Agent-based simulation of lock-in dynamics in a duopoly

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ABSTRACT
Lock-in is observed in real world markets of experience goods; experience goods are goods whose characteristics are difficult to determine in advance, but ascertained upon consumption. We create an agent-based simulation of consumers choosing between two experience goods available in a virtual market. We model consumers in a grid representing the spatial network of the consumers. Utilising simple assumptions, including identical distributions of product experience and consumers having a degree of follower tendency, we explore the dynamics of the model through simulations. We conduct simulations to create a lock-in before testing several hypotheses upon how to break an existing lock-in; these include the effect of advertising and free give-away. Our experiments show that the key to successfully breaking a lock-in required the creation of regions in a consumer population. Regions arise due to the degree of local conformity between agents within the regions, which spread throughout the population when a mildly superior competitor was available. These regions may be likened to a niche in a market, which gains in popularity to transition into the mainstream.

Categories and Subject Descriptors
I.6.5 [**Simulation and Modelling**]: Model Development, Modelling methodologies.

J.4 [**Social and Behavioural Sciences**]: Economics, Sociology.

General Terms
Experimentation, Human Factors, Economics

Keywords
Agent-based simulation, consumer behaviour, lock-in.

1. INTRODUCTION
The term lock-in is used to describe a situation where a single product dominates a market place. The dominance of a lone product ensures that competing products find it difficult to capture any significant market share. Frequent examples of a lock-in found in literature revolve around the QWERTY keyboard layout [7] and the VCR format [1][2]. The QWERTY keyboard layout has been claimed to be less efficient than alternatives, yet it has remained the dominating keyboard layout in current use; David's paper [7] provides a discussion of QWERTY's prevalence. The VCR format "war" between Betamax and VHS has also been repeatedly cited as an example of how an inferior product managed to dominate in a market place.

Economists have studied the lock-in effect with great interest, identifying a variety of areas and factors that may contribute to the development of a lock-in and whether a lock-in may be recognised in advance, or how sub-optimal choices may become locked in despite the knowledge of superior alternatives [1-3]; these will be examined in more detail in section 2.

We are interested in the contribution the choices made by a consumer have during the formation or maintenance of a lock-in, and breaking the lock-in. Economics and psychology have contributed extensively to studies of the lock-in effect and how a lock-in may occur. Simulations have formed an integral part of previous publications [1], playing a key role in examining the dynamics that lead to lock-in, but without investigation into breaking a lock-in. Carrillo-Hermosialla and Unruh [5] examine the technological standards of succession dynamics of markets involving technology innovators and producers through use of an agent-based simulation, which includes aspects breaking a lock-in.

In this paper we create an agent-based simulation of a market, consisting of consumers and two products competing for their custom. The consumers make repeat purchases, selecting the most suitable product based upon their perception of the product's quality and their conformity to their neighbours' choices. We simulate the market to examine dynamics of a lock-in, and then test various hypotheses on their effectiveness in breaking the lock-in.

The rest of this paper is structured as follows: Section 2 presents a background of research related to the lock-in effect, with a focus upon prior simulation models. We discuss the motivation for the simulation and a brief explanation of how we achieve our goals. Section 3 presents the consumer model utilised in the simulations and the assumptions we make. Section 4 presents the sensitivity analysis of the model, and discusses the relevance of the findings. In section 5 we highlight the experiments to test the model and various hypothesises to break a lock-in. The results are discussed in section 6, with section 7 concluding.

2. BACKGROUND
Several types of lock-in have been identified from the literature. At a market level a lock-in is where a single product dominates the market place, and the reversal of the dominance is unlikely to occur [15]. At an individual consumer level, a lock-in is where a product has an initial investment or set-up cost, and an ongoing cost of use. Researchers in the fields of economics and psychology have identified several reasons why a lock-in may be generated, such as path dependency (historical events), proprietary factors and cognitive behaviour.

In the literature Arthur [1] conducted a simulation of path dependency, examining how increasing returns can lead to a lock-in. Under increasing returns, the more adopters of a particular technology or product, the greater the improvement may be made to the technology and the product may capture the market. Initial advantage over a competitor may be due to innocuous events, leading to the lock-in; under different circumstances, a different outcome may occur. Path dependency, or historical events [1], is the distinction that the prior history of events determines the outcome. Katz and Shapiro [13] noted that products exist where the utility upon consumption of a product increases with the number of other agents consuming the product. Similarly, the bandwagon effect [14] is where consumers may purchase an alternative based upon other consumers' decisions, without having prior experience; both [13][14] are examples of network externalities, where a network externality is effect one user of a product has on the value of that product to others.

