Multi agent simulation of human behaviour using psychological theory

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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
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 predictability
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
Several simulation models have been developed to model market dynamics. 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 (theoretically empty).
Diffusion of innovation

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

![Graph showing market shares with different quality and preference values.](image)

Physicists: atoms communicate, translate to humans!
Diffusion of innovation
The agents rule: Is the quality (q) of this product higher than my preference (p), then adopt and inform my 4 neighbours

Percolation models
Diffusion of innovation

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

![Market shares graph]

- Agents with complete information
- Innovation diffusion model (regular network)
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
- Conformity
- Elaboration Likelihood Model
- Theory of Reasoned Action
- Balance theory
- Social cognition
- Social Judgment Theory
- Cognitive Dissonance Theory
- Habit formation
- 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

- Cerebellum
- Basal ganglia
- Brain stem
- Limbic system
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

- Neo cortex
- Cerebellum
- Basal ganglia
- Brain stem
- Limbic system
- Cerebellum
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

Mind that these systems often operate quite independently

Limbic system

Mind that questionnaires and interviews mainly address the Neo Cortex

Brain stem
What needs do consumers have?

Maslow (1954)

- 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.
What needs do consumers have?

Max-Neef (1992)
### A model of consumer behavior

<table>
<thead>
<tr>
<th>Brain systems</th>
<th>Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neo cortex</td>
<td>Identity</td>
</tr>
<tr>
<td>Limbic system</td>
<td>Social</td>
</tr>
<tr>
<td>Brain stem</td>
<td>Survival</td>
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</tbody>
</table>

**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

Long term

Individual heuristics
- Compensatory
- Non compensatory

Social heuristics
- Social comparison
- Imitation

Short term

Automatical heuristics
- Habits
- Reflexes
A model of consumer behavior

Brain systems

Neo cortex

Limbic system

Brain stem

Needs

Identity

Social

Survival

Deciding

Individual heuristics

Social heuristics

Automated decisions
Individual heuristics

When?
- High involvement
- Individual needs

How?
- Compensatory heuristics
- Non-compensatory heuristics

Innovative behaviour
Social heuristics

When?
- Uncertainty
- Complex decisions

How?
- Social comparison
- Norms
- Imitation
- Observation

Who to compare with? Similarity

Herding
Automated decisions

When?
- Stable situation
- Frequent behaviour

How?
- Habits
- Reflexes

Automated behaviour
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
Diffusion of innovation, a simple extension with social needs

- Network effects are critical
Diffusion of innovation

Market shares

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

- We want to address basic behavioural drivers in the agent rules
- Needs and decision making strategies
Consumer decision-making: the consumat (1999)

- **Satisfaction (involvement)**
  - high
  - low

- **Uncertainty (complexity)**
  - high
  - low

- **Individual strategies**
  - Low cognitive Effort
  - High cognitive Effort

- **Social strategies**
  - imitation
  - social comparison

- **Deliberation**
  - high
  - low

- **Repetition**
  - high
  - low
Consumat model
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
Market dynamics: Imitators

![Market shares of products over time steps]
Market dynamics: Social comparers

The graph illustrates the market shares of various products over time, showing fluctuations and changes in market dynamics.
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
Formalising all the factors just mentioned would – if possible – result in a model not accessible for research.

A simplification is required for developing a transparent simulation model.

The formalisations as presented are meant as a framework, simpler models can (and should) be used, and if necessary extended using the framework.
Product

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

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

With:
- \( U_{inj} \) = 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.

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

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 \( n \)
Product

- The weighting of utilities can be different for different agents, thus including heterogeneity (segments!) in the consumer population.

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

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 \( n \)
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
Product

- Note! The formulation of utility has the lay-out of a regression formula
- But: for each simulated consumer this formula may be different. Moreover, the utilities and their weighing are subject to change
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)
Promotion – by producer

- Convince consumers to attach more weight to a product attribute on which the product scores well (increasing the \( \beta \))

- Convincing the consumers that their utility for attribute \( n \) would be higher than they currently believe (increase \( U_{inj} \)).

- Inform consumers about other consumers (famous role models) that already use a product, thus affecting the social attribute.
Promotion – by producer

- Who to address?
  - Mass media
  - Random consumers
  - Consumers with particular characteristics (segments)
  - Clusters of connected consumers
  - A mix of strategies?
Promotion – consumers: word-of-mouth

- Specific information: exchange information concerning the product utilities (Uinj), e.g. fuel consumption of a car

- Generic information: discuss the importance of certain attributes (weighting of attributes), e.g. the importance of safety of a car.

- Norms: consider the number of neighbours consuming a particular product without considering further information (social attribute as defined in product)
Promotion – consumers: word-of-mouth

Scale free network connecting individual agents
(Barabasi & Albert)
Again, back to the diffusion of innovation

![Market shares diagram](chart.png)

- **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

![Graph showing the effect of promotion time and time step on a metric. The x-axis represents time steps, and the y-axis represents a value ranging from 0 to 0.35. There are three lines representing different promotion times: 10, 50, and 100. Each line shows a different pattern of growth, indicating the impact of varying promotion times on the metric.]
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)
Research organisation

- Micro level data (networks)
- Macro level data (markets)
- Agent & product/behaviour characteristics
- Simulation of market dynamics

- Hypothesising
- Experimentation
- Formalisation
- Validation

On process level rather than outcome level
Conclusions

- It is essential to capture behavioural processes and drivers in simulation models of consumer behaviour.
- Formalising the four P’s provides a perspective on:
  - Modelling complexities in markets.
  - Implementing and testing marketing strategies in complex markets.
  - The linkage of simulation models to empirical data on both the micro and macro level.
Simulating market dynamics:

It’s not aimed at predicting the future, It’s about shaping it!

The European Social Simulation Association

Special interest group on market dynamics