Consumer social learning and industrial dynamics

Francisco Fatas-Villafranca[a], Carlos M. Fernández-Márquez[b] and Francisco J. Vázquez[b]

[a]Department of Economic Analysis, University of Zaragoza, Zaragoza, Spain; [b]Departent of Economic Analysis and Quantitative Methods, Universidad Autónoma de Madrid, Madrid, Spain.

ABSTRACT

In this paper, we propose an agent-based model in which industrial dynamics depend on consumer social learning and firm innovation efforts. We draw on behavioural economics and consumer psychology to model consumer learning as a process of social adaptation-cum-individual novelties which operates within a stochastic dynamic network. In our model, consumers create original patterns of behaviour, but they also imitate similar others through a (degree-dependent) influence-biased process of change. Likewise, consumer behaviour is shaped by firms which attempt to capture larger market shares. Thus, we propose a model in which consumers update their position (tastes) in a product characteristics space through innovation and adaptation, and co-evolve with profit-seeking firms which observe and shape evolving consumer behaviour. We simulate the resulting market process obtaining trajectories and stationary states for the degree of industrial concentration, the number of producers, and certain features of the industry lifecycle.

The analysis of the model reveals how three demand parameters -consumer "insistence" (capturing inertia in decision-making), the "locality" of consumer learning, and consumer "loyalty" to firms- affect industry evolution. Likewise, the model generates a continuum of limit industrial structures –from perfect competition, to oligopolies or monopolies- with said demand parameters influencing the stationary states.

KEYWORDS

Consumer learning; Agent-based models; innovation; industrial dynamics; Evolutionary Economics

JEL CLASSIFICATION B52; O31; O33

CONTACT Carlos M. Fernández-Márquez. carlosm.fernandez@uam.es

1. Introduction

In this paper, we present an agent-based model with Neo-Schumpeterian roots in which consumer social learning and firm innovations drive an artificial market. By proposing this model, we seek to analyze the role of the *co-evolution between supply and demand* in *industrial dynamics* (Malerba et al. 2007; Almudi et al. 2013; Nelson, 2015; Fernández-Márquez et al. 2017a). We believe that the model may contribute, both, to the study of *industry evolution* (Nelson and Winter, 1982; Klepper, 1997; Mowery and Nelson, 1999; Malerba and Brusoni, 2007; Fernández-Márquez et al. 2017b), and to the *Schumpeterian literature on consumption* (Cowan et al. 1997; Aversi et al. 1999; Witt, 2001; Metcalfe, 2001; Fatas-Villafranca et al. 2007, 2009a; Nelson and Consoli, 2010; Chai and Moneta, 2012; Valente, 2012). This work also incorporates elements from the theory of the *active consumer* put forward by Bianchi (1998;

2007) and others (see Chai, Earl and Potts, 2007) during the last two decades.

In order to specify the ways in which this paper contributes to the different afore-mentioned literatures, let us start by linking our model with the economic theory of consumption. At least since Veblen (1899), we know that people demand goods not only because of their functional attributes, but also to signal status. This idea has stimulated decades of research (Lancaster, 1966; Stigler and Becker, 1977; Baudrillard, 1981; Deaton, 1992; Becker, 1996) revealing the importance of emulation, lifestyles and fads (Earl, 1986; Chai et al. 2007). In our model, we depart specifically from the work of Lancaster (1966) -on the characteristics possessed by the goods- and we exploit his framework by combining it with a vision of the consumer as an active agent who enjoys finding new combinations of these characteristics. The idea of the consumer as an active agent has been deeply explored by Bianchi and others (1998; 2007), and (from an evolutionary perspetive) by Fatas-Villafranca et al. (2004, 2007, 2009a) who have shown how consumers create in an *active* way their own welfare through: i) innovative social learning; ii) their taste for novelty; and iii) their need to create personal identities through the market.

In the model we now present, we incorporate these features of endogenous consumer behaviour in a model of demand-supply *co-evolution* which leads to remarkable industrial transformations. The model opens new ways to study such *emergent phenomena* as: fashions or changing consumption niches (on the demand-side); and emergent industrial structures and market dynamics (degree of market concentration, entry/exit patterns, or the rate and direction of innovation), on the supply-side.

It is clear to us that this theoretical conception of the consumer as an active agent, who lives in product characteristic spaces, is not far from the most advanced *neoclassical contributions* to consumer economic theory (Stigler and Becker, 1977; Becker, 1996; Deaton, 1992). Thus, in these neoclassical works, we find a vision of households as producers of commodities (in a wide sense), where commodites are related to consumption technologies which employ goods, time, human capital and specific skills. This vision is interesting and complementary to ours. Nevertheless, we believe that the "essentially" static setting of the neoclassical approach, is very far from (and much less permeable than) the dynamic visions of *institutionalists* or *neochumpeterian-evolutionary* economists when trying to assimilate contributions from consumer psychology, neuroscience and behavioural economics in economic theory. This is the reason why we address our exploration of consumer social learning and market dynamics in from an evolutionary perspective.

More precisely, as we show in this paper, it is possible to combine the (institutionalist and neoclassical) *insights on consumer habits and inertias*; the theory of the *active consumer* in evolutionary economics; and recent advances in *behavioral economics, network theory,* and *consumer psychology* (Vernon Smith, 2003; Kahneman, 2003; Vega-Redondo, 2007) in such a way that we can renew the representation of the demand-side of the market, so that we can fix it to co-evolve with supply (through complex but specific new mechanisms) at the very basis of market processes. In developing this line of thinking, it is a remarkable new feature of the model that we consider cognition as an ongoing distributed process in *evolving social networks*, in which (some kind of) homophily is crucial (Lazarsfeld and Merton, 1954; Saxe and Kanwisher, 2003; Centola et al., 2005; Lierberman, 2007; Tomasello, 2008; Giles, 2012). Let us notice that this is a key empirical fact observed in consumer social learning which –as we will see- leads to a peculiar type of *market co-evolution* in the model. In fact, the specific co-evolution mechanism that we devise in the present model is different from (e.g) the co-evolutionary processes involving *technical practice and understanding* driving technological change (see Almudi et al. 2016 -in this same journal- for an illustration); and it also differs from the co-evolutionary *political economy processes* underlying institutional change, as in Almudi et al. (2017). It may be useful to inform the reader that all these (different) types of co-evolutionary economic mechanisms have been discussed in a recent paper (Almudi and Fatas-Villafranca, 2018).