Proprietary lock-in is where purchasing a particular product results in a consumer being dependent upon the producer for services, products or component parts. An example of such proprietary lock-in was Apple's iTunes and iPod player, where iTunes purchases were encoded in a proprietary format, ensuring only Apple products may play the music (iPod). Consumers are subsequently locked into Apple products unless the consumer pays a significant switching cost for both player and music to an alternative format; proprietary lock-in is closely linked to cognitive lock-in.

Cognitive lock-in involves a learning process, which is both the initial investment and ongoing usage cost. The amount of thinking required to utilise a process may be great at the start, but as familiarity through repeated usage occurs, it decreases the amount of thinking required in order using the process. This creates the cognitive lock-in, a barrier between using a known product and learning a new product [12].

A distinction between the above factors may have become apparent. Proprietary lock-in exists when an individual consumer is locked into a product or service; the decisions made by others may not be a factor. Network externalities are where a consumer makes the best decision they can, which can be impacted upon by the decisions of others. We are interested in the dynamics of lock-in, particularly how the tendency to follow trends can cause regularities to appear in the global market, and how those regularities may be broken. Network externalities as outlined above features strongly in this type of model, whereas proprietary lock-in will not feature.

2.1 Existing lock-in models

Arthur's [1] simple model of a duopoly featured two types of homogeneous consumer, where each type of consumer has a preference for a different product. The consumer chooses according to their product preferences under conditions of increasing, decreasing and constant returns. Arthur found that in markets with decreasing or constant returns an equal market share must be achieved with probability of 1. In markets with increasing returns, there is a path dependency; the outcome is determined by "small events history" as Arthur terms it, the order in which agents make their decision.

Janssen and Jager [11] developed a multi-agent simulation model with a psychological perspective upon the consumer decision. Janssen and Jager fuse together various cognitive behavioural theories to focus upon understanding how behavioural processes drive consumer decisions as they claim economic approaches give little insight into how the decisions are made. They conclude that different patterns of consumption can emerge based upon the overall needs of consumers – such as low prices, high social comparison, and the type of cognitive processing consumers utilise.

Carrillo-Hermosialla and Unruh [5] created a multi-agent simulation model featuring a market of multiple products, where innovators and producers interact and enable the evolution of technological standards through diffusion of innovations in the product creation processes. Whilst their model features lock-in to technologies, and how a lock-in is broken during evolution of the technology, the dynamics are applicable to product production scenarios.

2.2 Motivation

Our motivation is to test various methods for breaking a lock-in of a market to a single product, where such market domination stifles competition and limits consumer's ability to receive value for money. We require a market simulation consisting of consumers making repeat purchases, enabling us to test the effectiveness of our hypotheses for breaking a lock-in.

Arthur's [1] model, which always generates a lock-in when simulating a market of increasing returns, consists of a single iteration of homogeneous consumer decisions based on product preference and increasing returns during a simulation. Arthur's model indicates the minimal assumptions required to simulate a market to lock-in.

Janssen and Jager's [11] model focuses on the behavioural process that underpins a decision made by the consumer. This is based upon complex assumptions with regards to consumers having four types of decision making choices in their repertoire, and the underlying cause of transitions between these types.

Our intention is to create model of a duopoly, which is able to simulate a lock-in of the market to one product. To achieve this we create heterogeneous consumers, bounded in their rationality and responsive to network externalities. A consumer's decision is based upon product utility, with the utility calculation including the consumer's perception of product quality, and their tendency to follow trends within a localised population. We simulate a lock-in before attempting to break it through two hypothesised methods: advertising and free give-away. To the best of our knowledge a simulation incorporating a break of lock-in, through testing and evaluation of various hypotheses for their effectiveness, is unique within the fields of multi-agent simulation, and economics.

3. SIMULATION MODEL

The simulation revolves around a market duopoly where we attempt to break a lock-in enjoyed by a single product. We assume products are identical, with no constraint or costs considerations (economies of scale, production limitations etc) and of identical monetary value. We therefore focus upon the interacting dynamics of consumers decisions.

The consumer calculates a utility value for each product available, and selects the product with the highest utility, where the utility is the consumer's derived personal pleasure. The utility depends upon the perception of the product quality and decisions of neighbours. Our model, shown in (1), is a general model, and does not describe scenarios of specific product type.

$$U_i = (1 - ft)(Q_i - Q_{des}) + ft\,\frac{N_i}{N_P} \qquad \textbf{(1)}$$

- U_i is the consumer's utility of product i, where $i \in P$ and P is the set of all products.
- ft is the follower tendency of the consumer, with a value in the range $(0,1)$.

