adoption, or on how individual market interactions are linked to global market behavior [5].

In contrast, at the microscopic level each decision unit (an individual, a household, a firm) must choose whether to adopt an innovation; in this approach, analytical emphasis is placed on understanding the processes and factors influencing the individual adoption behavior, including both product characteristics and social interactions and to analyzing how it affects the aggregate diffusion process [7,8]; understanding the nature of these processes can inform marketing strategy recommendations [9].

In the last few decades there has been growing awareness of the importance of social structure as the substrate for the diffusion of innovations. An implicit assumption in macro approaches such as the Bass model is that the target population is fully-connected, that is, that every individual potentially can interact with everyone else in the population and can exert the same social influence as everyone else [10]. This is clearly not realistic, as there is considerable evidence that social networks are neither homogeneous nor fully connected. In particular, the topologies known as small world networks (SWNs, [11]) appear often in models of social relations [12]. SWNs have high values of both connectivity (i.e., short average path length) and clustering, making propagation of information more efficient than in other topologies [13,14].

In addition to social structure, recent strands of the diffusion literature also emphasize heterogeneity in the characteristics of consumers – such as their susceptibility to the behavior of others or sensitivity to price – that lead to differences in an individual's propensity to adopt [8]. Recent studies have even challenged the prevailing notion that social contagion is an important driver of new product diffusion, instead pointing out that typical S-shaped diffusion curves need not stem from social contagion, but can result from heterogeneity among individuals in their intrinsic tendency to adopt [9]. Consumer heterogeneity, however, is not explicitly considered in macro-level diffusion models.

Simulation models (e.g., cellular automata, agent-based models, percolation models) provide a way to systematically conduct experiments on how micro-level variables affect innovation diffusion processes [8]. Recently, agent-based modeling [15,16] has increasingly been used in diffusion studies because it can overcome some of the limitations of aggregate-level models such as the assumption of homogeneous adopters, or the lack of explicit social structure. Reviews of agent-based modeling in the context of innovation diffusion are in Refs. [17,6].

In agent-based models (ABMs) of innovation diffusion the modeling unit is the individual consumer or agent, not the social system as a whole. The micro-level processes that drive adoption decisions are explicitly specified. In turn, macro-level adoption dynamics emerge from the aggregated individual behavior and the interactions between agents [18]. Moreover, ABMs can capture individual heterogeneity in several characteristics, including responsiveness to price and advertising [19], presence of negative word of mouth [20], intrinsic consumer innovativeness [21], and individual roles in the social network — that is, hubs, connectors, and experts [22]. In ABMs, agents can interact with other agents through social networks that can be explicitly specified with different topologies and parameters. The ABM approach thus allows definition of a broader range of social interactions than Bass' "word of mouth". For instance, [23] expanded adoption decision rules in order to reflect network externalities that exist when consumers derive utility from a product based on the number of other users.

The central goal of this paper is to explore associations between parameters of a micro-level ABM and emergent patterns [18] from widely-used, macro-level models of innovation diffusion. Previous studies linking individual-level behavior and market-level patterns have been undertaken by [9,24,25]. In particular, the relationship between ABMs and the Bass model was studied by [26,7]. Shaikh et al. [27] showed that adoption by agents connected by a small-world network can be aggregated to create the Bass model. However, the interface between the individual level and the aggregate level still needs further exploration. We show here that results from an ABM can be consistent with the aggregate-level empirical data about adoption that are typically more available for analysis [23]. From a theoretical point of view, our contribution is a micro-level approach that considers plausible social network topologies, and allows heterogeneity among decision-makers (not explored here for the sake of length). Moreover, the decision algorithm underlying our approach [28] would let us easily introduce uncertainty in adoption decisions (e.g., due to social and economic contexts). The combination of all these features offers a versatile tool for future work.

The paper is organized as follows: Section 2 provides a brief description of the Bass model and its associated parameters. Section 3 introduces the micro-level agent-based model we developed, including details about the adoption algorithm and the implementation that allowed numerical experiments. Section 4 describes experiments performed to link the micro and macro levels. We study how changes in the topology of the social network can affect the induced parameters of the Bass model and we estimate analytically how takeoff time changes. This allows us to understand the influence of micro-level processes on patterns of adoption at the macro level. Possible application of this understanding is illustrated with an example. Section 5 summarizes the main conclusions, and points to possible future work.

2. Brief overview of the Bass model

A large body of research using macroscopic models of innovation diffusion has been based on the framework originally developed by Bass [1]. The Bass model characterizes the diffusion of a product or technology as a contagious process initiated by the spontaneous adoption of consumers responding to external influences (such as mass media coverage), and propelled