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An agent-based market simulation for enriching innovation management education

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Abstract
It is not easy for students or junior managers to obtain first-hand experience in innovation and technology management. Business gaming simulations can remedy this, as they provide an opportunity to acquire practical skills. We developed such a business gaming simulation that enables teams of participants—each managing a virtual company that competes with other companies in several markets—to implement technology strategies, make resource allocation decisions, and test marketing strategies for introducing its new products. The salient feature of this simulation is its agent-based market model, which accounts for consumers' heterogeneity and social factors like word-of-mouth communication. In this paper, we describe the elements and dynamics of the market model, outline the didactic framework, and synthesize our experiences from using the simulation in classroom settings for several years. Overall, we find that using an agent-based model as the core of a business gaming simulation can facilitate experiential learning in management, particularly in fields that involve complex social system dynamics, as is the case in the diffusion of innovations.

Keywords Agent-based modeling · Business gaming simulation · Innovation management · Product diffusion · Pricing and timing strategies · Education

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"I hear and I forget. I see and I remember. I do and I understand."
Confucius

1 Introduction

Traditional management education can explain theoretical concepts and introduce students to management approaches, practices, and tools. However, it is very difficult to provide students and junior managers with first-hand experience in making critical (strategic) decisions because such decisions are typically only made by senior managers. Furthermore, consequences of strategic management decisions usually play out over an extended time frame, which implies that by the time the impact of a prior decision becomes apparent, managers may have transferred to a new post or even to a different company. Finally, outcomes are often influenced by other decisions or by general economic developments, which makes it difficult, if not impossible, to trace market behavior back to specific decisions made in the past.

Business gaming simulations can provide a solution to this dilemma, as they compress learning cycles of (management) action and (market) reaction—which may take months or years in real life—into merely minutes or hours in the simulation. They also make it possible to replay a scenario and, thus, to test alternative strategies to cope with a problem setting (whereas in reality, managers only have a single chance to make a decision). Thus, business gaming simulations allow participants to apply theoretical knowledge in close-to-reality situations and, hence, to improve their decision-making competence. Last but not least, the opportunity to immediately experience the outcome of one's own decisions, rather than only hearing or seeing what others have experienced, typically results in more sustainable learning outcomes (Tao et al. 2015). Owing to such benefits, general business gaming simulations and simulations that focus on specific management tasks (e.g., production and operations management) have become rather popular (Faria et al. 2009; Lane 1995; Liao et al. 2015; Vos 2015; Xu and Yang 2010).

The business gaming simulation described in this paper is concerned with innovation management, in which typically large amounts of resources are at stake: in Austria, for instance, businesses expended over € 8.5 billion on research and development (R&D) in 2018; for Germany, the respective R&D expenses sum up to more than € 72.1 billion (OECD 2020). In addition, companies dedicate substantial amounts of resources on marketing measures during market introduction and often have to make additional investments to set up or modify supply chains and distribution channels or to secure the availability of sufficient production capacities. When innovation managers make decisions on targeting, timing, and pricing for the market introduction of a new product, these decisions are particularly challenging because markets are complex social systems whose aggregate behavior is difficult to predict. Moreover, market dynamics are influenced by competitors' behavior, who also may introduce new products or change their policies with respect to pricing, distribution, etc.

We have been using business gaming simulations in innovation management education for over 30 years at universities in Austria and Germany and generally received extremely positive feedback from participants. Nevertheless, we were not fully satisfied with the fidelity of prior models in capturing and reproducing actual market behavior. Therefore, we followed the suggestion by Garcia and Jager (2011) and developed and integrated an agent-based market model as part of a business gaming simulation. The resulting simulation can serve as a valuable tool for exploring the dynamics of innovation diffusion (see also Deguchi 2005; Yilmaz et al. 2006, who raised related issues even earlier).

The research contribution of this paper is twofold. First, we present this business gaming simulation, which is based on an agent-based market model that accounts for consumer heterogeneity and word of mouth. The simulation considers multiple regional markets in parallel, which requires participants to make strategic decisions with respect to one or several target markets. Another critical aspect is market entry timing, that is, whether to enter the market as a first-mover, which may yield advantages but also comes with risks such as uncertainty regarding consumers' willingness to adopt an innovation (e.g., a novel smart product). Company resources are limited and, therefore, must be allocated wisely, weighing off investments in technology development, the launch of new products based on these technologies, and marketing expenses to develop a market (or several of them). All these decisions need to be made in a dynamic environment where competitors are attempting to do the same. Overall, this new business gaming simulation brings to light several management elements that have not been covered by previous simulations. Second, we applied the new business gaming simulation in a classroom setting on a regular basis at three universities in Austria and Germany for several years. Therefore, rather than merely presenting a proof of concept, we can report and reflect on actual teaching experiences.