- Q_i is the consumer's experienced quality of product i (the taste) and has a value in the range $(0,1)$.
- $Q_{des} = 0.5$, the consumer's minimum satisfaction quality.
- N_i is the number of neighbours within the Moore neighbourhood of range 1 when considering a local, or all the consumers in the simulation when considering a global, network who selected product i.
- $N_P = \sum_{j \in P} N_j$ defines the total number products purchased by all consumers in the neighbourhood.

We made six assumptions with regards to a consumers purchase decision:

1. Every consumer assumes all products are of equal quality at the start of a simulation.
2. Product experience is gained upon first consuming a product.
3. Consumers desire products to have a minimum quality (Q_{des}) in order to be satisfied with a product.
4. Consumers have different levels to which they follow or conform to their social network (represented by f_t).
5. Purchase decisions made by others within their neighbourhood are viewable.
6. Every consumer regards the members of their network equally, and network size is homogeneous for all agents.

The second assumption indicates consumers will only gain their accurate appraisal of a product's quality Q_i after they have purchased the product itself. Assumption three follows as we consider bounded rationality and satisficing theories [17], where Herbert Simon exposits that decision makers select a "good enough" option to satisfy their requirements. It follows that if the consumer's first experience exceeds the minimum quality criteria,$(Q_i - Q_{des}) > 0$, then dependent upon follower tendency, the consumer will repeat their purchase without further exploration of the available products.

The fourth assumption is based upon a population of consumers being heterogeneous; therefore the tendency to follow a trend will differ between consumers. A strong follower tendency may cause a consumer purchase a product that they do not believe to be good quality; with no follower tendency consumers will always purchase the product they perceive to have the best quality. The fifth assumption follows from the third, that consumers know the consumption choices of others within their network. The sixth assumption follows that every consumer regards the members of their network equally.

Equation (1) is similar in nature to Arthur's [1], but we model the consumer decision as a fusion of the individual element and conformity to the peer network, whereas in [1] decisions are modelled as homogeneous preferences and path dependency linked to increasing returns. We draw parallels between our model and Arthur's; the differences, however subtle, are significant. Increasing returns is defined by Arthur [1] as where the more the products are adopted, the more they are improved. Arthur's model consists of two homogeneous populations of agents, and relies more upon the product or producer market factors than consumer decisions. With increasing returns Arthur abstracted the improvement of a product to the number of consumers adopting the product. This assumes that agents know the product choices of all other agents in the environment, and improvements are proportional to consumption.

We model a heterogeneous population of agents and focus upon the consumer's decision at the micro level and the overall macro level these individual decisions exhibit. Recognising that the utility of a product may increase as the number of consumers of the product increases [14], we differ to Arthur by incorporating network externalities and assuming consumers are bounded in their ability to see neighbours' decisions. We therefore liken increasing returns to conformity, a process by which actions may be influenced by the actions or decisions of taken by others [6], which will add flexibility to our model. Conformity is closer to Katz and Shapiro's [13] definition seen in Section 2, and echoes Carrillo-Hermosilla and Unruh [5] observation that there exist "situations in which it is optimal for an individual, having observed the actions of those going before, to follow the behaviour of the preceding individual without considering his own information".

We justify the flexibility of conformity as follows: specific market types may lead to differing levels of conformity in a population, as some items define social status. Examples of this are fashion clothing or items, where there is a stronger emphasis on following a trend, or a white goods market, where the goods play little part in the public status of the consumer and therefore exhibit a lower follower tendency.

To enable conformity in the model we create an abstract social network for the consumers. Consumers may then consider the consumption choices of others in their utility calculation, tempered by the heterogeneous degree to which they conform. This abstract conformance network is similar in principle to previous work by Epstein [9], where agents conformed to the prevalent norm within their surroundings. We differ as consumers do not adapt their consideration range, and we utilise a different network type. Our consumers will be located in a torus grid, where their surrounding Moore neighbourhood with range 1 will represent the consumer's social network or peer group, to which they belong. We will contrast this in our experiments with consumers considering all members of the population (Moore neighbourhood = radius of grid).

In this section we discussed and contrasted the differences in assumptions, such as locally bounded heterogeneous consumer conformity in a grid network, identical product quality distributions and heterogeneous consumers. We place the emphasis upon the consumers' decisions, with the torus grid network providing a suitable abstract representation of a peer network. This allows us to examine the dynamics and spatial patterns of consumption and interaction instead of the abstract overall market share without the consumer interaction consideration. While we do not focus our attention on specific market of products, our model is simple and flexible enough to be applicable to any market due to conformity. The model will allow us to observe the simple dynamics involved in breaking a lock-in, without examining the complex causes and assumptions e.g. of technological standards succession and innovation diffusion, switching costs and cognitive processing.

4. EXPERIMENTS

First we outline the initial variables and conditions for a simulation before analysing the model behaviour.

