Abstract

Lock-in denotes a phenomenon of monopolistic dominating technologies or consumer goods in a certain market. These lock-ins cannot be explained by superior characteristics of the good or technology. Previous studies mainly used probabilistic models to study lock-in effects. In this paper an integrated conceptual model of consumer behaviour is used to identify relevant processes of lock-in dynamics of consumption patterns. An agent-based model is developed to simulate consumats, artificial consumers, who are confronted with two similar products. We found two types of lock-in, namely, a spatial lock-in and a global level lock-in. The spatial lock-in related to the spatial patterns that occur in consumption patterns and relates to the satisfaction of the need for identity. The global lock-in relates to price effects and occurs only if individual preferences are not significantly weighted in the cognitive processing.

Keywords:
Lock-in, multi-agent modelling, social psychology, need satisfaction, consumer behaviour

Introduction

1.1

When specific goods or technologies come to dominate a market in such a way that reversal is virtually impossible, we call it being locked-in. For example, we are writing this paper in Word on a Microsoft Windows platform using a QWERTY keyboard. Although we have no specific preferences for these products, it would be difficult to change. Our universities only support a limited number of software applications, and learning to type efficiently on a non-QWERTY keyboard will take too long to learn again although ergonomically it may be more efficient.

1.2

The locked-in QWERTY keyboard (David 1985), Microsoft operating systems, VHS recordings, etc. all have or had their alternatives. Which product finally locked-in depended on rather unpredictable historical events and behavioural processes (Arthur 1989). If we can understand under
which conditions these lock-ins occur, policies can be developed to stimulate preferred lock-ins (for example, products which are efficient with energy and material use and lead to a low pollution level) or limit or prevent undesirable lock-ins.

1.3

We can distinguish two types of externalities. The first is positive price externality, which refers to decreasing costs due to higher production levels and economies of scale (Arthur 1989). The more a product is being used, the lower will be the costs per unit of production which accelerates the introduction of the product. The more VHS recorders were sold, the lower the cost per unit of videorecorder. The other externality is the positive network externality where the costs of lack of compatibility decrease the more people are using a system (Liebowitz and Margolis 1994, Liebowitz and Margolis 1995). This insight inspired the companies in, for example, computer business, to give away free software, to stimulate lock-in. An interesting example is the battle between Netscape and Microsoft on the web-browsers Netscape Communicator and Microsoft Internet Explorer. The lock-in of one of the two browsers will be of high financial importance for the two companies.

1.4

In this paper we will study lock-in from a behavioural perspective. Lock-in effects are usually studied by stochastic models. Here, we use a more explicit description of human behaviour based on a multi-theoretical conceptual model combining different theories on behaviour that are relevant in the context of consumer behaviour (Jager et al. 1997, Jager et al. 1999).

1.5

There are various studies on modelling the lock-in of technologies. Brian Arthur (1989) provides a guiding principle on competing technologies to define under what circumstances an adoption market must end up being dominated by a single technology. According to this principle, products must have increasing returns, that is, the more agents adopt a certain technology, the higher the returns for others to adopt the same technology. Arthur describes the lock-in dynamics of agents making a choice every timestep on the basis of probabilistic models. The probabilities are related to what other agents have done before. The more agents have adopted a certain technology the higher the probability that the agents will do the same in the next period.

1.6

Decisions of the agents are therefore related to decisions of the other agents. Random events, leading to a minor dominance, can cause lock-in. Various scholars have developed sequential decision models in which each decision maker decides using information on previous decisions made by other decision makers (Granovetter and Soong 1986; Banerje 1992; Bikhchandan et al. 1992; Kirman 1993). An illustrating example is the choice for a restaurant (Banerjee, 1992). In choosing between two restaurants that are both more or less unknown, people who arrive in sequence are influenced in their decision making by the choices made by those before them. The more people have chosen restaurant A, the higher the chance that the next person will also choose restaurant A. Granovetter and Soong (1986) distinguish in addition to the "bandwagon effect" (Leibenstein, 1976), a "reverse bandwagon effect". This denotes the effect that some consumers choose the quiet restaurant if it is "too busy" in restaurant A. Granovetter and Soong (1986) show that these counteractive forces may lead to chaotic patterns of consumer behaviour.