The remainder of this paper is organized as follows: In Sect. 2, we provide an overview of agent-based modeling of new product market diffusion and outline prior approaches for modeling market demand in business gaming simulations. Next, we describe the learning objectives and the general course of our business gaming simulation as well as the elements and dynamics of the underlying agent-based model (Sect. 3). Then, we discuss participants' learnings and gains (Sect. 4), and we report on our experiences using the simulation in the classroom (Sect. 5). The paper concludes with a summary and discussion of remaining limitations to be addressed in future research (Sect. 6).

2 Background

2.1 Agent-based modeling of new product market diffusion

Agent-based modeling (ABM) can be described as a bottom-up approach in which "a phenomenon is modeled in terms of agents and their interactions"; an agent in this context is "an autonomous computational individual or object with particular properties and actions" (Wilensky and Rand 2015). ABM takes into account the individuals' behaviors, reactions, and interactions and, thus, has the potential to capture the behavior of a complex system, such as a market, more accurately than is possible in traditional approaches. In a market model, consumers can be represented by agents, which makes it possible to account for the (typically limited) local information that is considered in the (consumer) agents' individual decisions, to model agent's internal notion of the external world, and to incorporate the agents' expectation of possible reactions of other agents in response to their actions (Macal and North 2010). Furthermore, it is possible to account for heterogeneous behavior based on varying rules that guide individual agents' decision-making (for an overview, see Negahban and Yilmaz 2014).

Agents' interactions may be direct or indirect. Word-of-mouth communication is an obvious example for direct interaction, as is advertising, which might take various forms such as mass media advertising campaigns or point-of-sale advertising (e.g., Sonderegger-Wakolbinger and Stummer 2015; Stummer et al. 2015). Network effects are an example for indirect interaction, that is, one agent's decision is influenced by the decisions made by many other agents, even though that decision is not directly communicated to the focal agent (Clements 2004). The most common type of indirect interaction is social influence, which can be modeled through a threshold mechanism of collective action, that is, it takes effect once the number of peers showing a particular behavior (e.g., owning a product) exceeds a threshold (e.g., Delre et al. 2010), or, alternatively, the proportion of peers determines the strength of the social influence (e.g., Backs et al. 2019, 2020; Haurand and Stummer 2018).

In summary, agent-based modeling can account for (*i*) population heterogeneity in terms of attributes and decision-making processes, (*ii*) the impact of social influences on the dynamics of markets, and (*iii*) emergent phenomena arising from agents' interactions (Negahban and Yilmaz 2014). In the market model developed for our business gaming simulation, agents represent consumers with heterogeneous properties (e.g., individual preferences for certain product attributes and individual communication behavior). These consumer agents make purchase decisions (typically based on an evaluation of several product alternatives) and engage in word-of-mouth communication with their peers. In doing so, they spread information about newly available products and make other consumer agents aware of them. Thus, the individual behavior of agents also affects actions of other agents and the environment (e.g., the products offered by the companies in the business gaming simulation).

2.2 Prior business gaming simulations for innovation management

Modeling market behavior in a business gaming simulation constitutes an interesting challenge. Baptista et al. (2014) distinguished four major families of approaches that are outlined in the following (for a historical review of algorithm development for computerized business simulations, see also Gold and Pray 2001).

Equation-based approaches utilize mathematical functions for calculating total market demand and demand for an individual firm's products. In the context of innovation and technology management, an equation-based gaming simulation was introduced by Heidenberger et al. (2001). In this game, called *MERLIN*, participants are tasked with the development of several technologies that drive product performance (i.e., functionality and quality). The underlying technology trajectories follow s-curves that are unknown to the participants at the beginning. Product demand is a function of both product performance and price. Sales also can be influenced through advertising. The main challenge in MERLIN lies in establishing the right balance between (heavily) investing in technology development (i.e., being the first at the tipping point of the s-curve; Foster 1986) and maintaining a reasonable market position in order to make sufficient profit to be able to finance further technology development. Participants also must time the switch to new technologies when older ones reach the end of their life cycle. In a subsequent version of this business gaming simulation, participants are also required to predict production volume in advance (thus, they must make an educated guess regarding market development and their own relative market strength) and they can offer to or actually acquire technology licenses from other companies (if such an opportunity arises). For each simulated business year, the total market volume is calculated; companies earn a market share according to the consumption value of their product(s), prior sales (due to some brand loyalty), and their advertising activities. Overall, market behavior in MERLIN is fully deterministic.

In *interpolation-based* approaches, markets are modeled by specifying a number of key points (e.g., minimum, maximum, and bending points) for relevant functions, which are supposed to represent market demand and firm-specific demand—that is, for example, the relationship between price and the number of products sold (Goosen and Kusel 1993). The simulation interpolates between these points to determine outcomes. However, we are not aware of any such game in the context of innovation management.

For a *statistical* approach, Carvalho (1995) suggests utilizing a probability distribution showing the mathematical properties required by the law of demand. Market shares for products are determined based on this distribution. A particular challenge in this top-down modeling paradigm is the choice of suitable parameters. Statistical approaches have not been particularly widely adopted—at least as far as business gaming simulations for innovation management are concerned.