4.1 Initial settings and variables

The consumer experience of a product, or their perception of the product quality, is represented by $Q_i, i \in P\{A, B\}$. The quality experienced by the consumer upon the initial purchase of a product is drawn from a normal distribution; this allows for consumers to have heterogeneous tastes. We refer to this as the product distribution, with the parameters of the distribution stated in the experiment settings in Tables 1, 3 and 4. With identical distributions for two products we assume that both products are perceived to be equal in quality; however the individual taste experience allows each consumer to distinguish between the two products. Later experiments there may be product inequality, but this will be clarified in the corresponding sections.

At initialisation consumers have no prior experience of the products and the first assumption of the consumer purchase decision holds. At initialisation each consumer is given a random product from the set of available products P; the consumer does not experience this product until they purchase it. Follower tendency for each consumer is drawn from a distribution, where the distribution is referred to as the follower tendency distribution.

The social network for consumers may be of two types: A local social network, where only the consumers in the consumer's immediate Moore neighbourhood of range 1 are considered; or a global social network, where all consumers in the population are considered to have equal impact on the consumer's decision. This latter network is more representative of Arthur's [1] global knowledge of individual purchases and contrasts against our consumers bounded rationality.

4.2 Model Behaviour

Sensitivity analysis will allow us to determine how the variables affect the creation of, or cause, a lock-in; the role that they play in the dynamics. We test the effect of the network type upon the model, simulating both types of network, and compare the results. We investigate how the model responds to follower tendency by modelling two specific types of abstract market; one requiring a low follower tendency and the other requiring high follower tendency. We conclude sensitivity analysis by investigating how the model behaves with products that are not equal in quality.

Table 1: The settings for sensitivity analysis conducted in experiments 1-6. The table shows the distribution for product quality, follower tendency and the network the consumer considers.

Expt	Product quality distribution ($Q_A = Q_B$)	Follower tendency distribution	Network
1	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.5,0.167)$	Local
2	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.5,0.167)$	Global
3	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.05,0.0167)$	Local
4	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.05,0.0167)$	Global
5	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.85,0.05)$	Local
6	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.85,0.05)$	Global

We outline the settings for network and follower tendency experiments in Table 1, where we show the distributions from which consumer variables were drawn and the network type considered by each consumer. Every simulation consists of 1000 steps and is repeated 20 times. The results of the experiments were collected, correlated and presented in tables. The results tables are presented in individual sub-sections, for clarity, and the columns indicate the experiment, the mean market share of product A (M_A), and product B (M_B) as a ratio, and the standard deviation from the mean share. The final column of the results table will indicate observations noted during the experiments that would not be otherwise discernable.

4.3 Network type and follower tendency.

Network effects were investigated in experiment 1 and 2, and results shown in Table 2. The results for experiment 1, where consumers consider a local network, show that the market share is approximately 50:50. Under a local network no product successfully gains an overall lock-in of the market; either product may obtain a majority market share, or no majority may exist. Experiment 2 resulted in a lock-in, to either product, dependent upon initial product prevalence.

Table 2: Results of experiments 1 and 2, where consumers are considering different neighbourhood networks during their choice, and 3-6, where follower tendency distributions are altered.

Expt	$M_A : M_B$	σ	Lock-in?	Observations
1	55:45	15	No	Spatial lock-in occurs
2	100:0 or 0:100	0.26	Yes	A or B global lock-in.
3	50:50	3	No	No spatial regularities
4	50:50	16	No	Equilibrium, no lock-in
5	50:50	23	No	Strong spatial regularities
6	100:0 or 0:100	0	Yes	A or B global lock-in

The spatial representation of the simulation, shown in figure 2, allows us to observe a spatial pattern of consumption during the simulation. Each of the images represents the grid of consumers, with each square in the grid representing a consumer; the colour of the consumer represents the product being consumed. The first image is the initial state of the market, followed by the end state, given as the second image.

The spatial correlation between consumers' decisions and the overall market share show that, despite product equality, interesting spatial patterns of product choice occur due to the network effects. Consumers form regions that exhibit lock-in to a single product; Janssen and Jager [11] refer to this as local or regional lock-in.

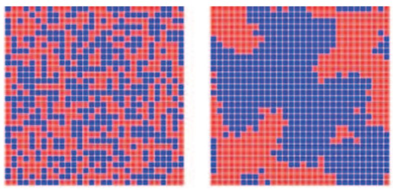

Figure 1: The spatial results of an Experiment 1 simulation run. The starting state is the left image, the finishing state on the right. The results show regions of a localised lock-in to a single product.