1.7

In our opinion these stochastic models may successfully produce lock-in behaviour, but do not provide insights into the behavioural processes that determine the specific decisions. Therefore, we aim to study the relevant processes of decision making in more detail, and relate this to empirical data from social psychology. In this paper, we use a rule-based multi-agent model in which we explicitly include behavioural rules from a multi-theoretical model of consumer behaviour.
First, we will illustrate the current type of modelling of lock-in dynamics. Then we will describe briefly the conceptual model of consumer behaviour we use for the development of agent rules. In this model, various theories from social science are integrated into one framework. In the subsequent section we will introduce a simulation model in which the conceptual model is operationalised for a specific case to study lock-in of consumer patterns. The next section describes a number of experiments done with this simulation model. A demonstration version of the model is linked to this article. The reader is encouraged to experiment with the software. We will end with some conclusions regarding the circumstances in which processes of lock-in occur.

Simple models of lock-in dynamics

2.1 A very simple model, which simulates lock-in, is the following. Consider a market of two products ($X_i = 0$ or $1$) and $N$ agents. The agents' probability of choosing product 0 or 1 depends on the proportion of agents that chose the particular product during the last period. The more agents choose a particular product, the higher the chance that others follow in the next time step, resulting in a lock-in.

2.2 The agent $i$ consumes in period $t$ ($X_i(t)$) product 1 if the uniform distribution $U[0,1] < P$ or else product 0, where probability $P$ is equal to the sum for all $i$ of $X_i(t-1)/N$, and $U[0,1]$ is a uniform distribution between 0 and 1. Some illustrative pathways, given an equal share at the start, are depicted in Figure 1.

![Figure 1: Share of product 1 for 3 possible runs of the very simple model](http://jasss.soc.surrey.ac.uk/2/2/2.html)

2.3 The simplest model is complex enough to simulate lock-in patterns but it does not provide insights regarding how and when lock-in occurs. A somewhat more advanced approach is to consider price-based consumption choices and learning-by-doing dynamics in the production process. The share of (exogenous) demand ($D$), which is supplied by product $i$ ($S_i$, $i=0,1$) depends on the costs or prices of the products ($P_i$), the sensitivity of the demand for price differences ($\mu$) and the adjustment time of the market ($t_a$) to go from indicated shares ($\text{IndSh}_i$) to actual market shares ($\text{Sh}_i$). The costs of the
product depend on the fixed costs (FC), variable costs (VC), the number of products sold, and a learning factor (LF). This learning factor declines with the cumulative amount of production (CL). Parameter gamma determines the learning rate of the production process.

2.4 Supply of product i \( (S_i) \) equals a share of the demand:

\[
S_i = Sh_i \times D
\]

The share of the demand is adjusted by changed in indicated shares \( (\text{IndSh}_i) \):

\[
d\text{Sh}_i/dt = (\text{IndSh}_i - \text{Sh}_i)/t_a
\]

This indicated share is determined by a multinomial logit function of the prices of the products. This logit function weights the relative prices \( (P_i) \) where parameter mu indicates the sensitivity of the consumers to price differences.

\[
\text{IndSh}_i = \frac{\exp(-mu \times P_i)}{\exp(-mu \times P_1) + \exp(-mu \times P_2)}
\]

Prices depend on fixed and variable costs, and a learning factor:

\[
P_i = LF_i \times (FC_i + S_i \times VC_i)/S_i
\]

The learning factor \( (LF) \) decreases by cumulative production of the product according to the principle of learning-by-doing \((\text{Arrow}, 1962)\). The more a product has been produces, the lower the cost price per unit. The parameter gamma determines the cost reduction per doubling of cumulative production.

\[
LF_i = (CL_i / CL_{i-in})^{\log_{10}(\text{gamma})/\log_{10}(2)}
\]

\[
dCL_i/dt = S_i
\]

2.5 If two products initially have an equal share and equal economic characteristics (that is the same values on gamma, FC and VC), the share remains equal in the long run. We can easily produce lock-in effects by adding a stochastic term in equation 1 simulating unexpected events in the market. The stochastic term, \( N(0, \sigma) \), is a normal distribution with zero mean and standard deviation \( \sigma \). Now we get lock-in effects if \( \text{mu} \) is large enough and the market is influenced by stochastic events \((\text{Figure 2})\). We assume that the supply of specific products does not exceed the total demand.

\[
1'a \quad S_1 = \text{MIN}(Sh_1 \times D + N(0, \sigma),D)
\]

\[
1'b \quad S_2 = D - S_1
\]
2.6

This simple model shows that lock-in occurs more frequently when \( \mu \) is higher and thus the agents are more sensitive to price changes. However, the model remains unsatisfying while it gives us limited insights into consumer decision making. In the rest of the paper we replace equations (1-3) by a multi-agent model which simulates consumer behaviour from a psychological perspective. But first we will discuss briefly the conceptual multi-theoretical model of consumer behaviour, which will be operationalised in the section thereafter.