Agent-based modeling has emerged as a recent family of approaches to design business gaming simulations upon. They follow a bottom-up modeling paradigm—that is, they model the individual behavior of stakeholders (i.e., agents)—from which emergent market behavior arises. Agent-based market simulations have become popular in various fields of application, including innovation adoption and diffusion (e.g., Delre et al. 2010; Stummer et al. 2015; Kiesling et al. 2012 provide a review). Baptista et al. (2014) have indicated that business gaming simulations based on an agent-based market model may result in better learning outcomes, both at the level of users' subjective self-assessment and at the level of performance metrics and knowledge acquisition tests. With respect to agent-based approaches in business gaming simulations for innovation management, we are only aware of a single game, namely, the business gaming simulation *MoTI* (Kiesling 2007; Günther et al. 2011). As in MERLIN, MoTI focuses on investments to further technological development but it is considerably more elaborate in this respect because it distinguishes between investments in research—which may lead to breakthroughs and performance leaps in the long run—and investments in the development of more sophisticated products based on available technologies. Thus, participants may experiment with various technology strategies—from pursuing technology leadership to behaving as an early adopter or a fast follower—and they can experience the respective advantages and drawbacks of these strategies. Most interestingly, MoTI already incorporated an agent-based market model, in which consumer agents have distinct characteristics regarding propensity to innovate, preferences, price sensitivity, sensitivity to advertising, and communication behavior, all of which determine the diffusion of information on new technologies and products. Although this game already exhibits many of the features of an agent-based market modeling approach very early, it was not used often in a classroom setting, because parameterization was highly sensitive; thus, it turned out to be difficult to find a sufficient number of parameter settings to cover a full course.

Other than the two games outlined above, more general business gaming simulations may be used for innovation management education as well. The BOSS business simulation[1] focuses on providing insight into the blue ocean strategy; it appears to implement some form of market mechanism. The somewhat older Intopia[2] game teaches students the concepts of strategic management of multinational business. This game is particularly concerned with the availability of patents, which may pop up in the game (with some probability) once investments in research and development have been sufficiently substantial and made on a regular basis. In the online Back Bay Battery Strategic Innovation Simulation,[3] participants are required to find trade-offs between sustaining investments in an existing battery business and investments in a new and potentially disruptive battery technology. Further business gaming simulations considering at least some innovation management issues are CAPSTONE,[4] CESIM,[5] HUBRO,[6] and MARGA.[7] However, information on the modeling of market mechanisms are not publicly available for any of these business gaming simulations and it appears that none of them employ agent-based market simulation.

3 Agent-based market simulation

3.1 Learning objectives

The business gaming simulation MIDAS (short for Management Game for Innovation Diffusion Using an Agent-based Simulation) has been designed to be part of a course on innovation and technology management for master's students at universities. Given the very promising experiences with the game in academic teaching, the business gaming simulation may very well also be used for professional training (e.g., in the course of a corporate trainee program).

As MIDAS is concerned with the market introduction of new products, participants need to decide when the product "is good enough" for market introduction; entering a market too late not only results in foregone sales but may also bring the threat of entry barriers established by faster competitors. Thus, students can experiment with strategies for deciding which market (out of several available markets representing,

1 https://web.stratxsimulations.com/simulation/business-strategy-simulation/.

2 http://www.intopiainc.com/.

3 https://www.hbs.edu/faculty/Pages/item.aspx?num=37262.

4 https://www.marketplace-simulation.com/capstone-simulations.

5 https://www.cesim.com/.

6 https://hubro.education/en/hubro-business-simulation.

7 https://www.marga.net/en/businesssimulation.

for example, regions or countries) to enter at which point in time. A common strategy is the so-called waterfall strategy (Kalish et al. 1995), in which markets are entered one by one. When following this strategy, students concentrate on one market at a time and make an effort to secure a strong position in this specific market (e.g., by investing sufficient resources in establishing sales channels). However, they may forego the opportunity of an early market entry in other markets. Alternatively, game participants may opt for a so-called sprinkler strategy (Kalish et al. 1995) and attempt to conquer several (or all) markets simultaneously, which obviously comes with high costs and risk. As resources are limited, this also implies that investments for supporting market introduction have to be spread across markets, which increases the risk of failure.

In addition to its emphasis on the market introduction of new products, which distinguishes MIDAS from prior business gaming simulations such as MERLIN and MoTI, MIDAS also still requires participants to strategically develop a company's technological capabilities (i.e., by funding R&D activities), which is a prerequisite to remain competitive in the long run. Accordingly, students who focus on developing the most advanced products but neglect market development, and vice versa, will experience difficulties. In this spirit, MIDAS actually encompasses a wide spectrum of innovation management issues.