Even though we designed a model that does not describe a specific type of market, we have carried out experiments with parameters to simulate some aspects of specific market types. Alterations to the mean of the follower tendency allow us to simulate two abstract specific market types, one where consumers conform strongly, and the alternative where consumers conform weakly. With a low mean for the follower tendency distribution, consumers will not consider the decisions of others strongly during their choice. With a high mean for the follower tendency distribution, consumers will have a higher follower tendency, and the decisions of others will strongly affect their choice. Experiments 3 and 4, shown in table 1, represent the settings for low conformity under local and global network types respectively. Experiments 5 and 6 represent a high conformity market under local and global networks respectively, where consumers may find their status is defined by conforming to their peer network.

In the simulated low conformity market (experiments 3 and 4) we find no lock-in exists, and the market remains in an equilibrium without any spatial patterns of purchases. The high conformity market shows strong regions of lock-in under local network effects (experiment 5), and a global lock-in to one product under global networks (experiment 6).

4.4 Superior competition

Economists find interest in perceived irregularities that permeate market behaviour. An example is the ability for a market to become locked into an inferior product. Experiments 7 and 8 test the model where a product is available that exceeds a competitor in quality. With a superior product being available to the consumer, we see whether it is possible for the market to lock into the inferior product, and if so, what dynamics caused this to occur.

At the start of the simulation for experiment 7 both products are viewed as equal until experienced ($Q_A = Q_B = 0.5$). Experiment 8 has altered this assumption so that $Q_B = 0.7$; the consumers therefore believe B to be superior.

Table 3 Product B is superior to Product A. Superiority is only realised through consumption in experiment 5, superiority is known from the start in experiment 6.

Expt	Q_A distribution	Q_B distribution	Follower tendency distribution
7	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.7,0.1)$	$\mathcal{N}(0.5,0.167)$
8	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.7,0.1)$	$\mathcal{N}(0.5,0.167)$

Table 3 shows the experiment settings, giving the distributions used for the quality a consumer experiences upon consumption of a product and follower tendency. The results are shown in table 4.

Table 4: Results from experiments 7 and 8, where consumers are choosing between goods that are not equal. During experiment 7 consumers must consume the superior product to realise its quality, whereas experiment 8 starts with consumers knowing it should be superior.

Expt	Network	$M_A : M_B$	σ	Lock-in?	Observations
7	Local	22:78	14	No	A retains small pockets of regional lock-in.
7	Global	100:0 or 0:100	0	Yes	A or B global lock-in
8	Local	0:100	0	Yes	Global lock-in
8	Global	0:100	0	Yes	Global lock-in

We observe that local network effects allow regionalised lock-ins of product A (inferior product) to occur and persist in experiment 7. We hypothesise that consumers become unwittingly locked into the inferior choice due to conformity in the initial stages of a simulation; the local lock-in is path dependent without switching costs. In a global network we find that the model shows an inferior product may gain the entire market majority based on the chance superior share at the start. These results are due to the bandwagon effect [14], previously explained in section 2.

Experiment 8, where consumers know the superiority at the simulation initialisation, we find that, as expected, the superior product dominates the market place under both network types. The market will, given an equal initial distribution of products, always lock-in to the superior product when the consumers know the superior product in advance.

A small extension was then undertaken, for Experiment 7, with the expectation (Q_{des}) of a consumer elevated from 0.5, to 0.6. This would mean that, for the majority of the population, product A would be below their expectation threshold. The result was the same as for experiment 7, which shows that, in the model, conformity may allow a market to become locked into an inferior product that exhibits quality below their personal desire.

5. BREAKING A LOCK-IN

From the sensitivity analysis carried out in experiments 1-8 we realise overcoming the network effect will be of major importance to breaking an existing lock-in. We test two hypothesised methods to breaking a lock-in, which include:

- advertising, whereby the advertisement will inform the consumers of the superior product and we observe the market dynamics after the advertisement; and
- free product give away, where we observe how giving consumers a free sample affects the dynamics of the market.

To achieve this we create a market lock-in, and then utilise the strategies outlined and evaluate their success in overcoming a market locked into a lone product.

5.1 Advertising

We assume advertising alerts a consumer to a product's claimed quality in a market and that the claimed quality is an accurate representation of the actual product quality, represented by the mean of the product distribution. Furthermore, we also assume consumers accept this information without reservation. We start the simulation by creating a lock-in, and then introduce the new competing product.

5.1.1 Experiment

We have two products, the market is currently locked into product A, and product B is the competing product. We initially set the consumer's $Q_B = 0.5$, and allow the market to reach a stable equilibrium. When a consumer receives advertising we set Q_B for the consumer to the mean of the product distribution, 0.8.