From a strictly technical/formal point of view, let us anticipate that, in the present work, we model consumer social learning-cum-innovations as a probabilistic process of gradual emulation -influenced by network proximity and degree-dependent influences- that changes the network itself in co-evolution with firm innovative efforts (firm entry, firm incremental adaptations, and the materialization of consumer opportunities through specific firm-product innovations). Thus, our conception of consumer social learning involves belongingness-driven dynamics (Tennie, Call and Tomasello, 2009; Huettel and Kranton, 2012), since consumers in our model tend to approach "better-connected" others. This attraction "plus" of influential agents (high-degree nodes) in consumption often appears in *network models* (DeMarzo et al. 2003; Golub and Jackson, 2010) and in *behavioural economics* (see the works in Wilson and Kirman, 2016), and it is crucial in driving consumption, innovation, and the market process in our co-evolutionary ABM.

Drawing on the afore-mentioned, we can follow Janssen and Jager (2001, 2003) (among others) in wondering whether these cognitive processes underlying consumer theory and the co-evolution between demand and supply may determine industrial dynamics and structures in certain sectors. To address this question, we integrate our consumption dynamics within a wider market framework, in which firm entry/exit and other Neo-schumpeterian findings regarding firm inertias and heterogenous innovation efforts operate. Thus, we end up with a model in which industry evolution and the determinants of market structure can be analyzed.

Regarding our results, we can say that the model continues the *(evolutionary) industrial dynamics research tradition*, but it reveals some new propoerties which are mostly driven by the demand-side of the market. As in previous evolutionary contributions (and here we can connect our model with the literature developing from Nelson and Winter, 1982), we consider boundedly-rational agents (consumers and firms), heterogeneity, routines, learning, innovations on the part of consumers and firms, and a conception of industry evolution as emerging from scattered interactions (Dopfer, 2005; Malerba and Brusoni, 2007; Dosi and Nelson, 2010; Almudi et al. 2012, 2013). But here, we present a stylized version of market supply, so that we can explore the role of demand in industry evolution while keeping the model simple. Our representation of supply does not mean that we deny the importance of technological regimes, firm-specificities and supporting institutions in industrial change; on the contrary, we have devoted a good deal of attention to these supply-side aspects in previous works (Fatas-Villafranca et al. 2008; 2009b; 2014). But in this paper, we try to prolongue the industrial dynamics tradition by examining in detail demand-side factors. This strategy allows us to visualize how consumers endogenously generate market niches through social learning, and guide firms when they enter and adapt to the market. In turn, profit-seeking firms perceive latent demand and, then, they innovate to materialize it. In this way, firms shape demand and allow for consumption patterns to evolve. Although there are inertias and informational shortfalls on the part of consumers and firms –inertias which are typical in evolutionary models-, firm entry/exit and firm innovations change the supply-landscape, and engender further learning and new behavioural patterns on the consumer-side. In turn, evolving consumption patterns guide firm innovations, and so on. This is the co-evolutionary mechanism underlying the model, and it deploys within a stochastic dynamic network which leads to emergent industry structures.

As we will see, we analyze dynamic paths and emergent stationary states for the level of industrial concentration, the number of producers, the pattern of adoption of innovations, and certain features of the industrial lifecycle through simulations. In Fernández-Márquez et al. (2017a,b) we explain in detail the technicalities of the analysis through which we detect three (non-pecuniary) demand-factors which play key roles in the model: the greater or lesser strictness of consumer requirements (which we call their degree of "insistence"); the degree of locality in social learning (which determines demand fragmentation and resembles "homophily"); and the "loyalty" of consumers to firms. In the present paper, we show how these factors engender (demand-driven) competitive advantages, and lead to significant non-linearities in the sectoral dynamics. Furthermore, we highlight how essentially spatial parameters (consumer insistence and affinity), and the intertemporal uneven inter-firm accumulation of consumer loyalty, interact, thus turning out to be crucial in market evolution.

On other side, *regarding stationary states*, let us say that the model generates a continuum of limit industrial structures (from perfect competition, to oligopolies, duopolies or monopolies), with said demand-parameters being crucial in generating path-dependet evolutions and specific stationary structures. We believe that these results add to *neoclassical and evolutionary previous insights* on the determinants of market concentration (Tirole, 1988; Geroski, 1994; Sutton, 1998; Malerba and Brusoni, 2007).

To sum up, we can assert that the model highlights demand-side factors underlying market concentration which add to the *technological* (increasing returns, learning cumulativeness); *strategic* (collusion); and *institutional* (patents; entry barriers; supporting institutions) determinants in the literature. Our model highlights the importance of analyzing market dynamics as resulting from a *demand-supply* co-evolutionary process. We will show how this approach opens new lines for future research.

The paper is structured as follows: in Section 2, we present the model. In Sections 3 and 4 we analyze the model through simulations, and we determine the effects of the demand parameters and of the co-evolution of demand and supply on the stationary states and upon the transitory dynamics. We show how consumer insistence, loyalty and the locality of learning influence firm behaviour which, in turn, shape evolving consumption patterns. Co-evolution brings about different degrees of market concentration and distinct sectoral dynamics in the model which emerge from alternative settings. Finally, in Section 5, we summarize the main conclusions and suggest future research lines.