3.2 Course of the game

In a business gaming simulation, participants interact with a modeled system; in MIDAS, these interactions are structured as follows: each team of participants (e.g., five teams, each consisting of four participants) is put in control of a company. The teams alternate between making decisions and analyzing results. Decisions are submitted by means of a web interface; once decisions by all teams have been submitted, the simulation commences for a given period. Once the halting point for the current period is reached, the simulation generates reports for each company, that is, (*i*) an income statement, (*ii*) a balance sheet, and (*iii*) notes. The latter break down sales and cost of goods sold and summarize sales and marketing expenses, technological progress, and inventory levels. Optionally, participants can also purchase a market report that provides market intelligence such as estimated market shares, size of market segments, and consumer preferences. The reports are available to the respective participants as spreadsheets and PDF documents and provide the basis for further decisions in the next round, thus starting the next decision cycle. A game continues until either (*i*) a pre-determined number of decision cycles (e.g., ten) or (*ii*) a time limit for the total duration has been reached. Teams are then ranked based on their companies' total equity, possibly with bonus points for their technological achievements. As the business gaming simulation is entirely web-based it can be used in various settings in both online and classroom formats. The embedding of the business gaming simulation into a broader didactic concept and course design is outlined in Sect. 5.1.

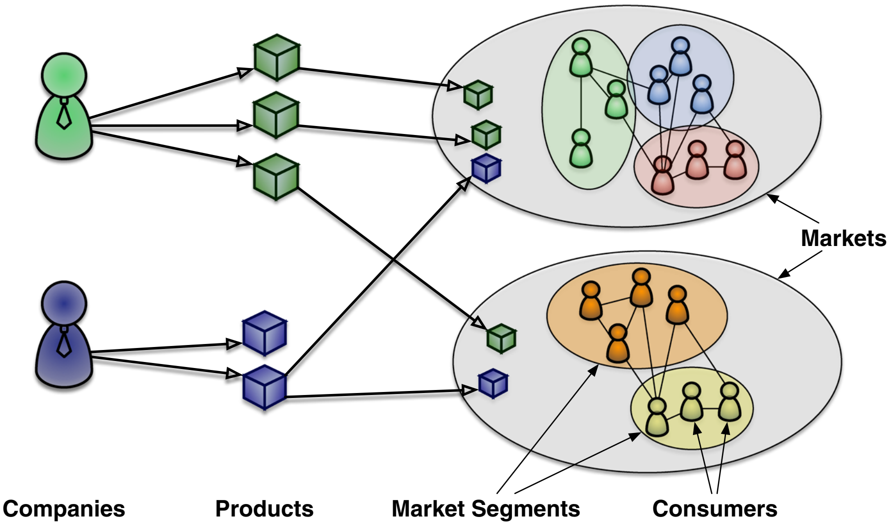

Fig. 1 Model entities

3.3 Model entities

From a modeler's viewpoint, the most critical aspect of the business gaming simulation is the agent-based market model (Fig. 1 provides an overview of elements considered in the model). The model accounts for several *companies*, each being managed by either a single game participant (i.e., a student) or by a team of participants. When the game begins, companies have a budget of freely available resources, have already made some (small) progress on technological s-curves (as described by Foster 1986), which help to determine product functionality, quality, etc., but (usually) have not introduced any product in any market yet. In a basic classroom scenario, all companies begin with the same initial amounts of budget and technological capabilities. Furthermore, certain operational aspects can be automated for the sake of simplicity. For example, the quantity of each product produced by each company may automatically be set to the demanded quantity. In advanced scenarios, participants also need to set production volumes for each product in advance. This implies that companies may overproduce, which results in storage costs, or companies may run out of stock, which results in foregone sales. Furthermore, initial settings for the companies may differ, which places a few companies in different financial, market, or technology positions.

In the course of the business gaming simulation, managing the products' life cycles is a key activity. Companies may introduce new *products* in one or several markets or may withdraw them from any or all markets. A particular product's technological capability level is determined by the company's position on the respective technological s-curves at the time of the launch of the product. This resembles, for example, a company's decision to introduce a new smartphone; while smartphones of this type are produced and sold, the manufacturer continues to work on the next generation and subsequently decides to introduce the next version, which ultimately makes several types of smartphones available in the market. At any time, the manufacturer may decide to no longer sell older versions.

MIDAS accounts for several parallel but distinct *markets*. These markets are non-overlapping, that is, each consumer is part of a particular market and only connected to other consumers within this market. If a product is withdrawn from a market, it cannot be imported by consumers from other markets. This restriction makes it easier to trace consequences of individual decisions. Depending on the parameterization, a game scenario may use markets to represent large regions (e.g., Western Europe, South Korea and Japan, Australia), several federal states of a single country, or even a local district (county). Each market is characterized by (*i*) its size (i.e., number of consumer agents), (*ii*) the structure of the social network that consumers are part of, (*iii*) intensity of communication, (*iv*) costs for market entry and market exit, (*v*) costs for launching a new product, and (*vi*) effectiveness of advertising in this market.