The consumers will only learn the true quality of product B when they experience the product. If the consumer experienced product B before the advertisement, the advert does not alter their experienced value Q_B. Consumers start with their true experience (Q_A) of product A, and product A as their current choice; this represents an existing lock-in to product A. We then conduct the simulation and advertise product B in the 10th simulation step.

Table 5 shows the settings utilised for the distributions in experiments 9 and 10. In experiment 9 consumers do not receive any advertising with regards to quality of product B, while experiment 10 advertises the quality of product B in the 10th step of the simulation. The advertised quality of product B is the mean of the product distribution, 0.8, which consumers adopt.

Table 5 Advertising attempts to break the prior lock-in of product A.

Expt	Q_A distribution	Q_B distribution	Follower tendency distribution
9	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.8,0.0667)$	$\mathcal{N}(0.5,0.167)$
10	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.8,0.0667)$	$\mathcal{N}(0.5,0.167)$

5.1.2 Results

The results of experiment 9, where the consumers receive no advertising with regards to the product, are shown in figure 2. We observe that product B only captures around 1% of the market, irrespective of network type, failing to break the lock-in. This indicates the power of follower tendency during a lock-in, as only consumers dissatisfied with product A and with very weak follower tendency purchase product B.

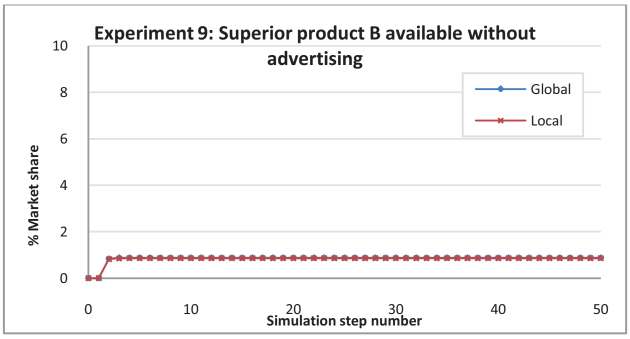

Figure 2: Percentage market share of product B during experiment 9. Consumers consider local and global networks when making decisions, but Product B is not known to generally be superior until first consumed.

Figure 3 shows the results of experiment 10, where we observe that advertising manages to reverse a lock-in to product B. By contrast, advertising in a global network resulted in a 10% market share gain.

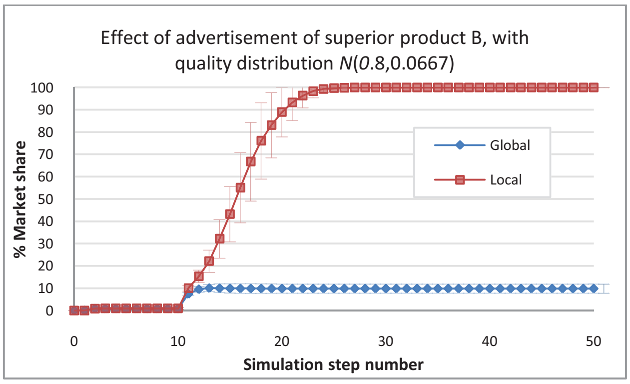

Figure 3: Percentage market share of product B during experiment 10. Consumers consider a local network when making decisions, but advertising of product B occurs in the 10th simulation step.

Examining the spatial representation for the local network in experiment 10, shown in Figure 4, illustrates how this lock-in was reversed after advertising. Local regions are formed and grow, gaining momentum and enables all agents to try the superior product. Within a global network a region may not form as the neighbourhood size is sufficiently large that the effects of an anomaly at the local level are insignificant globally.

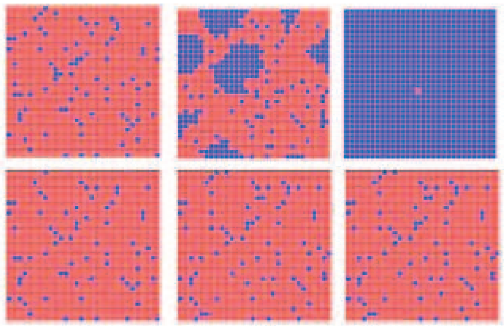

Figure 4: Spatial representations of local (top) and global (bottom) networks during Experiment 10. The first image in each row is the spatial representation at step 10 of the simulation, with the second image showing step 15 and the last image showing the final field state. Product A is red, Product B is blue.

5.2 Free give-away

We test our hypothesis that a method of breaking a lock-in is to give away a free sample of your product to a proportion of the population. This is a practice adopted by marketers in an attempt to start trends.

5.2.1 Experiment

At the beginning of the simulation, all consumers are locked in product A. During a simulation, a percentage of the population, selected at random, receive a free product during one turn of the simulation. This free give-away is in place of the consumer's decision making (at that step), and the consumer experiences the product during the give-away as if they had selected it. Table 6 shows the settings for the experiments in the free give-away.