Conceptual Model of consumer behaviour

3.1

Many behavioural theories are relevant for understanding human consumption to a more or lesser extent. Theories on human needs (e.g., Maslow 1954; Max-Neef 1992) provide a perspective on the pressures behind human consumption. Theories on motivational processes (e.g., Ölander and Thøgerson 1994) describe under what conditions people are motivated to consume. Social comparison theory (Festinger 1954; Faucheux and Moscovici 1972) describes the conditions that
stimulate people to compare their consumption with that of comparable others. Classical and operant conditioning theory (Pavlov 1927; Skinner 1953) teaches us about the importance of the immediate outcomes of behaviour (e.g., rewards), making clear that consumer behaviour is not necessarily following from extensive cognitive processing. Social learning theory (Bandura 1977; Bandura 1986) provides a perspective on processes that may guide consumption. Decision and choice theory (Janis and Mann 1977; Simon 1976; Vlek 1989) and theories of reasoned action (Fishbein and Ajzen 1975; Ajzen 1985; Ajzen 1988; Ajzen 1991; Ajzen and Madden 1985) provide a perspective on when and how consumers make deliberate choices. The theory of relative deprivation (Masters and Smith 1987) makes clear that a consumer's satisfaction partially depends on the consumption of the neighbours (keeping up with the Jones's). The theory of normative conduct (Cialdini et al., 1991) provides a perspective on how norms may guide consumer behaviour. The conceptual model developed by Jager et al., (1997), combines these various theories in a single framework. On the basis of this conceptual model, we have developed a comprehensive set of rules reflecting what we consider the essence of the various behavioural processes. In defining rules for an agent, a balance should be found between simplicity and realism. Simplicity is required to keep the behaviour of a group of agents accessible for scientific research, whereas realism adds to the validity and relevance of simulation results. We chose to develop a set of simple rules that in combination represents a multitude of relevant behavioural processes. The agents we will use to simulate consumer behaviour are called 'consumats', analogous to the term 'animats' that Wilson (1985) coined to notify simulated animals.

3.2

The various behavioural theories identified earlier all explain parts of the processes that determine consumer behaviour. For example, theories on human needs may explain the preferences a consumer has, while theories on social comparison and learning explain how consumption behaviours can diffuse through a population. To include such processes in a simulation, we use this integrated conceptual framework for the development of agent rules.

Micro and Macro variables

3.3

Driving factors at the micro and macro level influence consumption behaviour and the associated cognitive processes. Therefore the conceptual model includes theories and variables at both the micro level and at the macro level. At the macro-level we may distinguish between technical, economical, demographic, institutional and cultural developments (Opschoor 1989; Stern 1992; Vlek 1995). These macro-level pressures affect the micro-level pressures, e.g., economic developments affect the price of an opportunity (e.g. the price of a product). At the micro level we distinguish between the needs (N) of the consumer, the opportunities (O) that can be consumed, and the abilities (A) the consumer has as to engage in consuming (the NOA model). These micro-level pressures result in consumers being more or less motivated to consume, and more or less certain about the opportunity characteristics.

3.4

A consumat can be equipped with several needs that can be more or less satisfied. The level of need satisfaction for need i (LNS_i) is represented by an index varying between 0 (fully unsatisfied) and 1 (fully satisfied). The overall level of need satisfaction (LNS_1..n) is represented by the weighted average of the included needs.

3.5

The consumats can use opportunities in order to satisfy their needs (e.g., consuming food) or to increase their abilities (e.g., work for money). Opportunities have predefined resource demands, e.g., the financial costs. Depending on the abilities that are being addressed in the simulation, more
or less resource demands are defined for each opportunity. In many cases these resource demands take the form of operational costs, that is, they require the use of resources. The availability of opportunities may be limited, e.g. in the case of a common renewable resource, where scarcity may emerge. The consumat will be motivated to elaborate on which opportunity to consume if it is dissatisfied (low LNS\textsubscript{1..n}) and/or if its abilities are too low for consuming a good that is perceived as need-satisfying (low Behavioural Control - BC). Moreover, the consumat will be uncertain (C = low) if the outcomes of previous behaviour differ significantly from its expectations.