To model each market, we divide it up into several *market segments*: consumers who are assigned to the same market segment have similar preferences and are typically connected to each other with a higher probability than they are with consumers from another segment. Market segments may be based on geographic, demographic, psychographic, or behavioral similarities among consumers; or they may refer to adopter categories (such as innovators, early adopters, early majority, late majority, and laggards, as classified by Rogers 2003). They are characterized by their size (number of consumer agents), consumer preferences, price sensitivity, extent of brand loyalty, strength of normative social influence, eagerness to possess the newest version of a product (which determines the time between two subsequent purchases), and minimum product value (utility) required before a particular product is considered (which differs for adopter types, from innovators to laggards).

Consumers are represented by consumer agents who have individual preferences for product attributes (e.g., features), including price. They are embedded in a *social network* produced by a configurable graph generator (random, scale-free (Dangalchev 2004), or small world (Watts 2004)). The most common setting we used in typical game configuration creates a small-world network using the Beta-model (Watts 2004) with rewiring probability $\beta = 0.1$ and $k = 4$ neighbors. This generative model starts with a one-dimensional ring lattice in which each vertex has k neighbors; it then randomly rewires the edges with probability β. For various values of β and k, the resulting networks exhibit the low path lengths and high clustering coefficients being characteristic of small-world networks (Newman and Watts 1999).

3.4 Timeline and event types

With regard to the treatment of time in the model, we opted for a continuous timeline on which events can be scheduled at any point. In order to provide participants with regular reports (e.g., on financial and business indicators regarding sales or achieved technological capabilities), we place halting points for the simulation in fixed intervals on the timeline. Halting points at the end of a business year also invoke the procedures that close the business year and generate annual reports (i.e., a closing balance as well

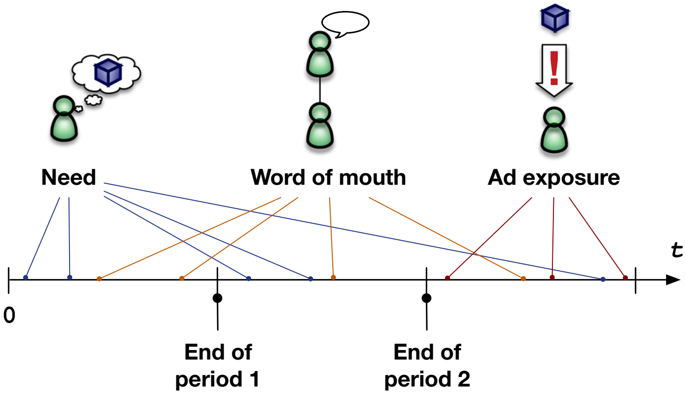

Fig. 2 Time and event types

as a profit and loss statement). Apart from these halting points, three main types of events occur in the simulation (Fig. 2 provides an overview).

A *need event* represents the situation in which a consumer's potential need arises for a given product (e.g., a new smartphone). Consequently, the consumer agent may consider initial adoption or repeat purchase, which may trigger a purchase process (for a description, see Sect. 3.5). Need events are generated by a configurable stochastic Poisson process (i.e., a process in which the interarrival intervals have an exponential distribution function). Its parameterization is based on aspects such as typical product life and consumer characteristics in the segment, as consumers from certain market segments will seek the newest version of a product much before others.

Consumer agents are not necessarily fully aware of all new products that are available in the market and, therefore, must be made aware of their existence. This can be achieved through communication or advertising.

Word-of-mouth (WoM) events represent information exchange between two consumers. These propagation events may be initiated if an agent has either recently purchased a new product or learned about it. Hence, the scheduling of WoM events is triggered by a product purchase or by another WoM event, both of which take effect with configurable probabilities. The check for whether a WoM event is scheduled is performed for each of the originating agent's edges in the social network. For each of the edges that are activated, a WoM event is scheduled accordingly with a given delay drawn from a configurable exponential distribution. Once a WoM event is executed, it has two effects: First, the corresponding agent becomes aware of the product, if the agent is not yet already aware of it. Second, if the agent is not yet aware of the brand of the product (i.e., the company that produces the product), the agent also becomes aware of the company.

We also experimented with significantly more complex models of WoM propagation during the development of the business gaming simulation and tested several variants in a classroom. For example, we incorporated a mechanism for bilateral information exchange during which the consumer agents influenced each other's perception of the available products in different ways, depending on the stage of adoption. However, this variant led to rather volatile market behavior, which made it difficult for participants to appropriately link market outcomes to the decisions they had made. The simple awareness propagation model we finally implemented produces organic patterns of market development and realistic first-mover advantages, as earlier market entry will foster brand and product awareness; in turn, this may lead to faster initial adoption and continued brand loyalty.