2. The model

2.1. Overview

We present an agent-based model (Tesfatsion, 2002; Di Guilmi et al., 2017) for a discretionary consumption sector (bottled-beer, wine, cosmetics, entertainment, consumer electronics, etc), in which –on the one hand- *demand* is partially-shaped by innovative firms which try to induce, discover and satisfy latent needs, and, -on the other hand- active consumers enjoy firm innovations, create new niches, get involved in social learning, and select among innovative firms thus shaping *supply*. This co-evolution process develops in our ABM within a (stochastic) complex evolving network. For expositional clarity, we follow Pyka and Fagiolo (2007) to present the model:

Time: The system evolves in discrete time units, that is $t = 1,2,3, \dots$

Agents: The system consists of an evolving supply-side formed by a variable (entry/exit) number of productive innovative firms; and an evolving demand-side composed of active consumers (in the sense of Bianchi, 1998). The population of potential consumers is made up of a constant set of individuals $C = \{C_1, C_2, C_3, \dots, C_N\}$, $\text{card}(C) = N$; the population of producers is initially $P(0) = \emptyset$ and it is formed over time by firms entering and exiting.

Microstates: On the one hand, each firm (*producer*) $P_i(t) \in P(t)$ is characterized by the particular variety of a given product (the consumption good) that she offers. This variety can be represented by its characteristics in the *n*-dimensional plane. The value for each dimension represents the degree to which a specific product-variety (firm) satisfies every single characteristic. All dimensions are re-scaled to [0,1]. Thus, each producer/firm $P_i(t)$ is characterized by a state vector $p_i(t) = (p_{i1}, p_{i2}, \dots, p_{in})$ in the space of characteristics.
We assume that firms can satisfy any level of demand at hedonic prices (price and unit costs increase with characteristics; we deal with prices implicitly, so that we can focus on non-pecuniary dimensions of consumption; see Chai, Earl and Potts, 2007). For simplicity, we assume that the unit-profit is constant and common over firms (we may think of a typical sectorial unit profit); thus, *any difference in profits will be attributable to the number of consumers that each firm attracts at t*.

On the other hand, *market demand* is represented in the *n*-dimensional plane so that each consumer $C_j \in C$ is characterized by a state vector $c_j(t) = (c_{j1}, c_{j2}, \dots, c_{jn})$ in the space of characteristics that represents a desired consumption pattern. Each dimension represents the level of each characteristic desired by consumer *j* at time *t* (no matter whether there exists this offer in the market, or not). Thus, (e.g.) for the case of bottled-beer, we can consider four characteristics (Rabin and Forget, 1998): bitterness (measured in the IBU scale); strength (in the Plato scale); alcohol (in percentage by volume); and color (in the Lovibond scale).

Consumers would be placed (according to their tastes) in the characteristics space and these desires will evolve.

Parameters: From the *demand-side*, apart from the number of consumers (N), and the parameters related to learning and consumer innovation (subsection 2.2 below), we introduce two parameters here: the radius for the consumer buying-process $r \geq 0$ (degree of consumer "insistence" related to inertias in choice); and the discount rate on brand image δ (which we will relate soon to consumer "loyalty").

Regarding the *supply-side*, we have (as we will see later): q, the probability of firm exit (a producer may exit when sales are below some minimum level); λ, the distance that each producer can move in one period (capturing firms' innovative capacity. This parameter captures the dynamic capabilities of firms); K, the autonomous brand image (visibility of a producer who has not made any sales); M, entry-barriers. This parameter is related to the specific technological regime and the institutional conditions prevailing in the sector; and σ, the degree of market opaqueness (imperfect information in entry). All parameters are defined on [0,1].

In the simulations, we start out from an initial setting in which the *demand-side* is formed by N uniformly distributed consumers, while the *supply-side* contains no producers. At any t the processes described below occur.

2.2. Consumer social learning and demand change

The space of characteristics is defined as $S = [0,1]^n$ and it is populated by N consumers. At time t, each consumer C_i is represented by a vector $c_i(t) \in S$. We interpret the *Euclidian* distance between the positions of two consumers in S as an indicator of the *social distance* between them (difference between their desires, tastes). It is remarkable that we conceive consumers as active agents in the sense of Bianchi (1998; 2007), so that they explore and figure out consumption possibilities in the characteristics space. Our consumers, despite of being boundedly-rational (inertias), have a clear taste for novelty; they continuously update their behaviour. Formally, we put forward three hypotheses regarding *consumer social-learning dynamics*:

i) *Locality of consumer learning*: The probability that two consumers as active agents may interact is greater the more similar they are (our interpretation of homophily/affinity). Given two consumers C_i and C_j (located at $c_i(t)$ and $c_j(t)$), and given the social distance between them, $d_{ij}(t)$, the probability that they interact is:

$$P_{ij}(t) = P_{ji}(t) = \left(1 - \frac{d_{ij}(t)}{d_m}\right)^{\alpha},$$

where d_m is the maximum distance between two consumers in the space of characteristics, and $\alpha \geq 1$ is a parameter capturing the degree to which affinity affects the probability of interaction (a mechanism resembling homophily, being interpreted as the degree of locality in social learning). Thus, given a distance, a smaller α (less required affinity) implies a greater probability of interaction between distant consumers. Small values of α can also be interpreted as representing a high degree of consumer capacity to explore distant (non-affine) consumption patterns; in this way, a very small α indicates an intense consumer taste for (eventually) enjoying distant areas of the prevailing distribution of consumption patterns.

ii) *Influence/degree-biased attraction*: if any two agents interact, we assume that they approach each other becoming more similar. Thus, they learn from each other, but we assume that the better-connected (more visible) agent induces greater attraction. More precisely, let $V_{j/i}(t) \in (0,1)$ denote the visibility of consumer C_j relative to that of C_i (given by the relative proportion of interactions at *t*); we consider that the movement of C_i towards C_j at *t*, takes place along the segment that joins the two points $c_i(t)$ and $c_j(t)$:

$$c_i(t+1) = c_i(t) + m_{ij}(t) \cdot \left(c_j(t) - c_i(t)\right), \quad \text{where}$$

$m_{ij}(t) \in (0, d_{ij}(t))$ is $m_{ij}(t) = \left(V_{j/i}(t)\right)^{\beta} \cdot d_{ij}(t)$, and $\beta \geq 1$ is a parameter fixing the intensity of gradual imitation (that is, the speed of social learning). The same applies to the movement of C_j towards C_i. Notice that, both, affinity and influence-based learning are well-known stylized empirical features observed in consumer behaviour. As Bianchi and others (2007) show, the "activity" of innovative consumers updating their behaviors usually deploys along these lines.

iii) *Innovation in consumption*: Consumer desires can undergo random changes because of factors different from social learning (e.g. because of an intense taste for radical novelty). We assume that consumer C_i, placed at $c_i(t)$, may decide to change (with probability $p > 0$) towards a different position $c_i(t+1)$ in the characteristics space, which is calculated from a random variable with continuous uniform distribution on $S = [0,1]^n$. This is another assumption crucially inspired by Bianchi (1998) and her followers. As it is the case with innovative firms, consumers in our model can move even to unexplored areas of the characteristics space, opening the way to firms that may (or may not) take advantage of these opportunities. Market as a discovery process in the model develops as a supply-demand co-evolutionary process.