### Cognitive processes

#### 3.6

Two dimensions are acknowledged regarding cognitive processing. The first dimension relates to the cognitive effort involved with the process. Reasoned behaviour is associated with a high motivation to elaborate, whereas automatic processing is more likely when this motivation is low. The second dimension relates to the social or individual orientation of the process. Social comparison theory ([Festinger 1954](http://jasss.soc.surrey.ac.uk/2/2/2.html)) states that the drive to compare one's opinions and abilities with that of others is larger, the more uncertain one is regarding one's own opinions and abilities. This has consequences for consumer behaviour, because the less certain one is that one is consuming a good opportunity given one's opinions and abilities, the more likely it is that one will observe the consumption behaviour of others with similar opinions and abilities. Individual processing thus dominates when one feels certain, whereas uncertainty stimulates the social processing of information. Social processing usually involves comparison processes with other consumats, which are similar with respect to abilities and opinions. The two distinct dimensions of behavioural processes yield a fourfold perspective on cognitive processing and associated behavioural theories. First, deliberating is addressed by decision and choice theory and theories of reasoned action (attitudes). Social comparison is addressed by social comparison theory, theories on relative deprivation and by theories of reasoned action (social norms). Repetition is addressed by classical and operant conditioning theory. Imitation is addressed by social learning theory and theory of normative conduct.

#### 3.7

To operationalise cognitive processes, we first have to equip the consumat with a mental map. The mental map contains the consumat's previous behaviours. This implies that the need-satisfying capacities and ability changing properties of opportunities are memorised. The mental map is also used to store information on which other consumats serve as comparison-consumats and the behaviour these consumats performed in the previous time step (t-1). Finally, the mental map contains the perception of the consumat's own abilities, e.g., what the financial budget is at a particular moment and how much money can be earned by a certain type of work. The mental map is being used in the different cognitive processes. The fourfold perspective on behavioural processing has been operationalised in the following four processing rules for the consumat:

1. Deliberating its performance (low LNS, low uncertainty). The consumat will first update its mental map. Then it will choose the opportunity that optimises its outcomes by deliberating all possible opportunities to maximize LNS.
2. Social comparison with similar agents (low LNS, high uncertainty). First the consumat will update its mental map. Then it will observe the consumption behaviour of the other consumats with about the same abilities. It will calculate the expected outcomes if this consumption behaviour is imitated. These expected outcomes are compared with the expected outcomes for not changing behaviour. The behaviour with the highest expected outcomes is chosen.
3. Repetition of own behaviour (high LNS, low uncertainty): The consumat does not update its mental map and does not change its behaviour.
4. Imitation of another agents' behaviour (high LNS, high uncertainty): The consumat copies the behaviour at t-1 of the consumat last compared with.

**Actual behaviour**

For the consumat, the actual behaviour may result in changes in the level of need satisfaction (LNS\textsubscript{1..n}), and abilities. Moreover, their perception of opportunities may change. Finally, the opportunities may change. For example, a large consumption may result in the scarcity of a resource and an increase in its price (using a price-demand function).

**Policy Strategies**

The two main interest parties at the meso/macro level that spend a lot of effort in changing (or consolidating) consumption behaviours are the government and the suppliers/producers. However, also various consumer organisations, interest groups, churches and the like may try to change consumer behaviour. If an interest party is not satisfied with the impacts of behaviour, it may react by altering macro and micro variables. On the basis of literature (Sheth and Frazier 1982; Cook and Berrenberg 1981; De Young 1993; and Vlek and Michon 1991) we distinguish between five types of general strategies for behavioural change: (1) providing physical alternatives and arrangements, (2) regulation and enforcement, (3) financial-economic stimulation, (4) social and cognitive stimulation, and (5) changing values and morality. For the consumat this implies that a measure is either affecting its abilities (e.g., its available budget) or its needs, opportunities and/or resource demands.

**The Simulation Model**

4.1 The conceptual model is the starting point for a simulation to study lock-in of consumption patterns. We chose a cellular automata approach because we wanted to include the dynamics of local interactions of agents. An excellent introduction to the use of cellular automata in social simulation can be found in Hegselman and Flache (1998). We describe consumption by using a simple cellular automaton A defined by a lattice L, a state space Q, a neighbourhood template delta and a local transition function \( f \), thus \( A = <L,Q,delta,f> \)

4.2 We use a lattice, L, of 30x30 grid cells, thus 900 agents, and distinguish two possible states, Q(x=0; x=1), of the cells: product 0 or product 1. Cells can change their states in discrete time steps, and all cells change their states simultaneously. We use a Moore neighbourhood template, delta, which consists of the central cell and eight adjacent cells (Figure 3). The local transition function, \( f \), is actually our behavioural model, which will be described below.
4.3
The corresponding edges of the grid have been "pasted together", resulting in a three-dimensional solid called a torus. A cell in the corner of the lattice has neighbours in other corners of the lattice as depicted in Figure 4, and a three-dimensional version is given in Figure 5.

Figure 4: The red cells are the neighbors of the cell in the left lower corner of the lattice.

Figure 5: A torus, a 2-dimensional cellular automatum with the edges pasted (Hegselman and Flache, 1998).