Advertising exposure events are generated by the simulation at the beginning of each period, based on the resources that a company decides to invest in advertising each of its products in each market. A configurable market-specific function then assigns a (randomly selected) proportion of consumers to be reached for a given advertisement investment. More often than not, we model this function as an s-curve to incorporate both a minimum effective level and diminishing marginal returns for extensive advertising activities. Once a scheduled advertising exposure event is executed for a particular agent, the agent becomes aware of both the brand and the particular product being advertised. Apart from creating awareness, advertisement does not influence consumers' perception of a product, since this is neither the main focus of the simulation nor do we explicitly consider the content of the advertisement or the complex ways in which advertisement may affect consumers' perception of the product.

3.5 Purchasing process

Consumer agents construct an evoked set of available alternatives before making a buying decision. In this evoked set, a particular product is included if (*i*) it is generally offered in this consumer's market, (*ii*) it is available at this point in time (i.e., the company has not run out of stock), (*iii*) the consumer is aware of the existence of this product (otherwise, the product will still be added to the evoked set with some probability if the agent is aware of the company and with another probability if the agent is generally aware of the product category), and (*iv*) the product's price (set by the company separately for each market) is below the consumer's individual threshold determining their willingness to pay.

Next, product values u_{ij} for consumer agent i and each product j from the evoked set is calculated on the basis of (*i*) product j's attributes a_{jk} in each of the k criteria under consideration (e.g., quality, performance, etc.; $k = 1, \ldots, K$), (*ii*) product j's price p_j, and (*iii*) agent i's weights (preferences) for the attributes w_{ik} and the weight for the price w_{i0}. Weights are individual (fixed) parameters for each consumer agent (which, of course, differ between consumer agents), whereas the product attribute values are variables that are determined by the company's technological progress on the respective technological s-curves at the time when the product is launched (i.e., they will change in the course of a simulation run). Price p_j is set by the company (i.e., the respective participant of the business gaming simulation).

In most of our game configurations, we use the following multiplicative utility function with exponential weights and a stochastic random variable ϵ representing further (minor) influence factors that are not explicitly accounted for by the other terms:

$$u_{ij} = \frac{\prod_k a_{jk}^{w_{ik}}}{p_j^{w_{i0}}} + \epsilon \tag{1}$$

The calculated product values are used as weights in a random choice between the items in the evoked set in order to determine the specific product to be purchased by the consumer agent.

3.6 Technology development

In the technology development model, we assume that a product's attributes (except price) are determined by the company's technological development level at the time when the product is launched. By further investing in a particular technology, the performance of this technology can be improved. The progress on the respective (configurable) s-curve for each attribute is typically slow in the beginning, until a breakthrough is reached and marginal returns become higher. Finally, progress slows down when the technology development in an attribute reaches its potential (for a discussion, see Foster 1986).

Procedurally, we use logistic functions that can be easily parameterized to produce any desired variant of an s-curve to be used for translating investments in technology development into progress on the respective attribute development curve. In doing so, we also account for economies and diseconomies of scale—that is, very small or very large investments are associated with a small marginal development return. Accordingly, an exceptionally high investment in one period yields less progress than if the same amount of resources are split into smaller investments in consecutive periods. The underlying reasoning is that technology development also usually requires time (and not just money). Nevertheless, larger investments will always result in (somewhat) greater technological progress than smaller investments.

3.7 Economic issues

Production cost is composed of fixed costs and variable costs. Whereas the former costs increase due to inflation over time, the latter costs also depend on the lot size produced—that is, economies of scale are considered. The MIDAS model enables participants to invest in improving the production process to lower variable production costs. The same effects regarding an efficient investment level apply as for product attribute development investments.

The initial *market entry* of a company requires one-time (market-specific) investments for establishing distribution channels as well as annual operating costs for maintaining them. Additional costs arise when launching a new product in a given market (one time), as well as in each year in which the product is offered in this market. Discontinuing a product is associated with one-time costs, as is an exit from a market. As a decision aid in such instances, the business gaming simulation enables participants to commission a detailed market report that also provides information regarding competitors and their behavior in a market.

Further *financial issues* include the consideration of inflation and interest rates for deposits, both of which may fluctuate over time. It is also possible to lend capital; the maximum amount depends on a company's credit rating (which is determined with respect to several financial indicators) and the interest rate to be paid equals the interest rate for deposits plus a fixed spread.

3.8 Implementation

For the implementation of the simulation model, we identified a number of general requirements, that is, support for classroom and online settings, moderate resource consumption to allow for the simulation of multiple game instances in parallel on standard hardware, platform independence, and deployment flexibility. Major functional requirements included an intuitive web-based user interface for both participants and instructors, the generation of reports in a standard spreadsheet format that allows participants to develop their own analytic workflows, and extensive configurability and parameterization options to allow instructors to model various scenarios and tailor the simulation to the needs of both novice and experienced participants. Finally, the system shall give ample and easily understandable feedback to provide a solid base for decisions and facilitate an effective learning process.