Thus, given hypotheses i), ii) and iii), consumers update their desires (via social learning, or via innovation in consumption) bringing about the emergence of *market niches*. These niches are made of consumers with similar tastes (identified by the usual hierarchical cluster analysis). The set of all clusters is denoted $G(t) = \{G_1(t), G_2(t), G_3(t), \dots\}$; $\text{card}(G(t))$ is the number of clusters, $\text{card}(G_i(t))$ is the number of consumers in each cluster, and $g_i(t)$ is its center. For simplicity, we assume that our partitions are mutually exclusive, so that it happens that $G_i(t) \cap G_j(t) = \emptyset$ for $i \neq j$, implying that $\text{card}(\bigcup_i G_i(t)) = \sum_i G_i(t) = N$.

In what follows, and as an illustration of the process we are proposing, we will refer to *Figure 1* in which we show a specific simulated *market evolution* emerging from our model, for a two-dimensional characteristics space. Figure 1 clearly represents the market discovery process developing as a result of the co-evolution between demand and supply. We have already explained some features (still not all the mechanisms) of demand evolution. Later on we will move to supply. But let us begin illustrating our conception of demand-supply co-evolution by representing in Figure 1 with *black small Circles* the distribution of desired characteristics by heterogeneous consumers, with the population of consumers being observed at different times of the simulation (t=0; t=40; t=80; t=120). On the other side, *white squares* represent *firms* placed in the characteristics space according to the varieties they produce at any time. Finally, the lines represent social interactions among consumers representing the mechanisms already explained above.

Figure 1 shows the gradual entry and exit of firms (squares), as well as the transformation of a social network of interactions among consumers (circles) and, as we will explain below, among consumers and firms. In order to fully understand the supply-demand co-evolutionary process which the endogenous emergence of market niches (clusters), its disappearance, or the splitting and the merging of former clusters, we are going to explain now how consumers "buy" (make their consumption choices), and how firms enter, innovate and –eventually- exit if they do not attract and/or maintain customers. As we see in the four pictures of Figure 1, *circles* and *squares* (consumers and firms) co-evolve in the market. For instance, see the initial departure point (t=0) in which we show the latent demand possibilities at time "0"; see (in the second pinture for t=40) how the morphology of demand is gradually appearing thus attracting and being shaped by the firms (squares); observe in the third picture (t=80) how some niches appear while –because of the role of supply in providing (or not!) what is desired- certain areas in the space remain unattended; and finally (for t=120) we can see the emergent stationary structure of the market.