4.4
When there is a change in consumption, the cells change state. The behavioural model as described in the last section determines such a transition. In our application, we distinguish four types of need: identity, personal taste, leisure and subsistence. Both products have the same characteristics but may differ in prices and the degree of pollution. Agents may also view them differently due to personal tastes and are affected by the consumption of their neighbours. The agents differ in their abilities and have different financial budgets, B. Furthermore, the agents may differ regarding their sensitivity to pollution. The scheme in Figure 6 gives the most important relations of the model.
4.5

The following four consumat-needs have been operationalised in order to include these various aspects in the consumats' behavioural processes:

Identity

4.6

The level of satisfaction for the need identity (LNS$_1$) depends on the number of neighbours that consume the same product, that is, the satisfaction of the sense of belonging. We assume that LNS$_1$ increases linearly with the proportion of neighbours consuming the same product. The more neighbours ($x_{N_i}$) consume the same product, the higher the LNS for identity of the consumat on position $ij$ of the torus:

\[ LNS_1 = 1 - Sx_{N_i}/8 \] if $x_{ij} = 0$ else $LNS_1 = Sx_{N_i}/8$

Personal taste

4.7

Personal taste is assumed to be an individual characteristic of an agent. The level of satisfaction for personal taste (LNS$_2$) is therefore equal to the individual "taste" of product $i$. And for simplicity's sake we assume that the agents know the taste of the products ($b_{0ij}$ and $b_{1ij}$).

\[ LNS_2 = b_{0ij} \] if $x_{ij} = 0$ else $LNS_2 = b_{1ij}$
Leisure

4.8
We relate leisure to the price of the products by assuming that products with lower prices require less time to earn the money. We acknowledge that this is a crude assumption but it gives us the opportunity to balance leisure time and working time.

\[ \text{LNS}_3 = B/P_0 \text{ if } x_{ij}=0 \text{ else } \text{LNS}_3 = B/P_1 \]

Subsistence

4.9
Subsistence is assumed to be related to the degree of pollution. Each product \( i \) is assumed to contribute \( l_i \) units of pollution. The concentration of pollution (\( C \)) decays every time step with ratio \( m \).

\[ C = C_{-1} \times (1-m) + l_0 \times \#(x_{ij}=0) + l_1 \times \#(x_{ij}=1) \]

Individual sensitivity to pollution (\( a_{ij} \)) determines the individual level of satisfaction for the need subsistence and is related to the concentration level.

\[ \text{LNS}_4 = 1 - \exp(-a_{ij}/C) \]

4.10
The total level of need satisfaction of agent (\( i,j \)) is a Cobb Douglas type of utility function in which each need satisfaction is weighted by \( \gamma_{\text{need}_{ij}} \). The choice of this type of LNS function assumes substitution of needs in order to increase to total level of need satisfaction.

\[ \text{LNS}_{ij} = \text{LNS}_1 \gamma_{1ij} \times \text{LNS}_2 \gamma_{2ij} \times \text{LNS}_3 \gamma_{3ij} \times \text{LNS}_4 (1-\gamma_{1ij} - \gamma_{2ij} - \gamma_{3ij}) \]

In fact, the way the different needs are implemented cause four different feedbacks: (1) the need for identity related to the local (neighbourhood) characteristics, (2) the need for personal taste is related to individual preferences, (3) the need for leisure related individual abilities to macro information (product prices), and (4) the subsistence need may lead to a product related feedback, while pollution is caused by consumption of specific products.

4.11
As described in the conceptual model, the behavioural rules differ in case of uncertainty compared to the case of no uncertainty. However, it is not obvious how one could define a quantitative measure for the agents' uncertainty. We assume that the summarised difference between the expected LNS and the actual LNS of each need \( k \) can be used to measure uncertainty (\( \text{Unc}_{ij} \)). For simplicity's sake, we have assumed that the expected LNS is equal to the experienced LNS in the last period. Thus:

\[ \text{Unc}_{ij} = \sum_k \text{abs} (\text{LNS}_{kij} - \text{LNS}_{1kij}) \]

4.12
We will now describe the four cognitive processing rules that operate under different conditions of uncertainty and satisfaction, and that are used to decide which product to use.

Deliberation
4.13 Agents optimise decisions if they feel certain, and if the level of need satisfaction does not reach some exogenously set minimum level LNSmin. The agent will check all possible solutions and choose the best possible solution.