Table 6 Experimental settings to break a lock-in through free give-aways of product B.

Expt	Q_A distribution	Q_B distribution	Follower tendency distribution
11	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.5,0.167)$
12	$\mathcal{N}(0.5,0.167)$	$\mathcal{N}(0.8,0.0667)$	$\mathcal{N}(0.5,0.167)$

All consumers start the simulation with $Q_B = 0.5$, and learn its true quality upon initial purchase or receipt of a give-away. Consumers draw experience of product A, and product A is set as their current choice, to represent the current market lock-in of product A. The give–away of product B occurs in the 10th simulation step, with all agents not given a free sample deciding which product to choose afterwards. When a consumer is given a product, it draws its experience of the product (if not previously experienced) and is not allowed to choose another product until the following simulation step.

5.2.2 Results

Experiment 11 uses the same product quality distribution for both products A and B. The effect is to simulate a competing product of equal quality entering an already dominated market. We utilise four different levels of free give-away.

The results of experiment 11 at a range of population percentage free give-aways are plotted in Figure 5. It should be noted that a greater portion of the population sample product B during the free give-away than proportion of the population received the free product, an initial surge in consumers purchasing product B.

However, despite the increased uptake, equilibrium returns with product A retaining its lock-in of the market.

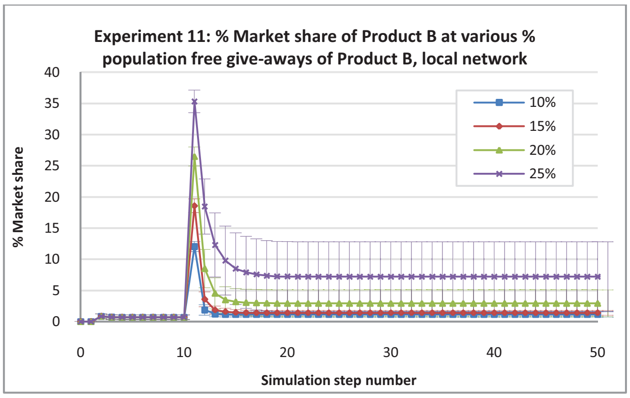

Figure 5: Percentage market share of product B during experiment 11. Each line represents the result of the percentage of population given product B in the 10th simulation step as shown in the legend. A local network is considered during consumer choices.

Figure 6 shows that no other consumers try product B during the free give-away under global network, and equilibrium quickly returns with product A retaining a lock-in.

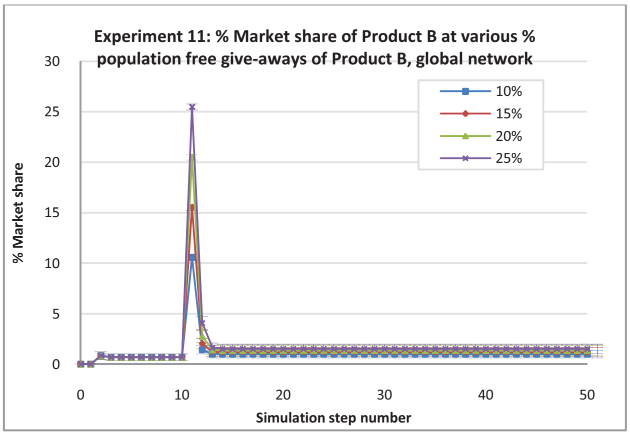

Figure 6: Percentage market share of product B during experiment 11. Each line represents the result of the percentage of population given product B in the 10th simulation step as shown in the legend. A global network is considered during consumer choices.

Experiment 12 repeats Experiment 11's settings, but we use a higher mean product quality distribution for product B compared to product A. We are simulating a free give-away of a superior product into a market already locked-into a competitor's product.

The results for experiment 12, under a local network, are plotted in Figure 7. These results illustrate that a greater portion of the population sample product B during the free give-away than proportion of the population received the free product. Additionally, a significantly higher proportion of the population retains their choice than during experiment 11, and the lock-in is broken as the proportion of the population receiving the free give-away increases.

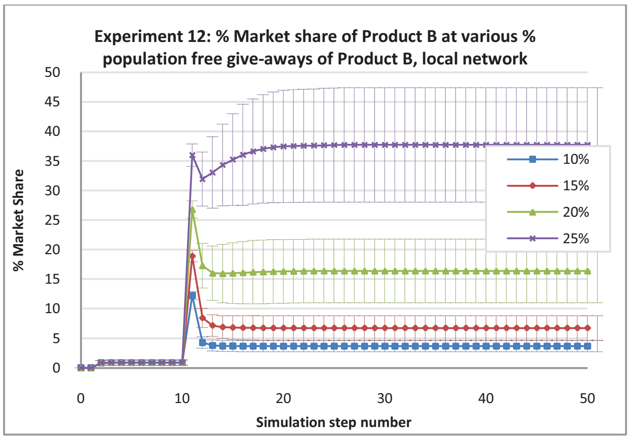

Figure 7: Percentage market share of product B during experiment 12. Each line represents the result of the percentage of population given product B in the 10th simulation step as shown in the legend. A local network is considered during consumer choices.

