A Business Simulation with an Agent-based Deliberative Model of Consumer Behaviour

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Abstract. Agent-based modelling, a way to simulate complex systems comprised of autonomous and interacting agents, is perhaps one of the most promising developments in experiential learning. In this paper we present a business simulation where the marketplace is modelled as an evolving system of deliberative (consumer) agents acting as utility maximizers. Concretely, we describe the deliberative-based architecture of our consumer agents and its unique properties. Additionally, we present our preliminary results which suggest participants are better able to understand the simulation when provided with the unique information of the agent-based approach.

Keywords: Beliefs Desire Intention (BDI) Architecture, Agent-Based Computational Economics, Economic Theory of Consumer Behaviour, Neoclassical Maximization Theory

1 Introduction

The problem of modelling the marketplace is perhaps the most central and unavoidable issue of a business simulation. Often, the algorithms responsible for calculating market and firm level demand have been considered the most complex and important calculations of these simulations [1]. Their importance follows from the fact that the ability of a firm to capture market share from other firms forms the essence of this kind of learning experience. Their complexity comes from the considerable number of variables involved in such algorithms, such as price, advertising and sales staff expenditures, and their intricate interaction.

Since Goosen [2] first proposed a generalized algorithm to simulate demand in business simulations, several techniques have been studied, such as the equation-based [3], interpolation-based and statistical-based [4] approach, with much effort being devoted to enhance the flexibility and validity of the proposed models.

A paradigm not yet extensively applied to demand modelling in business simulations [5] is the agent-based approach [6], a technique increasingly used in a broad range of social sciences, which involves the computational study of a system as a collection of autonomous interacting individual actors, the so-called agents. This paradigm presents several advantages [7] as a representational system that could help promote better demand systems for business simulations.

One major advantage of agent-based modelling is that it does not impose restrictions on the linearity, homogeneity, normality, and stationarity of its solutions. This could mean more realistic marketplace simulations and contribute to the upward trend in complexity of business simulations [8].

Agent-based models are also known for their potential to demonstrate emergent phenomena. The use of this technique could thus result in more natural descriptions of the marketplace and its individual entities, the consumers, where it would be simpler to provide more information to participants and disclose the system's structure without hindering the strategic value of the simulation game. This could in turn create more transparent [9] simulations and lead to more effective learning experiences.

Given the not yet extensively explored possibilities of agent-based modelling, we present in this paper a business simulation with an agent-based model of consumer behaviour. In the following section we review previous demand models for business simulations (Section 2). We then proceed to describe our consumer behaviour model (Section 3), prototype game (Section 4) and experimental findings (Section 5). We conclude with our final remarks (Section 6).

2 Background

The following approaches have been used to model demand in business simulations:

- Equation-based: mathematical functions model industry and firm demand.
- Interpolation based: an interpolation method derives the graphics of industry and firm demand functions.
- Statistical: the proportion of consumers which consume a given product is measured using purchase probability distributions.
- Agent-based: the complexity of the marketplace is captured using a bottom-up approach, modelling the behavioural rules of each consumer.

2.1 Equation-based models

An equation-based model consists of two functions:

1. A function of market demand (Q) calculated from the average values of demand determinants such as price (P), advertising and promotion variables (M) and product quality variables (R):

$$Q = f(P, M, R) \tag{1}$$

2. A function of firm level demand (q_i) used to calculate the weight of each firm (w_i) when allocating market share:

$$q_i = w_i Q \tag{2}$$

$$w_i = g(P_i, M_i, R_i) \tag{3}$$

The equation-based approach uses a set of equations to express the emergent relationships which occur between consumers in a marketplace.

2.2 Interpolation approach

Goosen and Kusel [10] recognized that to try to find a single general flexible demand equation for modelling market and firm demand was an intricate task. Therefore, the authors proposed a method of implementing self-designed functions. Their proposed method had however some limitations. First, the method did not prescribe the nature of the self-designed functions. Consequently, this approach did not solve the problem of finding a flexible demand function. Furthermore, the designer had the burden of identifying all the relevant points in the modelled functional relationships. Modelling interactivity effects was also not straightforward as Gold [11] showed.