Considering all functional and non-functional requirements, we chose Java/Jakarta EE[8] as a platform and implemented the front-ends for the participants and the instructors using Jakarta Server Faces.[9] The core component that manages user accounts and game instances, as well as executes the simulation model, is hosted on an application server that connects to a MariaDB[10] database for persistence.

4 Learnings and gains for participants

4.1 Professional skills

The primary goal of the business gaming simulation MIDAS is to teach participants sound concepts and methods that increase their ability to make strategic and tactical management decisions in a competitive environment, with a particular focus on the management of technology and innovation. In the remainder of this section, we summarize key skills that participants developed in the course of the gaming simulations in this thematic area.

Market entry and global product launch strategies are fundamental in MIDAS. Participants learn to analyze market entry conditions in a competitive setting and to trade off risks and benefits of, for example, waterfall and sprinkler approaches. Furthermore, participants learn to align the selected market entry strategy with new

8 https://jakarta.ee.

9 https://jakarta.ee/specifications/faces/.

10 https://mariadb.org.

product development and launch strategies as well as to trade off first-mover and follower advantages.

Learning to develop *pricing strategies* in the context of competitive market conditions is another key aspect. We found that in the early stages of the game, participants usually find it difficult to calculate a cost-covering baseline, given the various fixed and variable costs involved as well as uncertain demand. It is critical to learn how to develop a pricing framework that accounts for all costs rather than using only variable costs as a baseline and following an appropriate pricing strategy rather than a reactive approach based on competitors' prices. Typically, upon instruction, most participants quickly progressed from a rather erratic pricing approach and began to systematically experiment with dynamic pricing strategies. This experimentation was often performed in parallel within a game through price differentiation across markets. We also frequently observed a loss leader strategy, in which companies priced their products below variable costs in order to drive out competitors.[11] Interestingly, we found that neither of the two basic dynamic pricing strategies, that is, entering the market with a new product priced low and raising this price later (i.e., penetration pricing) or the inverse (i.e., skimming) was a dominant strategy that worked best under all circumstances.

Product life cycle and portfolio management is another skill that participants develop during the games. This includes making decisions on product launch and discontinuation across markets and maintaining a strong product portfolio; this involves considerations such as cannibalization of sales of existing products and calculating whether products at the end of their life cycle still contribute a positive marginal return. A commonly observed error was pulling a product that was continuing to generate sufficient sales—and, thus, was cost-covering—from the market, while awareness of a newly launched advanced product had not yet sufficiently diffused. In the context of product portfolio management, various strategies emerged. One extreme strategy, which ultimately required changes in the parameterization of the game, was to essentially "flood" the market by launching a new (not particularly advanced) product every period, thereby cumulatively taking up a larger share in the evoked set of consumer agents. Therefore, we adjusted the product launch costs to a realistic level in order to prevent such extreme strategies.

Technology strategy constitutes a further core aspect of the business gaming simulation, for which participants usually develop skills in terms of formulating and applying such a strategy. In this context, a fundamental decision is whether to follow a first-mover or follower strategy and accordingly how much to invest in the development of innovative products. Another trade-off that participants had to learn to make is whether to specialize in particular product attributes and aim for a leadership position in particular product characteristics (of which there were typically two, in addition to price) or whether to aim for products with more balanced performance characteristics. A final learning relates to trade-off investments in product innovation (i.e., improving product attributes) and process innovation (i.e., lowering production costs). The relationship between the two has been a key topic of interest in innovation literature since the

[11] This also necessitated rule changes—that is, hard upper limits and profit requirements in the implemented credit rating scheme, which in previous versions of the game limited the credit amount as a percentage of revenue.

seminal article by Utterback and Abernathy (1975); practical experience with these concepts proved to be a valuable learning outcome.

4.2 Social skills

We teamed up participants in groups of three or four, which made the game more manageable in large classroom settings, but more importantly, also created an appropriate environment for imparting cooperation and communication skills. Participants typically learned how to organize work as a team, define roles, and divide responsibilities. Teams that performed well in the game were usually also good at solving such organizational issues and negotiating and discussing constructively while dealing with different perspectives and managing conflicts.

4.3 Personal skills

In addition to professional and social skills, the game also helped participants to develop personal skills that motivate and empower them. This includes general decision-making ability, which involves tasks such as developing alternatives, setting priorities, finding a solution within a reasonable time frame; thinking, deciding, and acting entrepreneurially; constructively dealing with difficult conditions such as time pressure and uncertainty; and adapting rapidly to changing conditions. On a more concrete level, participants developed personal skills such as reading and interpreting financial statements, extracting relevant information from a wealth of data, and using spreadsheet software to perform simple data analyses under time constraints.