The results from experiment 12 are plotted in Figure 8, where a global network fails to have the lock-in broken unless the greater majority of the market is given the free product.

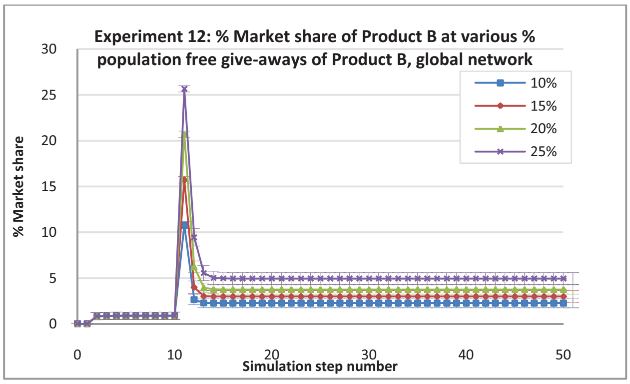

Figure 8: Percentage market share of product B during experiment 12. Each line represents the result of the percentage of population given product B in the 10th simulation step as shown in the legend. A global network is considered during consumer choices.

The spatial representation of simulations in Experiment 12 is displayed in figure 9, where local network effects allow the formation of regions where consumers become locked into the competing product. These regions persist for the duration of the simulation.

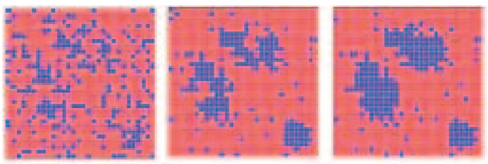

Figure 9: The spatial representation of a simulation during experiment 12 at 20% free give-away. After the initial give-away (first image) very little regionalised lock-in is evident. The subsequent images are 2 and 5 steps later respectively, where regionalised lock-in has occurred. Such regionalised lock-in allows a product to break the overall market lock-in of product A.

6. DISCUSSION

We made several simple assumptions during the creation of our model: the two products have an identical distribution on quality (in most experiments), consumer decisions are based upon product quality and the neighbouring consumer's decision choices, tempered by a consumers certain degree of follower tendency. We found that when considering a local network the consumers would form regions within the global population, where consumers are locked into one product, but overall no market lock-in existed. Under a global network a market lock-in to one product would occur, mirroring Arthur's finding [1]. Simulating specific market types altering the network externality strength further reinforced findings related to Arthur's model of no returns[1] [1]. When follower tendency is universally low, indicating little rationality in conforming against your own personal evaluation of a product, we found that the market retained an approximate 50-50 equilibrium.

We then tested hypotheses to break an existing lock-in. We assumed an equal product distribution and found that it was not possible to break an existing product lock-in under equal product qualities, using either of the two hypothesised methods of free-give away and advertising; under those conditions consumers would not find it rational to deviate from the most popular choice. This is in keeping with empirical studies where significant improvements in product quality are required to displace a locked in product [10].

Altering the assumptions slightly to allow a superior product to be introduced, we found the key factor in breaking a lock-in depended upon the network dynamics, the local network consideration; local conformity allowed regions to develop which may spread throughout the population. A similar result was found when comparing the results of a free give-away. We found that the local conformity network allows a free give-away to create a region locked into a singular product, with the degree of success in the breaking of a lock-in linked to the magnitude of the give-away. Formation of niche areas of a product allows the spread of the product to permeate the population.

7. CONCLUSION

We created a model that is the first to focus on exploring the basic dynamics of breaking a lock-in, without account for properties specific to certain markets (e.g. switching costs). Using simple assumptions with regards to a consumer purchase decision being based only upon the perceived quality of the products and conformity with their neighbours, we observed that methods which overcame a lock-in exhibited similar patterns. Lock-in was only successfully overcome if spatial regions of the superior product are formed within the population locked into the inferior product. Future work would focus upon targeting specific regions related to consumers, and investigate the affect of such specific targeting over the more general approach exhibited here.

8. REFERENCES

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[1] With costs as an example, increasing returns means that the unit price will decrease with increased adopters, and decreasing returns means the price increases with increasing numbers of adopters. No returns mean that unit price is independent of the scale of adoption.