A behaviour theoretical perspective on agent based simulation

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Projects involving the use of simulation

Market dynamics and innovation diffusion
Stock market dynamics
Crowd and riot control
Opinion dynamics
Self organisation in teams
Agricultural production (consumer demand)
Today a focus on market dynamics and innovation diffusion

Many markets display characteristics of complex systems:

- many interacting components
- non-linear behaviour
- path-dependent developments
- No long term equilibrium
- limited predictibility
Complex behaviour ≠ complicated

Limited predictability of a complex system does not exclude the possibility to manage this system
Market dynamics

- A main source of this complexity resides in consumer behaviour: heterogeneous and moving preferences, social exchange of norms and information, social relevance of consumption

- Also producers compete for market share by developing and marketing new products
Market dynamics and social simulation

- General Linear Models (GLM) have a fundamental problem in modelling complexity in markets
- Social simulation provides a suitable tool to study such complex market dynamics
GLM versus Social simulation

SocSim: How to sail?

GLM: Where do we arrive?
Goals of market simulation

Identification of the market dynamics emerging from individual consumer behaviour

Experimentation with policy measures/interventions to change behaviour

A better understanding of the complex nature of systems contributes to shaping the future rather than predicting it

Econophysicists were among the first in developing percolation models of diffusion dynamics.

These models often consider individuals as identical particles communicating with their local neighborhood in trying to optimise their outcomes.

Diffusion of innovation

The agents rule: Is the quality \( q \) of this product higher than my preference \( p \), then adopt – perfect information

\[
\begin{array}{cccccc}
0.2 & 0.4 & 0.6 & 0.8 & 1 & 1.2 \\
0.25 & 0.35 & 0.45 & 0.55 & 0.65 & 0.75 \\
\end{array}
\]

Uniform distribution

Physicists: atoms communicate, translate to humans!

*Journal of Product Innovation and Management.*
Percolation models

The agents rule: Is the quality (q) of this product higher than my preference (p), then adopt and inform my 4 neighbours
Diffusion of innovation

The agents rule: Is the quality (q) of this product higher than my preference (p), then adopt – perfect information

![Market shares diagram](image)
Diffusion of innovation

The problem:

- People do not optimise their outcomes according to the rational actor approach

- People are connected in various ways (social networks)

The challenge:

- Representing human decision-making and social networks in a multi agent based model
What theories of behaviour?

- Social comparison theory
- Elaboration Likelihood Model
- Theory of Reasoned Action
- Balance theory
- Social cognition
- Social Judgment Theory
- Cognitive Dissonance Theory
- Theory of Normative Conduct
A model of consumer behavior

Brain systems
Evolutionary origins of need

Basal ganglia

Brain stem
The reptile brain (brain stem, cerebellum)

The reptile wants:
- order
- physical safety
- repetition
- security

The reptile fears:
- change
- dislocation
- novelty
Evolutionary origins of need

- Basal ganglia
- Brain stem
- Limbic system
- Cerebellum
The mammalian brain (limbic system)

The limbic system wants:
- Affiliation
- Celebration
- Emotional involvement
- Recognition

The limbic system abhors:
- Alienation
- Emotional threats
- Lack of communication
Evolutionary origins of need
The primate brain (neo-cortex)

The neo cortex wants:
- activity
- challenge
- novelty
- stimulation

The neo cortex deplores:
- boredom
- deprivation
- stagnation
A model of consumer behavior

Brain systems

- Neo cortex
- Limbic system
- Brain stem

Mind that these systems often operate quite independently

Mind that questionnaires and interviews mainly address the Neo Cortex
A model of consumer behavior

Brain systems

Needs

Neo cortex

Limbic system

Brain stem
What needs do consumers have?

- **Physiological needs**: hunger, thirst and so forth.
- **Safety needs**: to feel secure and safe, out of danger.
- **Belongingness and love needs**: to affiliate with others, be accepted, and belong.
- **Esteem needs**: to achieve, be competent, and gain approval and recognition.
- **Cognitive needs**: to know, understand, and explore.
- **Aesthetic needs**: symmetry, order, and beauty.
- **Self-actualisation needs**: to find self-fulfilment and realise one’s potential.