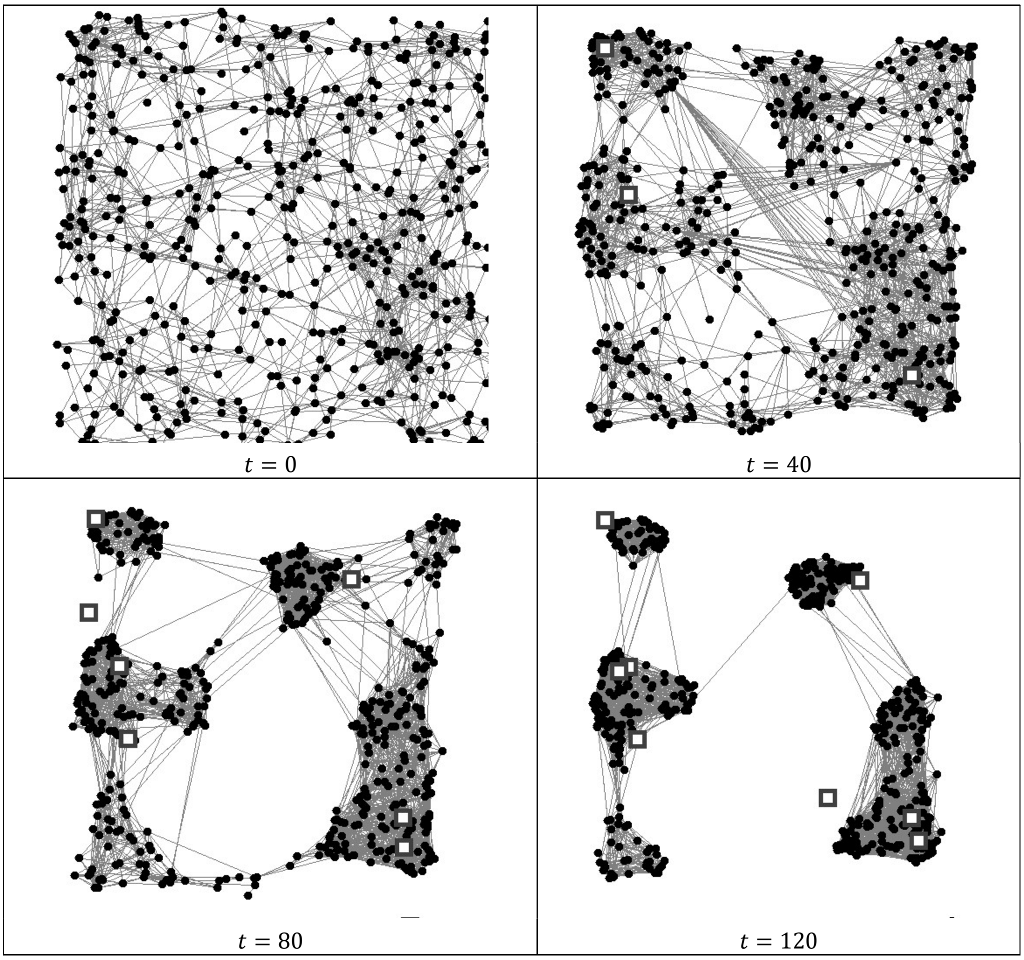

Figure 1. Co-evolution of demand and supply over the characteristics space

Consumer choice: We now define consumer (boundedly-rational) choice. That is to say, after having posed above the dynamics which explain in the model consumer innovation and social learning, we are going to define now the process through which each consumer decides which particular variety of the consumption good she wants to buy at *t*. This new mechanism ("buying") together with firm behaviour (below) and the taste updating mechanisms (above) will provide us with a complete description of the process driving Figure 1 (and the simulations in Sections 3 and 4). Thus, we assume that consumers consider that only those varieties lying within a distance "$r > 0$" from their current position are suitable to be bought. This is what we mean by "insistence" (inertia) in consumption. Then, from the potential firms placed within radius r (if there are any, i.e. firms may leave unattended areas in the demand-space), each consumer makes a random purchase of a single unit, from a specific firm within his/her radius, with a probability that is proportional to the brand image of each firm. We define the instantaneous brand image of firm P_j as:

$$I_j(t) = K + \sum_{i=1}^{t} \delta^{i-1} \cdot v_j(t-i),$$

where K is the autonomous brand image, δ is a discount rate or memory-effect resembling consumer "loyalty", and $v_j(t-i)$ denotes firm sales at period $t-i$. The dynamic gestation of $I_j(t)$ is a key intertemporal process which, together with the "more spatial" parameters explained above, drive consumer choice and, as we will see, firms' evolution.

2.3. Production, firm entry-exit and firm innovation

We assume that firms carry out three actions (apart from producing and selling): i) market entry; ii) innovations in which firms adapt to, and, at the same time, conform and shape the morphology of demand; and iii) eventually, market exit.

i) *Market entry*: We assume that, at most, one fim can enter per period; the new firm will choose as its *target* one of the consumption clusters. We assume that the potential entrant decides whether or not to enter with an endogenous probability that depends upon the firm's expectations:

$$p_{entry} = \sum_{\substack{G_i \in \mathrm{G}, \\ \mathrm{card}(G_i) > 0.05}} M \cdot \frac{K}{K + \sum_{P_j \in P_{G_j}} I_j} \cdot \frac{\mathrm{card}(G_i)}{N} = \frac{M \cdot K}{N} \sum_{\substack{G_i \in \mathrm{G}, \\ \mathrm{card}(G_i) > 0.05N}} \frac{\mathrm{card}(G_i)}{K + \sum_{P_j \in P_{G_j}} I_j},$$

where G is the set of all clusters (we only add up upon relevant clusters $\mathrm{card}(G_i) > 0.05N$); M depends on entry barriers; K is autonomous brand-image; $\mathrm{card}(G_i)$ is the number of consumers in G_i ; and P_{G_j} is the number of firms that have sold to cluster G_j in the current period. The probability of entering into G_i depends on the expected market share:

$$M \cdot \frac{K}{K + \sum_{P_j \in P_{G_j}} I_j} \cdot \frac{\mathrm{card}(G_i)}{N} = M \cdot \text{expected\_market\_share}.$$

Thus, a market can be "not very attractive" because all the niches are already attended by firms with significant image; or because demand is very fragmented (small niches). Once a firm has made a decision on its entering location, we assume that it ends up entering into a *neighborhood of the target* G_i , (i.e.) we assume imperfect information but also, technological restrictions and/or specific firm strategies and contingencies which influence the decision regarding the final place (within the characteristics space) in which each firm decides to settle. Of course, this location is a supply-side choice which constraints and shapes strongly which consumer desires are going to be finally satisfied, which specific exchanges may take place, and the final materialized structure of market demand. Depending on the opaqueness of the market and technological/strategic contingencies, measured by parameter σ, the new entrants will decide the exact entry place. The firm will enter to a position calculated from a normal distribution with mean the center of the cluster (g_i), and standard deviation σ.

ii) and iii) *Market exit or incremental innovations:* Those firms that, in period *t*, do not reach a minimum level of sales (5% of total consumers *N*), exit the market with probability *q*. With probability $1-q$ they innovate and adapt their product variety to the closest cluster. This adaptation implies a reduction of the distance $d(p_j, g_i)$ between the position of the firm p_j, and that of the center of the closest cluster (g_i). The reduction will be: $\min\left(\lambda \cdot d_{\max}, d(p_j, g_i)\right)$, where $d_{\max}$ is the distance between the two most distant points in the characteristics-space. Parameter λ represents the capacity for firm innovation (depending on sectoral technological opportunities, dynamic capabilities, institutional constraints or firm inertias).

2.4. Aggregate variables at the industry level

We are interested in the dynamics of the following aggregate variables at the industry level:

i) The number of producers in the market: $\Pi = \mathrm{card}(P)$.

ii) Sectoral adoption, that is to say, the proportion of potential consumers that already buy the good: $\Lambda = \frac{1}{N}\sum_{P_j \in P} v_j$.

iii) The Herfindahl index, *H*, which measures the degree of market concentration:

$$\frac{1}{\mathrm{card}(P)} \leq H = \sum_{P_j \in P} s_j^2 \leq 1,$$

where s_j is the market share of firm P_j in the period under consideration. If $H \approx 0$, the industrial structure approaches perfect competition; if $H \approx 1$, there is a monopoly.

3. Simulations and Dynamics

In order to carry out the computational analysis of the model, let us say that our ABM-computational model has been developed on JAVA employing the REPASTJ ABM framework (version 3.1). Data from simulations were statistically analyzed using PROJECT-R. Although our model includes a significant number of parameters, in Fernández-Márquez et al. (2017b) we have proved that only three of these parameters play a key role for our purposes (we follow the so-called KIDS strategy; Pyka & Fagiolo, 2007). These parameters are: α, *r* and δ. We now study the effects of these parameters upon the sectoral aggregate variables. That is, we analyze the influence that: affinity required for social learning; consumer insistence; and loyalty have on the sectoral asymptotically stationary states, and on the transitory dynamics of the system. In what follows, we shall report and comment upon the properties obtained from the simulations.