Max (LNS(xij=0), LNS(xij=1))

LNS = LNS1gamma1ij * LNS2gamma2ij LNS3gamma3ij * LNS4 1-gamma1ij-gamma2ij-gamma3ij

LNS1 = 1-(SxNij)/8 if xij=0 else LNS1 = (SxNij)/8

LNS2 = b0ij if xij=0 else LNS2 = b1ij

LNS3 = B/P0 if xij=0 else LNS3 = B/P1

LNS4 = 1-exp(- aij/(C1*(1-m)+l0)) if xij=0 else LNS4 = 1-exp(- aij/(C1*(1-m)+l1))

4.14 Social Comparison

Suppose the level of need satisfaction drops below a threshold value (LNSMIN) and the agent is uncertain, then it acts by social comparison. That is, the behaviour of the neighbours with comparable abilities is copied. Abilities are assumed to be related to the individual (financial) budgets Bij. Agents will consume that product which has been consumed the most by neighbours with similar abilities during the previous period. The larger the tolerance range Btol, the more agents are considered to be similar. The product with the highest share among those similar neighbors is consumed by the consumat.

xij = 0 if

[#(xNij=0) and (Bij *(1-Btol) £ Bneighbours £ Bij *(1+Btol))] >

[#(xNij=1) and (Bij *(1-Btol) £ Bneighbours £ Bij *(1+Btol))] else xij = 1.

4.15 Repetition

If the agent is satisfied but not uncertain, it consumes the same product as in the last period.

xij = x-1ij

4.16 Imitation

Agents behave automatically and socially in case of uncertainty, Uncij > UncMAX, and when needs are satisfied at a minimum level (LNSij>LNSMIN). In such a case, the agent adopts the behaviour of the majority of the neighbourhood. If more than 4 agents in the neighbourhood of 9 cells consume product i, the agent will also consume product i.

xij = 0 if #(xNij=0) > #(xNij=1) else xij = 1.
4.17
The model is implemented using the simulation modelling environment M and runs under Windows 95/NT. A demonstration version of the model is available and can be downloaded.

Lock-in when products are similar

5.1
We start our experiments with a large number of runs to discover which behavioural processes and agent characteristics determine whether a lock-in occurs.

5.2
Consider two products, 0 and 1, with similar characteristics in price/technology dynamics and environmental impacts. The 900 agents in the 30x30 lattice differ in their financial budgets (leisure need), their individual preferences (need for personal taste) and their sensitivity for pollution (subsistence need). In the initial situation, the distribution of consumption is random. We will first discuss a typical model run in detail, after which we will explore the general characteristics of the lock-in behaviour of this model. In Figure 7 we depict a simulation in which a spatial lock-in can be observed.
5.3

Figure 7 shows a typical evolution of consumption patterns. Initially, the distribution is random but after 10 time steps the consumption shows a spatial pattern, which, after some changes lead to a stable spatial pattern (t=100). In the beginning of the simulation there is also uncertainty causing social processing (Figure 8). This uncertainty disappears due to the lock-in of consumption, that is, the more agents consume the same as the last period, the less expected LNS differ from realised LNS. The consumats optimise or behave automatically at the end of the simulation period, which depends on the level of need satisfaction. The share of automatic behaviour increases due to higher satisfaction of the leisure need due to decreasing prices of the products from learning.

Figure 8: Types of cognitive processes for the population of 900 consumats (red = deliberating; yellow = social comparison; green = repetition; blue = imitation)

5.4

As this example indicates, there are two kind of lock-ins in our model world, where we consider
lock-in as a stable state after a number of iterations of consumption. The different types of lock-in show that a 100 per cent adoption is not necessary to imply lock-in.

- spatial lock-in: a stable pattern of consumption occurs with clustered groups of consumats who all consume the same product.
- global lock-in: one product becomes to dominate the whole lattice.

5.5

Because of the many variables that affect consumer behaviour we have performed a large number of model runs (1000) using stochastic values (from a uniform distribution) for the parameters $\gamma_i$ in the range $[0,1]$ with $S \gamma_i = 1$, $LNS_{MIN}$ in the range $[0,0.5]$ $Unc_{MAX}$ in the range $[0,0.1]$ and $Btol$ in the range $[0,1]$. Using such a large number of experiments we try to identify the factors that are determining the occurrence of the two types of lock-in processes.

5.6

Figure 9 depicts the distribution of the proportion of product 1 after 100 time steps when the patterns has been stabilised. It shows that for most random values of the parameters, the share of each product is near 50%. In 33 cases a global lock-in situation occurred. It appears that a total lock-in occurs only for particular parameter values. In Table 1 we show the average values for the locked-in and not locked-in runs. It can be observed that in case of a lock-in, the value of $\gamma_2$ is near zero and $\gamma_3$ is somewhat higher than average. Also $LNS_{MIN}$ and $Unc_{max}$ are higher than the average value. These results can be explained as follows.