5 Didactic reflections

5.1 General didactic process

The business gaming simulation was typically organized in two half-day sessions and delivered as part of courses in innovation management. The game was scheduled toward the end of each course; concepts and theory had already been covered in prior lectures. The first game session began with a general introduction and demonstration of the game mechanics and web interface, followed by a briefing of the first game. We use a simple configuration for the introductory game, which reduces the decision space and number of topics covered to core aspects related to managing market introduction of new products. This first game involves only a single market, does not allow teams to invest in process innovation, and does not require them to set production quantities. Participants usually used one of their team member's laptops to submit their decisions and the other laptops to analyze results and devise a strategy. Time limits were more generous at the beginning of each game and strictly enforced only in subsequent stages. During the decision periods, teams were supported by instructors through the provision of background information on the concepts covered, general explanations, and by offering hypotheses on the effects observed; however, no hints or recommendations were provided for current decisions.

At the end of each game, a debriefing phase first summarized the results and then required each group to reflect on their learnings. Teams were also invited to share their strategy, mention which aspects of their strategy worked and which did not, and, crucially, the mistakes that they had made. Further, the debriefing included a discussion on how the effects observed in the game translate into a real-world setting.

5.2 Class size and number of teams

The number of participants in the courses ranged from 15 to approximately 90; participants were divided into teams of 3–4 students, and a maximum of 5 groups (i.e., companies) were assigned to each game instance. In larger classroom settings, this resulted in multiple concurrent game instances, each of which was supported by additional teaching staff. Although the software was flexible and in principle allowed an arbitrary number of teams and parallel games, we found that a class size of no more than 15 participants organized into, for example, 5 teams of 3 students each was ideal. The teams were either formed through self-selection of participants or participants randomly assigned to their teams. A special report only available to the instructor that summarized all market developments and provided key figures proved to be highly valuable as a basis for supporting student groups in analyzing their mistakes or even addressing general questions.

5.3 Time limits

Another learning for the lecturer is that time limits for decisions are important and must be strictly enforced. Given the wealth of data provided, the variety of methods for analyzing them, and the difficult decisions faced by participants, a few groups tended to exceed reasonable time for conducting their analyses, often with a small marginal learning effect and growing frustration on account of other groups that had already submitted their decision. Therefore, we introduced a countdown timer for each decision period (typically 15 min initially and 10 min in the later stages of a game) and threatened monetary sanctions within the game.

6 Conclusions

Markets are complex social systems in which consumers are not merely passive entities that make deterministic choices based on perfect information and static knowledge; instead, consumers are heterogeneous in their preferences and behavior as well as in the manner in which they interact and influence each other. An agent-based model can account for corresponding market dynamics; therefore, it is a suitable foundation for a business gaming simulation that can be used in management education, particularly in the context of technology strategy, innovation diffusion, and new product marketing strategies.

In this paper, we described such an agent-based model and reported on our teaching experiences using it at the core of a business gaming simulation that is—to the best of our knowledge—unique in its scope and in the experiential learning setting that it creates. We conclude that the simulation is effective in supporting our students in developing a profound understanding of vital concepts in innovation management.

Although agent-based models in general and business gaming simulations in particular may benefit from more realism and complexity (Baptista et al. 2014; Sun and Naveh 2004), we deliberately chose to deactivate a number of advanced model features after pre-testing them. This was motivated by our impression that students—at least when involved in such a business gaming simulation the first time—can be overwhelmed by too many influence factors and, thus, can more easily grasp the intended learning objectives when confronted with a somewhat less complex model of consumer behavior. Moreover, a suitable parameterization and balancing of all possible aspects included in the simulation, while maintaining a manageable scope for our educational purposes, turned out to be difficult (and more testing is necessary in this respect). The thus far unused extensions of the agent-based market model include aspects such as (*i*) social influence, measured in terms of the proportion of direct peers in the social network or, alternatively, proportion of all consumers in the same market who have already purchased a particular type of product; (*ii*) brand loyalty, measured in terms of past purchases of products from the same company; and (*iii*) a 'follower's advantage'—that is, the effect that technology followers can advance faster on the technology curve than the technology leader. These aspects may be reintegrated into a future version of the business gaming simulation to be used for participants in a follow-up course.

A more challenging, but in settings with a high number of students possibly useful extension of the business gaming simulation is the integration into a so-called smart learning system that provides individual guidance based on artificial intelligence, as envisioned by Klat et al. (2014). Implemented as an expert system, this may help overcome the problem that traditional (i.e., personal) supervision conducted by a teacher or qualified teaching assistant is only feasible for a limited number of participants. To this end, the system would recognize when participants need support and offer them individual feedback and information regarding decision alternatives in the current phase of the business gaming simulation.

In conclusion, we demonstrated the applicability of an agent-based market model at the core of a business gaming simulation. This approach turned out to be highly valuable in the domain of innovation management education, with strong potential for also being applied in further business domains in which social processes play a major role (e.g., for creating effective marketing campaigns). Moreover, modeling social processes as part of a simulation game may also turn out to be valuable in other disciplines apart from management.

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