2.3 Statistical approach

Carvalho [12] proposed another approach to model market demand. The author disagreed with the fact that previous models were mostly based on input decisions, not modelling explicitly the crucial element of a demand model: the consumer himself. Accordingly, Carvalho proposed a model of market demand based on the equimarginal principle using the gamma probability distribution to simulate the preferences of the consumers. Carvalho's model allowed a more explicit modelling of consumers given that the probability distribution parameters could be changed to reflect changes in the consumers' incomes, tastes and market dimension. However, as Gold and Pray [13] noted, it was difficult to select and modify the distribution parameter values.

2.4 Agent-based approach

In the general area of agent-based models of consumer behaviour, a number of models have been proposed [14–16]. These models are however, not specially as models of business simulations since their primary purpose is to explain particular economic phenomena such as the decoy effect[3] [16], or the lock-in effect[4]

[3] The decoy effect can be defined as a phenomenon whereby consumers will tend to have a specific change in preference between two options when also presented with a third option which is asymmetrically dominated.

[4] The phenomenon of lock-in occurs when the consumer becomes dependent on a supplier for products and services, unable to switch to another supplier without substantial switching costs.

[15, 14]. In contrast, we aimed to develop a demand model able to simulate simple general concepts from economics such as the law of demand, diminishing marginal returns and other phenomena such as substitution and complementary effects.

3 Model

Our proposed model of consumer behaviour[5] is based on the deliberative Beliefs, Desires and Intentions (BDI) architecture [18], perhaps the best known and most studied model of practical reasoning agents. The BDI architecture provides a simple and efficient psychological framework for modelling the behaviour of agents acting under incomplete or incorrect information in their environments. This is typically the case of consumers in the marketplace which often have to decide based on uncertain information about the prices, quality or availability of products in their surroundings. In our reasoning architecture the internal state of the consumer consists of the following elements (Figure 1):

Beliefs represent the information the consumer holds about the current state of the world, that is, the marketplace, and its internal state. Two types of beliefs can be identified:
- Belief in the availability of a particular product.
- Belief that given the available budget (I) the consumer is able to purchase products.

Desires represent the goals of the consumer. For instance, the consumer can have the desire to consume an additional unit of a given product.

Intentions representing the possible courses of action. Purchase intentions are generated during the reasoning process of the consumer, each for a possible bundle of products.

The reasoning process of a consumer consists in the following steps:

Step 1 The consumer verifies if the desire to consume goods is a current goal. In the affirmative case, the reasoning process proceeds to step 2. Otherwise, the reasoning process proceeds to step 5.

Step 2 For each affordable combination of goods the consumer generates a purchase intention. This generation of intentions is supported by the current beliefs of the consumer in the availability of products at the market and its belief in his own economic capabilities.

Step 3 The consumer selects from the list of purchase intentions a preferred intention according to the maximization of an utility function. In case of identical utility values, a random factor is used to decide. The following utility function can be used to simulate the preferences of the consumer:

[5] For a more detailed description of the model please refer to [17].

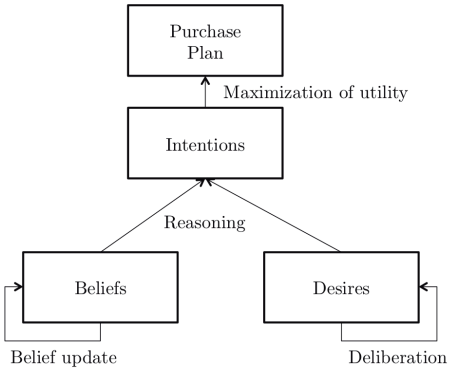

Fig. 1: The rationality elements of the BDI architecture of a consumer.

$$U(x_1, ..., x_n) = \sum_{j=1}^{x_1} b_1(j) + ... + \sum_{j=1}^{x_n} b_n(j) \tag{4}$$

$$x_1 p_1 + x_2 p_2 + ... + x_n p_n \leq I \tag{5}$$

where $x_1, x_2, ..., x_n$ *represent the quantities of distinct products* $1, 2, ..., n$ *which can be purchased at prices* $p_1, p_2, ..., p_n$ *for a consumer with a budget* I*.*

Step 4 The consumer attempts to accomplish his preferred purchase intention as an effective purchase plan.