Maslow (1954)
What needs do consumers have?

- Freedom
- Identity
- Creation
- Leisure
- Participation
- Understanding
- Affection
- Protection
- Subsistence

Identity needs
Social needs
Survival needs

Max-Neef (1992)
A model of consumer behavior

Brain systems | Needs
---|---
Neo cortex | Identity
Limbic system | Social
Brain stem | Survival

**Involvement:**
The more important behaviour is for the satisfaction of (several) needs, and the lower needs satisfaction is, the higher involved the consumer will be.
Decision strategies

- Short term
- Individual heuristics
  - Compensatory
  - Non compensatory
- Social heuristics
  - Social comparison
  - Imitation
- Automatical heuristics
  - Habits
  - Reflexes

- Long term
Internal conflicts between needs
A model of consumer behavior

Brain systems

Neo cortex

Identity

Individual heuristics

Limbic system

Social

Social heuristics

Brain stem

Survival

Automated decisions

Needs

Deciding
Conclusions on modelling consumer behaviour

- Needs as motives of consumer behaviour
- Consumer decision making: cognitive effort & individual and social dimensions
Why do we try to formalise this?

- Behavioural drivers, such as needs and decision strategies:
  1: Lay at the foundation of many behavioural dynamics
  2: Provide points of application for policy measures

*Mimicking just doesn’t do the job!*
Including behavioural drivers. An example of needs

Including behavioural drivers. An example of decision-making

Back to the diffusion of innovations

- The problem: people attach a social value to products (conspicuous consumption)

- The challenge: representing conspicuous consumption in a multi agent based model
Diffusion of innovation, a simple extension with social needs

\[ N_i = \beta_i \cdot N_{s,i} + (1 - \beta_i) \cdot N_{p,i} \]

- \( N_i \) = Need satisfaction agent \( i \)
- \( N_{s,i} \) = Social need satisfaction
- \( N_{p,i} \) = Personal need satisfaction

Agents may initially decide not to adopt, but due to social pressure decide to adopt later.
Diffusion of innovation, a simple extension with social needs

- Network effects are critical

Regular lattice  Small World  Scale Free
Diffusion of innovation

Market shares

- Scale free network
- Average Social influence
- High Social influence
- Regular network
- Average Social influence
- High Social influence
Towards more complex agents

- We want to address basic behavioural drivers in the agent rules
- Needs and decision making strategies
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<th>Satisfaction (involvement)</th>
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Consumat model

Human environment
Culture
Institutions
Demography
Technology
Economy

Natural environment

via the micro level
Strategies for behaviour change

via the macro level

Opportunities
Opportunity consumption similar others
Abilities
Needs and level of need satisfaction
Uncertainty

Memory (mental map)
Behavioural control

Cognitive processing
Repetition
Deliberation
Imitation
Social comparison

Expectations regarding the outcomes of opportunity consumption
Opportunity consumption
Market dynamics (2001)

- Varying the tendency of agents to (1) invest cognitive effort in the decision making process, and (2) using individual versus social strategies
- 10 products, removed if share remains low
- Different types of consumer markets:
  - involved individualists (much deliberation)
  - low-involved social oriented (much imitation)
  - involved social oriented (much social comparison)

Market dynamics: Deliberators
Example 1: a market of imitators

Market dynamics: Imitators

[Graph showing market shares of products over time steps]
Market dynamics: Social comparers

![Graph showing market dynamics over time steps with varying market shares of products.](image-url)
Balancing between simplicity, complexity and applicability: redefining a behavioural model

- Agent architecture has to reflect the key-drivers of consumer behaviour
- Marketing strategies can be implemented as affecting these key drivers
- The conceptual & formal model should serve to program simulation models of varying complexity – simple models can be extended using this model.
The four P’s of Marketing (McCarthy, 1960)

product
pricing
placement
promotion

Product

- Product characteristics relate to individual preferences (related to needs)
- Vector model of preferences: the more, the better (quality, service)

\[ U_{ijn} = A_{jn} \]

With:
- \( U_{ijn} \) = Utility of consumer \( i \) on attribute \( n \) for product \( j \)
- \( A_{jn} \) = Score of product \( j \) for attribute \( n \)
Product