3.1. Asymptotic study

The first property that we find is that consumer "insistence", as defined by *r*, generates two types of firm advantages that affect the asymptotic number of producers and market concentration. Thus, when the level of insistence is high (*r* is low), that is to say when consumers are very inertial and not very active in the sense of Bianchi (1998, 2007), it is difficult for firms to gain access to consumption clusters. Therefore it emerges a significant advantage for those firms who are the pioneers in access.

This advantage weakenes as the insistence of consumers decreases (higher values of *r,* indicating more active and permeable consumers). Interestingly, for medium values of *r*, we find privileged locations that are not always noticed by firms. This happens when the radii of several clusters overlap. In this settings, it is crucial the strategic ability of firms. In fact, those firms which manage to innovate and adapt their products, thus attending the zones privileged by latent overlapping demand-clusters, earn an advantage from location, and they increase their market shares and profits. It is remarkable that this firm-advantage from strategic location is at its maximum, when the size of the inter-cluster areas is such that one and only one firm can exploit them. In this case the number of producers in the asymptotic state is minimized, and industrial concentration is maximal. On the other side, if we were to reduce insistence (higher *r*), then the locational advantage weakenes until it (eventually) disappears; then, the market becomes global and location is irrelevant.

Figures 2 and 3 show the asymptotic number of producers, and the asymptotic level of market concentration for different parametric values.

As we see, both Figures 2 and 3 show that moderate levels of *r* lead to a very significant reduction in the number of producers, and to an increase in industrial concentration (with parameter α strengthening the intensity of the *r*-effect). On the other side, in both figures we can see that, by changing the parameters, the model generates a continuum of asymptotic industrial structures (in number of firms and considering the Herfindahl index): monopoly, oligopoly with a dominant firm, conventional oligopoly, and a variety of levels of concentration that approximate perfect competition. The model can also generate non-typical structures (such as markets that are partially or totally unattended).

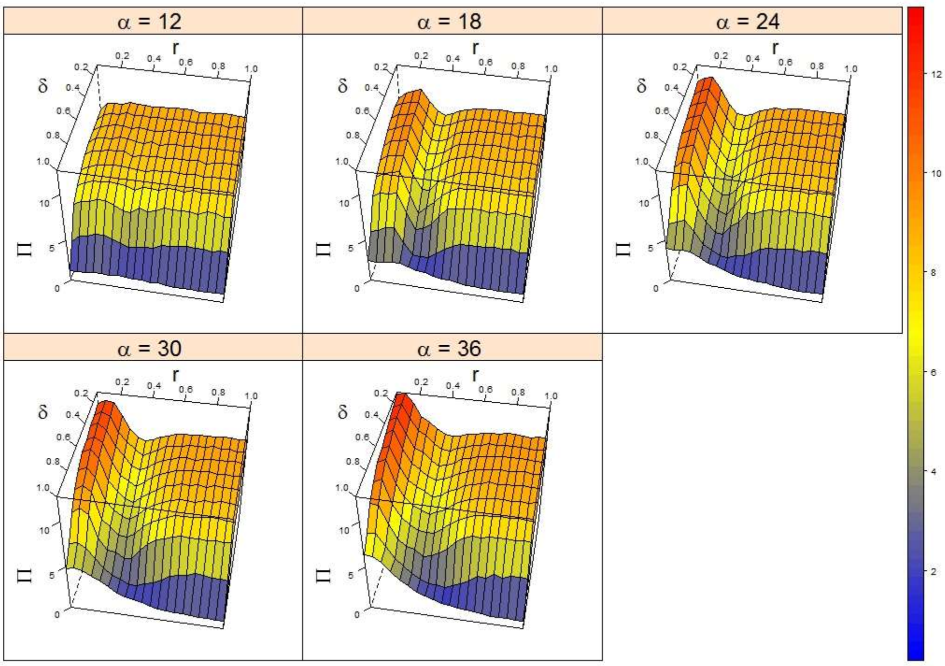

Figure 2. Number of firms as a function of loyalty and insistence, for different levels of affinity

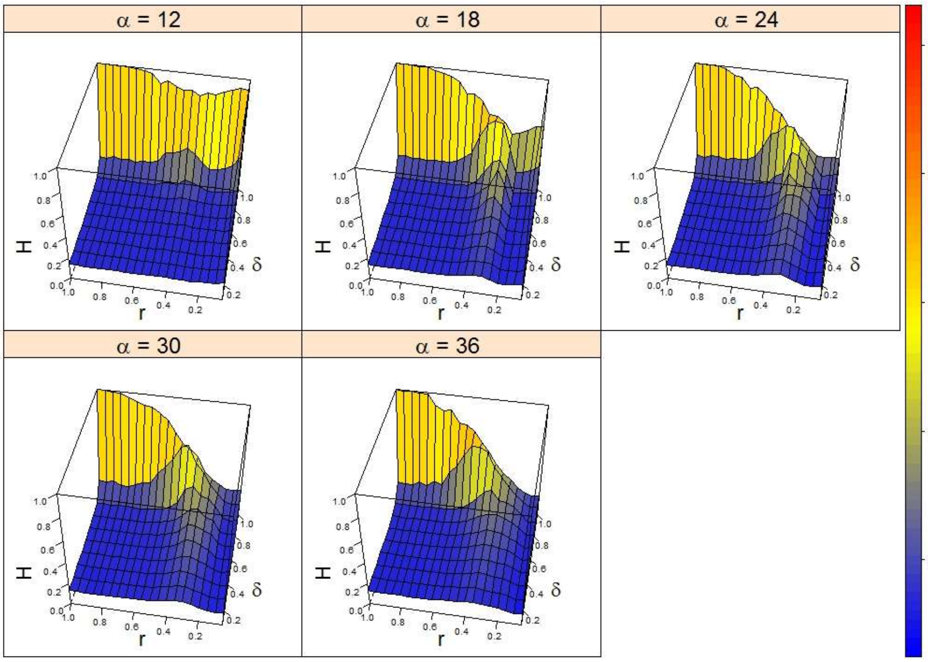

Figure 3. Industrial concentration as a function of loyalty and insistence, for different levels of affinity

All of the industrial structures that are obtained can be explained as emergent properties from the co-evolution between changing demand, and the innovative (and strategic) capacity of certain firms which take advantage of latent advantages. In general, let us remark that attractiveness, profitability, and the specific materialization of supply-demand exchanges in our model emerge, endogenously, from the co-evolutionary dynamics of the system. Firm rivalries evolve depending on the emergent cluster-topography of interactions, which is determined, indirectly, by the three demand parameters and firm innovative entry and product adaptation.