Step 5 The consumer updates his beliefs and desires.

4 Game

Our proposed agent-based model of consumer behaviour was implemented in a concrete business simulation to further analyse the educational possibilities of the model. The simulation game models the following entities (refer to Figure 2):

Firms represent the participants. Each participant acts as a firm and manages a retail store where the participant can purchase and sell a number of different products to the final consumer. In each round, participants have to decide on two fundamental topics: (a) quantity of each product to purchase and (b) selling price of products at the store. The performance of firms is evaluated according to their profit.

Fig. 2: Game interface: A) panel of decisions, B) simulation panel and C) panel of information of firms, suppliers and consumers.

Products represent the goods sold by firms to the final customer. Each product has an associated purchase cost and is characterized by a type and a quality measured in a scale from zero to one. The type defines the quantity in average a consumer requires of that product according to his available budget. The quality defines his preference over other products.

Consumers represent the virtual agents of the game. Each consumer decides which products to purchase and attempts to accomplish his purchase intentions. Consumers attempt to accomplish their intentions sequentially according to a random arrangement in each round of the game. The intentions of consumers to purchase a particular product from a specific firm are represented by their movement from their houses to the firm (see Figure 3) and the accomplishment of such intentions are expressed through graphical changes of colour (green, yellow and red representing full/partial and non accomplishment of purchase intentions respectively).

Participants are requested to submit their decisions during each round of the game which ends after all participants have submitted their decisions. After the submission of all decisions the processing of the decisions unfolds and the results are returned to the participants who can then simulate the marketplace in virtual time.

In most business simulations results are presented to participants managing firms in a static manner through the use of spreadsheets. In our game, the results of a round, are not the outcome of an equation, emerging instead from the complex interaction of several agents during a period of time. Consequently, at the end of a round participants can analyse in virtual time the animation of several indicators of performance of firms such as quantities bought, quantities sold, stock and current cash and analyse the interconnected behaviour of consumers.

This execution can be rerun several times providing the participants with the possibility to revisit the simulation to acquire new learning perspectives.

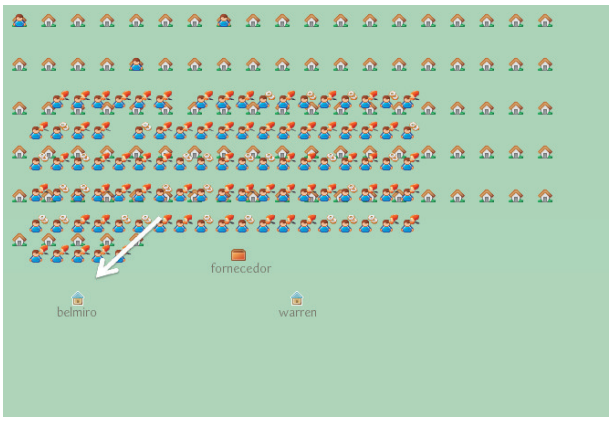

Fig. 3: Movements of consumers as displays of purchase intentions.

5 Experimental results

Table 1: Results of evaluation of "I understood the results".

Classification	Exercise A	Exercise B
Agree	85%	15%
Somewhat agree	11%	18%
Neutral	4%	33%
Somewhat disagree	0%	30%
Disagree	0%	4%

Table 2: Results of evaluation of "The information was useful".

Classification	Exercise A	Exercise B
Agree	48%	34%
Somewhat agree	41%	22%
Neutral	11%	22%
Somewhat disagree	0%	22%
Disagree	0%	0%

Our prototype was tested experimentally with a total of 27 volunteers, between the ages of 22 and 35 from an applied sciences background. Each participant was subject to two different exercises: exercise A where they were able to play the complete game and exercise B with same game where the participants were only provided with the final outcomes (cash, stock and quantities sold) of their decisions at the end of each round, as it is standard in business simulations. In both exercises participants played the game in pairs during five rounds. The order in which the participants performed the two exercises varied.

The results (Table 1) revealed high levels of agreement (96%) when the participants where asked if they understood the results of the game in exercise A. However, in exercise B, the responses of the participants varied, revealing a low level of agreement, with 34% of the respondents stating they were not able to understand the results of the game. In terms of understandability of the results, all participants rated exercise A with a higher (85.1%) or equal (14.8%) grade than exercise B.