![Figure 9: Distribution of share of product 1 in time step 100. If this share is equal to 0 or 1 a macro-level lock-in has occurred.](http://jasss.soc.surrey.ac.uk/2/2/2.html)

5.7

The weight of the need for personal taste is very important because strong specific preferences for a certain product will reduce the possibility of a lock-in. If the need for personal taste is not weighted much in the cognitive processing, and the price-based leisure need is weighted significantly, consumats will choose the cheapest product, which in return reduces its price due to learning-by-doing cost reductions. The relative high values of $LNS_{MIN}$ and $Unc_{max}$ suggest that deliberating is important to derive a global lock-in because high values of $LNS_{min}$ and $Unc_{max}$ refer to unsatisfied but certain consumats. In sum, a global lock-in of two similar products occurs if agents, reasoning
individually, choose the cheapest product. The initial (random) distribution of consumption and agents's characteristics determine which product locks-in.

**Table 1:** Statistics for the experiment of 1000 model runs: the average values of the model parameters and the standard deviation (in brackets).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>General</th>
<th>Locked in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma(_1)</td>
<td>0.251 (0.142)</td>
<td>0.290 (0.147)</td>
</tr>
<tr>
<td>Gamma(_2)</td>
<td>0.253 (0.142)</td>
<td>0.020 (0.018)</td>
</tr>
<tr>
<td>Gamma(_3)</td>
<td>0.250 (0.146)</td>
<td>0.424 (0.164)</td>
</tr>
<tr>
<td>Gamma(_4)</td>
<td>0.245 (0.141)</td>
<td>0.266 (0.166)</td>
</tr>
<tr>
<td>LNS(_{MIN})</td>
<td>0.499 (0.291)</td>
<td>0.594 (0.272)</td>
</tr>
<tr>
<td>Unc(_{MAX})</td>
<td>0.493 (0.291)</td>
<td>0.680 (0.214)</td>
</tr>
<tr>
<td>Btol</td>
<td>0.499 (0.285)</td>
<td>0.434 (0.241)</td>
</tr>
<tr>
<td>#</td>
<td>1000</td>
<td>33</td>
</tr>
</tbody>
</table>

5.8

In Figure 10, the average number of different products, consumed by the neighbours, is depicted for the 1000 experiments. The neighbours of a consumat consume at least one product, and at most two types of products. If this indicator is 2, each consumat has neighbours who consume product 0 and 1. Consumption is distributed rather randomly over the globe.

![Figure 10: Distribution of the average different types of products consumed by the neighbors in time step 100. If this average is 1, a macro-level lock-in has occurred. If this average is 2, the consumption is randomly distributed over the lattice. A low average suggests spatial patterns.](http://jasss.soc.surrey.ac.uk/2/2/2.html)

5.9

If the indicator is equal to 1 each consumat consumes the same product as their neighbours. That is a global lock-in. The indicator shows the spatial lock-in of consumption. If we relate the indicator values to the parameters that we have changed for the experiment, we find a satisfyingly simple
linear relationship (Table 2). We excluded $\gamma_4$ because the products are assumed to have the same pollution rate and $\gamma_4 = 1 - \gamma_1 - \gamma_2 - \gamma_3$.

5.10

A higher weight on identity leads to a higher degree of spatial lock-in, while a higher weight on individual taste leads to a lower degree of lock-in. This is not surprising given the findings of Table 1. The leisure need is found less important but is in line with the price effect as presented in Table 1. Furthermore it is found that a higher minimum level of need satisfaction leads to lower spatial lock-in. Imitation seems to be important for spatial lock-in.

5.11

The simulation experiments clarified that two types of lock-in processes can be distinguished, each with their own dynamics. The global lock-in effect is most likely to occur under conditions where the consumats have no preferred "taste" for one product in advance (the need for personal taste is absent) and the price of the product is playing an important role (a high leisure need). The spatial lock-in is most likely to occur when the consumats find it important to consume the same product as their neighbours (a high identity need). For example, often one can observe that a small group of people is using one product, while the majority uses another. On the basis of the simulation experiments we expect that this is most likely to occur under conditions where (1) people have no initial preference for the taste of a product, (2) the price of the product is playing a modest role, and (3) people prefer to consume the same as their "neighbours". In trying to expand their market share, the suppliers of both products should employ different strategies. To increase the market share of the product with a low market-share it would be most beneficial to make the taste of the product a more important issue. For the market-leader, it would be a good strategy to approach individuals in the groups that use the other product, and make them a special offer. If one or two group members change their consumption, the others may follow. Commercials focus often on the identity need satisfying capacity of the product in a market of similar goods, like cars and softdrinks.