Finally, Figure 4 shows that, outside of certain extreme cases, the level of adoption always reaches (approximately) 100% when the system becomes stationary.

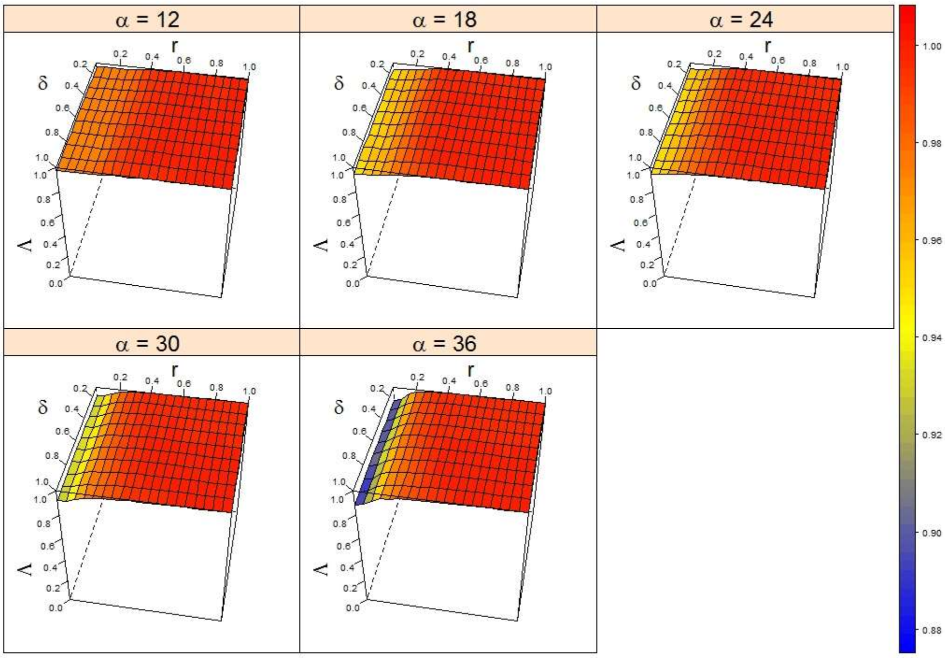

Figure 4. Rate of adoption as a function of loyalty and insistence, for different levels of affinity

3.1.1. The effect of r

The 3D graphs above have given us an initial idea of the effect of *r* and of the interrelationships between the parameters. We will now look into these effects in more detail. Note in Figures 2 and 3 (and also in Figures 5 and 6 below) that the effect of *r* upon the asymptotic state is not linear. In Figures 5 and 6, we can see that the effect of *r* upon the asymptotic number of producers has an initial phase of growth; then a contraction phase in which a minimum is reached; a third phase in which the number of firms increases again; and a final phase in which it stabilizes. In Figure 6 we show the corresponding phases of contraction, growth, contraction and stabilization in the industrial concentration index (*H*). As we have already mentioned, this property is generated by two mechanisms: firstly, when consumer insistence (inertia) is high (*r* is small, indicating low permeability of consumers to novelty, low consumer "activity" in the sense of Bianchi, 1998), then, only those firms which have strategically and technologically managed to enter near a particular cluster, have the opportunity to innovate in an adaptive way to capture enough customers before they are forced to exit. Thus, they can avoid bankruptcy. This specific effect is weakened as the radius increases (consumers are less insistent and more phrone to explore new options).

Secondly, if we consider higher and higher values for *r* (lower inertia, higher taste for exploration and discovery in consumer behavior), we get overlapping consumer radii in different clusters. Then, firms which have strategically and technologicaly targeted these intersections will have access to more consumers, and, eventually, will capture a larger market share. This advantage is maximal when just one producer can exploit it, that is, when the intersecting areas are sufficiently small. From these combined effects it follows that the intensity of specific firms' advantage initially grows, reaches a maximum, and then decreases until it fades away at the point at which all consumers can be attended from any position, that is, when the market is global (*r* very high).

3.1.2. Joint analysis of r and α

Figures 5 and 6 also help us to understand how the *r*-effect interacts with α. We need to bear in mind the four phases of the *r*-effect. We have already seen in Figures 2 and 3 that the *r*-effect gets intensified as α increases. Higher levels of α shorten the first section of the graph for the asymptotic state, because the more local consumer social learning is (more required affinity), the smaller the distance between neighboring clusters becomes. Likewise, the convex section of the graph is lengthened, because the distance between the clusters that are furthest apart gets larger with high α, which leads to the market becoming global for large values of *r*.