A Spearman's correlation analysis showed a strong correlation ($\rho = 0.677, p = 0.005$) between the perceived usefulness of information and comprehension in exercise A. In exercise B, no strong correlation between these two variables was registered.

6 Conclusion

We presented an agent-based model of consumer behaviour. The model applied concepts from artificial intelligence and was consistent with neoclassical economics. Additionally it captured the fundamental teachings of introductory economic courses and provided a natural description of economic phenomena.

A business simulation was designed with this agent-based model as its demand model. In the development of the game, we tried to create an effective interface which took advantage of the descriptive potential of the model.

Our experimental results suggest the game was more straightforward to understand due to the presence of the unique information elements provided by the agent-based model. Hence, we believe our results provide evidence that information about the consumers' final actions as well as their cognitive reasoning processes, that is, their beliefs, desires and intentions, either fulfilled or failed, can play an important role in the participants' understanding of business simulations.

References

1. Goosen, K., Jensen, R., Wells, R.: Purpose and learning benefits of simulations: A design and development perspective. Simulation & Gaming **32**(1) (2001) 21–39
2. Goosen, K.R.: A generalized algorithm for designing and developing business simulations. Developments in Business Simulation and Experiential Learning **8** (1981) 41–47

3. Gentry, J.W., ABSEL: Guide to Business Gaming and Experiential Learning. Nichols/GP Publishing (1990)
4. Gold, S., Pray, T.: Historical review of algorithm development for computerized business simulations. Simulation Gaming **32**(1) (2001) 66–84
5. Baptista, M.L., Martinho, C.R., Lima, F., Santos, P.A., Prendinger, H.: Applying agent-based modeling to business simulations. Developments in Business Simulation and Experiential Learning **41** (2014) 179–183
6. Bonabeau, E.: Agent-based modeling: Methods and techniques for simulating human systems. Proceedings of the National Academy of Sciences **99**(Suppl. 3) (2002) 7280–7287
7. Bankes, S.C.: Agent-based modeling: A revolution? Proceedings of the National Academy of Sciences **99**(Suppl. 3) (2002) 7199–7200
8. Faria, A., Hutchinson, D., Wellington, W., Gold, S.: Developments in business gaming - A review of the past 40 years. Simulation & Gaming **40**(4) (2009) 464–487
9. Machuca, J.: Transparent-box business simulators: An aid to manage the complexity of organizations. Simulation & Gaming **31**(2) (2000) 230–239
10. Goosen, K., Kusel, J.: An interpolation approach to developing mathematical functions for business simulations. Simulation & Gaming **24**(1) (1993) 76–89
11. Gold, S.: Modeling interactive effects in mathematical functions for business simulations: A critique of Goosen and Kusel's interpolation approach. Simulation & Gaming **24**(1) (1993) 90–94
12. Carvalho, G.: Modeling the law of demand in business simulators. Simulation & Gaming **26**(1) (1995) 60–79
13. Gold, S., Pray, T.: The use of the gamma probability distribution: A critique of Carvalho's demand simulator. Simulation & Gaming **26**(1) (1995) 80–87
14. Said, L., Bouron, T., Drogoul, A.: Agent-based interaction analysis of consumer behavior. In: Proceedings of the first international joint conference on autonomous agents and multiagent systems, IFAAMAS (2002) 184–190
15. Janssen, M., Jager, W.: Simulating market dynamics: Interactions between consumer psychology and social networks. Artificial Life **9**(4) (2003) 343–356
16. Zhang, T., Zhang, D.: Agent-based simulation of consumer purchase decision-making and the decoy effect. Journal of Business Research **60**(8) (2007) 912–922
17. Baptista, M.L., Martinho, C.R., Lima, F., Santos, P.A., Prendinger, H.: An agent-based model of consumer behavior based on the BDI architecture and neoclassical theory. Developments in Business Simulation and Experiential Learning **41** (2014) 170–178
18. Bratman, M.: Intentions, Plans, and Practical Reason. Cambridge, MA: Harvard University Press (1987)