- Ideal point model of preferences: relative position on a scale (design, colour, taste)

\[ U_{inj} = 1 - |A_{jn} - P_{in}| \]

With:
- \( U_{inj} \) = Utility of consumer i on attribute n for product j
- \( A_{jn} \) = Score of product j for attribute n
- \( P_{in} \) = Preference of consumer i for attribute n
Besides individual preferences, consumers also have social preferences for products. Networks play a critical role in social effects, and much can be said about preferential attachment.

\[ U_{inj} = \frac{N_j}{N} \]

With:
\( U_{inj} \) = Utility of consumer \( i \) on attribute \( n \) (here the social attribute) for product \( j \)
\( N_j \) = Number of neighbours consuming product \( j \)
\( N \) = Number of neighbours
Product

- The utilities (vector, ideal point and social) are summed to construct a total utility. Beta indicates the relative weight of each utility in the total utility.

\[
U_{ij} = \frac{\sum_{n=1}^{n} (\beta_n \times U_{ijn})}{n}
\]

With:
- \(U_{ij}\) = Utility of consumer \(i\) for product \(j\), ranging from 0 to 1
- \(\beta_n\) = Weighting of attribute \(n\), ranging from 0 to 1
- \(U_{ijn}\) = Utility of consumer \(i\) for product \(j\) for attribute \(n\)
The weighting of utilities can be different for different agents, thus including heterogeneity (segments!) in the consumer population.

\[
U_{ij} = \frac{\sum_{n=1}^{n} (\beta_{in} \cdot U_{ijn})}{n}
\]

With:
- \(U_{ij}\) = Utility of consumer \(i\) for product \(j\), ranging from 0 to 1
- \(\beta_{in}\) = Weighting of attribute \(n\), ranging from 0 to 1
- \(U_{ijn}\) = Utility of consumer \(i\) for product \(j\) for attribute \(n\)
Product

- Needs can be represented as the type of (conflicting!) preferences satisfied by the attributes belonging to a product.

- The decision process of consumers can be represented by the values of the betas:
  - Cognitive effort: the number of product aspects taken into account (involvement)
  - Social v.s individual orientation: weighting of social utility
Price

- The concept of value-for-money is being used to link price to utility.
- The value for money will be closer to the utility of the product the lower its price and the higher the consumers budget.

\[ V_{ij} = U_{ij} \times B_i \times (1 - P_j) \]

With:
- \( V_{ij} \) = Value for money of product \( j \) for consumer \( i \)
- \( U_{ij} \) = Utility of consumer \( i \) for product \( j \)
- \( P_j \) = Price of product \( j \), ranging from 0 to 1
- \( B_i \) = Budget of consumer \( i \), ranging from 0 to 1
Placement

First a focus on distance:

- Simple formalization: distance as additional attribute in the model
- Heterogeneity in distance score expresses the distance to a buying location.
- Weighting the distance attribute (with a $\beta$) distinguishes between markets where distance is important (e.g., groceries) versus unimportant (e.g., e-commerce)
Promotion

- Promotional activities by *producers* (i.e., mass media, viral techniques) and other stakeholders (government, NGO’s)

- Interaction between *consumers*, such as Word-of-Mouth (normative & informative)
Again, back to the diffusion of innovation

market shares

- Agents with complete information
- Innovation diffusion model (regular network)
- Innovation diffusion model (scale free network)
Some preliminary results on promotion

The problem: who should we address in a promotion campaign: a cohesive group, or random people?

1 of 90 means targeting 1 group of 90 agents
90 of 1 means targeting 90 groups of 1 agent
Some preliminary results on promotion

The problem: when should we start a promotion campaign

- Promotion time = 10
- Promotion time step = 50
- Promotion time step = 100
Empirical data

- Macro level sales data (& timing of marketing strategies) – development of market shares over time and indication of marketing effects
- Micro level sales data (loyalty card data) – how do consumers behave in a market
- Micro level data on decision-making – getting grip on the decision-making process of consumers (attributes & weights)
Sailing Social Dynamics

It’s not about predicting the future … it’s about shaping it!

The European Social Simulation Association

http://www.essa.eu.org/

Special interest group on market dynamics