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Decision Support

Innovation diffusion of repeat purchase products in a competitive market: An agent-based simulation approach

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ABSTRACT

When introducing a new product into market, substantial amounts of resources are put at stake. Innovation managers therefore seek for reliable predictions of the respective innovation diffusion process. Making such predictions, however, is challenging, because the diffusion trajectory is affected by various factors such as the type of innovation, its perceived attributes, marketing activities and their impact, or consumers' individual communication and adoption behaviors. Modeling the diffusion of innovations accordingly is of interest for both practitioners and management scholars.

An agent-based model can overcome many limitations of traditional approaches. It accounts for heterogeneity in consumer preferences as well as in the social structure of their interactions and allows for modeling consumers as boundedly rational agents who make decisions under uncertainty and are influenced by micro-level drivers of adoption. We introduce an agent-based model that deals with repeat purchase decisions, addresses the competitive diffusion of multiple products, and takes into consideration both the temporal and the spatial dimension of innovation diffusion. The corresponding simulation tool can support decision makers in analyzing the prospective diffusion of an innovation in scenarios that differ in pricing strategy, distribution strategy, and/or communication strategy. Its applicability is illustrated by means of an empirically grounded example for a second-generation biofuel.

1. Introduction

In order to survive in a competitive market, firms have to develop new products on a regular basis. When introducing these innovations into market, managers need to select appropriate strategies for pricing, distribution, and communication. Such decisions require a thorough understanding of consumers' preferences, consumption patterns, and word-of-mouth referral behavior, which together with the firm's strategies leads to specific diffusion processes and eventually market acceptance of the innovation. Thus, models that can predict the impact of a chosen strategy on the diffusion of a new product are valuable tools for managing innovation.

Traditional models based on differential equations (e.g., Bass, 1969) represent the diffusion process at the aggregate level of the entire population. However, such models do not explicitly account for the heterogeneity of consumers who differ in their preferences, are distributed across diverse geographical regions, and are connected to each other in various ways. An agent-based approach can overcome such limitations by modeling the diffusion of innovations at the micro level. For a comprehensive survey of agent-based diffusion models and a discussion of their advantages see Kiesling, Günther, Stummer, and Wakolbinger (2012).

Although agent-based models (ABMs for short) allow to represent rich behavior at the micro level, and to derive conclusions at the aggregate level from this micro-level behavior, they are often criticized as 'toy models' that do not adequately capture actual behavior in a real market setting, mainly because many of them lack an empirical foundation. The aim of this paper is to present a model that on the one hand is based on empirical data in the context of an actual case study, and on the other hand extends previous models in several directions by (i) considering repeat purchase decisions, rather than only initial adoption of consumer durables, (ii) representing interactions between multiple products, rather than a fixed market potential for the innovation, and (iii) taking into account the spatial dimension of diffusion.

The real-world context in which we apply this model is the potential diffusion of a novel second-generation biofuel on the Austrian

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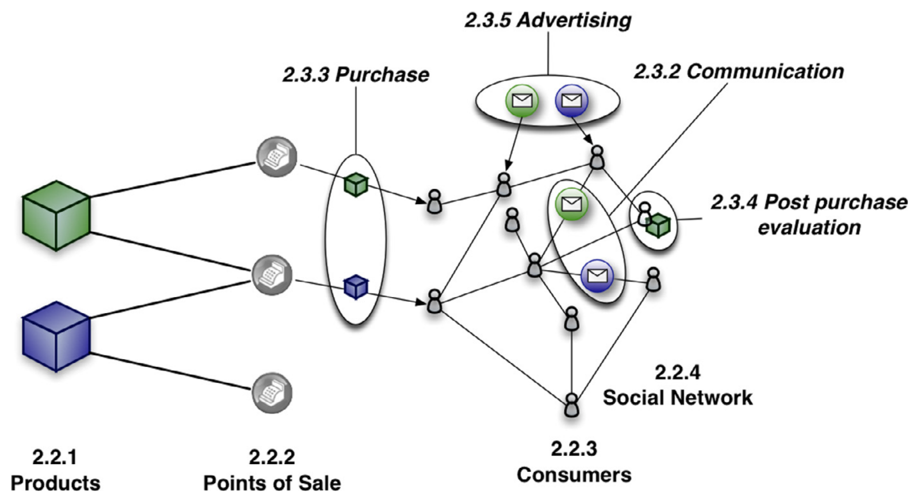

Fig. 1. Model entities and dynamics.

market. Using empirical data from this case, we demonstrate how the simulation model can be used to evaluate product launch strategies in a competitive setting.