| Table 2: Statistics based on the results of 1000 model runs (t-values are in brackets) |
|--------------------------------|----------------|
| $R^2$                          | 0.489         |
| $c$                            | 1.789 (53.15) |
| $\gamma_1$                     | -0.538 (-11.48) |
| $\gamma_2$                     | 0.685 (14.58) |
| $\gamma_3$                     | -0.196 (-4.25) |
| $LNS_{MIN}$                    | 0.159 (8.54)  |
| $Unc_{MAX}$                    | -0.237 (-12.78) |
| $Btol$                         | 0.004 (0.21)  |
| #                              | 1000          |

6.1

In this section we will analyse under what conditions an alternative product will lock-in. Initially, the alternative product has a market share of 1 per cent and differs from the locked-in product in that...
it does not lead to pollution. The zero-pollutant alternative also has a much lower cumulative learning factor, \( CL_{I-in} \) is 1, compared with the locked-in product, for which \( CL_{I-in} \) is 100.

6.2

As in the last section, we perform 1000 runs with the model. The average share of the alternative product shows a slight increase, on average, to 20 per cent in time step 100 (Figure 11). Only in a small number of cases will the zero pollutant lock-in (Figures 12 and 13).

Figure 11: The average share of product 2 for a whole range of time steps

Figure 12: Distribution of share of product 1 in time step 100. If this share is equal to 0 or 1 a macro-level lock-in has occurred
Figure 13: Distribution of the average different types of products consumed by the neighbors in time step 100. If this average is 1, a macro-level lock-in has occurred. If this average is 2, the consumption is randomly distributed over the lattice. A low average suggests spatial patterns

6.3 Often marketers and engineers are astonished by the fact that a new product does not conquer the market, despite the fact that it is far better than the existing products. The simulation experiments suggest that two processes hinder the introduction of a new product in a market. Firstly, when the consumats are satisfied they process automatically, thereby copying their own previous behaviour (repetition) or someone else's previous behaviour (imitation). It is clear that as long the consumats perform automatic behaviour, no new product will enter the market. If 1 per cent of the consumats uses the new product (as was the case in the last experiment), the chances of a consumat copying this new behaviour are very small. A second process that is often neglected is that the need satisfaction derived by consuming a given product is not only provided by the product characteristics, but also by information regarding which other people consume this product already. In situations where consuming the same product as the neighbours satisfies the identity need, a strong barrier exists for a new product to conquer a market.

6.4 The simulation experiments thus strongly suggest that it is very hard to introduce a new product in a locked-in market where most consumers are satisfied and prefer to consume the same as their neighbours. A strategy that can be advised is to approach a group of consumers with a special offer in order to get a starting point in the market.

Discussion

7.1 Lock-in dynamics are important phenomena to understand in relation to behavioural change policies. In this paper, we have used a rule-based multi-agent model instead of the more traditional probabilistic models. This enabled us to derive some insights about the conditions under which lock-in of consumption patterns occurs. We found that a global lock-in only occurs if the "personal taste" need is little weighted by the agents and the need for leisure, which is related to product prices, is highly weighted.

7.2 Spatial lock-in often occurs when the need for identity is highly weighted. This leads to the
clustered consumption of a certain product, which may not be in line with the individual preferences of the consumats.

7.3

These findings lead to an interesting advantage of using simulation models, namely the formulation of new hypotheses. The model-based results suggest that the neighbour effect may be very significant in certain circumstances. It might be interesting to perform empirical research on social comparison to discover under what conditions consumers copy the product choice of which other consumers.

7.4

There are various starting points for improving the simulation model. For example, the satisfaction of the identity need is related to the proportion of neighbours consuming the same product as the particular consumat itself. This relates to the 'belongingness' that is associated with this need. However, consumats may differ in the interpretation of identity. For example, some agents stressing their uniqueness in their need for identity, and will experience a high satisfaction of the need identity if there are few neighbours consuming the same product (differentiation). Another possible improvement is a more advanced description of the price dynamics. We could enlarge the model with the simulation of behaviour of companies leading to a co-evolutionary approach to consumption and production.

7.5

The developed simulation framework to study consumer behaviour is a transdisciplinary product. Traditional social psychology often studies static psychological factors affecting human behaviour. Through this modelling framework we hope to contribute to a better understanding of dynamic behavioural processes. The case studies of lock-in effects showed clearly that different type of lock-in effects exist in different circumstances. Additional empirical research is needed to confirm these findings. The agent based simulation models do not predict the future. They may be viewed as cartoons expressing clearly insights and gaps in insights from a complex system. The combination of empirical research and modelling may increase our understanding of complex systems.

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