The paper is organized as follows: First, we introduce the agent-based model and its core elements (Section 2). Then, we describe the sample application (Section 3) and present exemplary results (Section 4). Finally, the paper concludes with a summary of findings and an outlook to promising areas for further research (Section 5).

2. Model formulation

2.1. Framework

Rogers' (2003) well established conceptual model distinguishes five phases in the adoption or non-adoption of an innovation: (i) learning about the existence of an innovation and its basic functions (*knowledge phase*); (ii) forming a favorable or unfavorable attitude based on information (*persuasion phase*); (iii) decision to adopt or reject the innovation (*decision phase*); (iv) actual use of the innovation (*implementation phase*); (v) seeking information to reinforce the decision (*confirmation phase*). In each phase, the individual may revert to a preceding phase, based on new information. Our model covers the complete process, including the two latter phases that are not considered in most previous ABMs. Fig. 1 gives an overview of its main entities and the dynamics between them.

Our model also differs from many other ABMs in its representation of time and space. Approaches using fixed time intervals force events to occur at the same (simulated) time and results thus may depend on the specific scheduling mechanism used in the simulation (Radax & Rengs, 2010). Our approach avoids such modeling artifacts by using a discrete event approach in which specific events (e.g., communication, need/purchase, and post-purchase evaluation) are scheduled by stochastic processes at arbitrary points on a continuous time scale. Accordingly, each event takes place at a unique point in time and triggers subsequent events after inter-event times drawn from suitable distributions.

The relevance of space for innovation diffusion processes has long been recognized in literature (cf., e.g., Hägerstrand, 1967). Still, space has rarely been explicitly considered in ABMs. In some models, the existence of communication channels between agents can be interpreted to represent space. In others, agents are allocated on a uniform grid that is used to structure social interactions. Our model, in contrast, assigns geographical locations to agents based on actual population density, and takes them into account in interactions between agents.

2.2. Model entities

The model at hand allows for multiple products (Section 2.2.1), points of sale (Section 2.2.2), and heterogeneous consumer agents (Section 2.2.3), who are connected by a social network that structures their interactions (Section 2.2.4).

2.2.1. Products

We consider a set P of m products indexed by $i = 1, \ldots, m$, which are characterized by n attributes indexed by $j = 1, \ldots, n$. The true performance of product P_i in attribute A_j denoted by $v^{true}_{i,j}$ is typically unknown to consumers, who rely on (potentially conflicting) information. In our model, each consumer agent maintains a distribution of information on attribute values received from various sources. Furthermore, consumers are not necessarily aware of all products or attributes, but learn about them over time.

Information reduces, but does not eliminate uncertainty about attribute values. Even first-hand experience may not provide perfect information about all attributes (e.g., a fuel's environmental impact). We therefore introduce an attribute-specific parameter o_j that determines the "observability" of an attribute. Likewise, information obtained via communication is not necessarily credible, and thus is weighted with similar factors.

2.2.2. Point of sale agents

Points of sale (POS) are characterized by the (sub)set of products they carry and their current prices. Product prices may vary between points of sale and over time. They are defined exogenously, which allows us to study the effects of pricing strategies.

2.2.3. Consumer agents

The model accounts for a set C of heterogeneous consumer agents indexed by k. Each consumer agent $C_k \in C$ is characterized by a number of parameters. Heterogeneous preferences are represented by individual partial utility functions $u_k()$ that, for instance, may take the form of additive utility functions with piecewise marginal utilities as in our application case. Additional parameters describe application-specific agent characteristics (e.g., mobility behavior).

Since consumer agents do not know the true attribute values, their decisions are based on estimates $v^{est}_{i,j,k}$ of product characteristics, which are updated whenever a consumer receives new information. Consumers may not even necessarily be aware of all products available on the market and/or their attributes which is why information about individual awareness is also stored for each agent. In