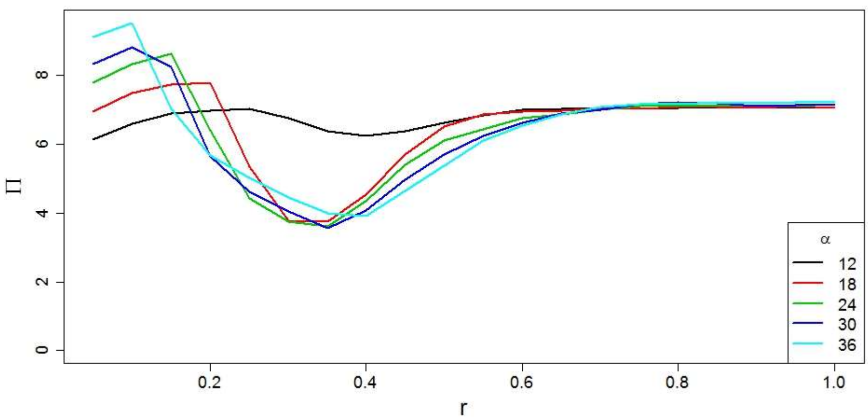

Figure 5. Asymptotic behavior of the number of producers as a function of *r*, for different levels of affinity

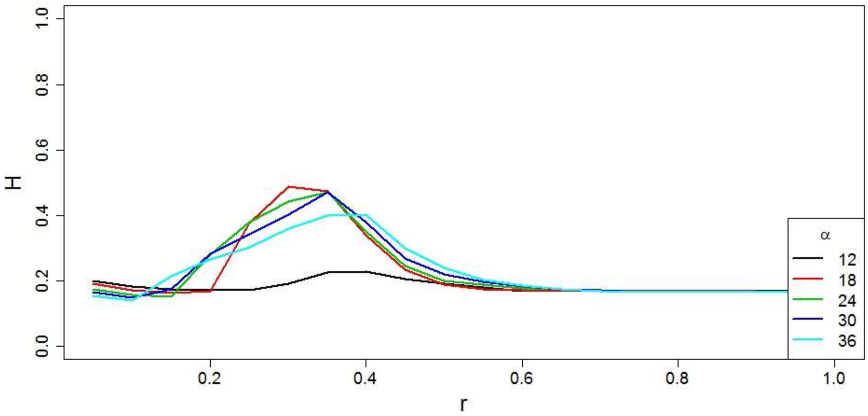

Figure 6. Asymptotic behavior of industrial concentration as a function of *r*, for different levels of affinity

Figure 6 supports what we have just argued: when the fragmentation of demand increases, the firms' advantage from targeting the correct location appears earlier. A more fragmented demand leads to a higher level of consumer dispersion, so that higher values of *r* (lower consumer inertias) are required to eliminate the (by-firm location) competitive advantage.

3.1.3. Joint analysis of r and δ

Figures 7 and 8 show the existence of an interaction between *r* and δ that is only perceptible for $\delta \geq 0.9$. High consumer loyalty leads to a fast increase in brand image; this explains why a firm that, eventually, obtains a small advantage in image, ends up taking control of the industry. When δ is very large, the advantage from being the pioneer in a zone eclipses any other factor. Somehow paradoxically, this is especially drastic as *r* increases; that is to say, when consumers are phrone to explore far options. In these cases, the market becomes global fairly quickly, and the early dominant firm (often the initial *pioneer*) ends up with an absolute advantage.

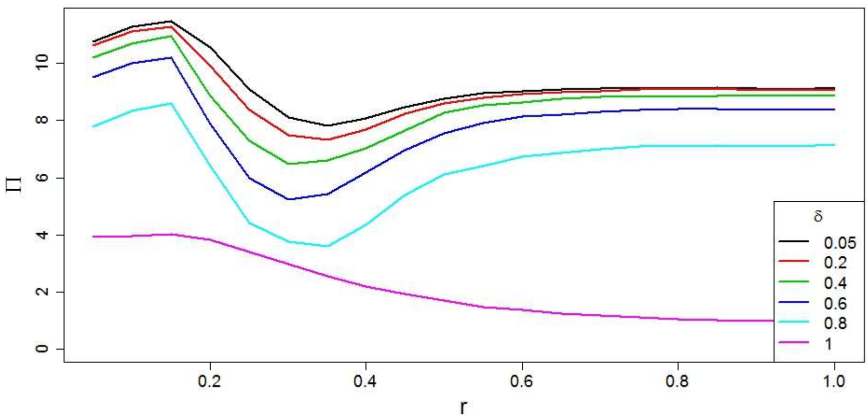

Figure 7. Asymptotic behavior of the number of firms as a function of *r*, for different levels of loyalty

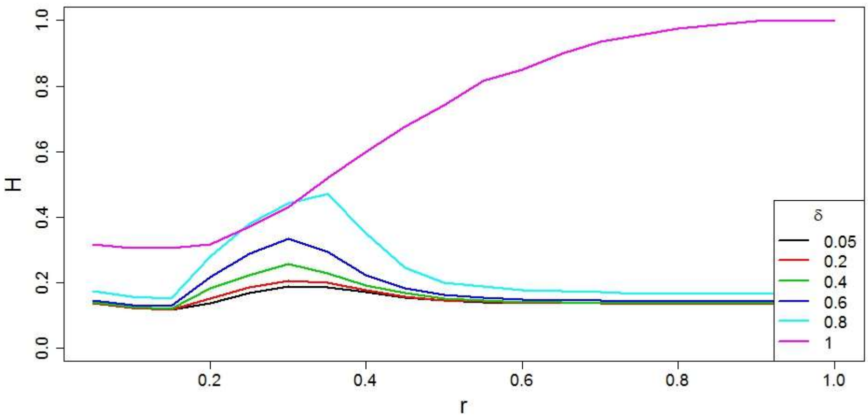

Figure 8. Asymptotic behavior of market concentration as a function of *r*, for different levels of loyalty

3.2. Analysis of the transitory dynamics

Up to now we have studied the system in its stationary states. Now we move on to the properties of the transitory dynamics of the model as regards the three crucial parameters. For simplicity, we asume that the industry reaches maturity when the rate of adoption, the number of firms, and market concentration all have stabilized.

3.2.1. Probability of entry

In general, the simulations reveal that the evolution of the entry rate is closely related to what would be expected during an industry life cycle. We can sum up our results on the dynamics of the probability of entry, and its interaction with supply-demand co-evolution, as follows:

i) The entry probability grows while demand is in the process of formation (clusters are emerging); afterwards, the entry probability decreases asymptotically approaching zero.

ii) If the consumers are very insistent (low *r*, indicating not very “active” pro-discovery consumers), the entry probability can remain positive even when the industry has reached maturity.

iii) A greater consumer loyalty leads to a smaller probability of entry, even in a state of industrial maturity.

Figures 9, 10, and 11 show that the entry probability resembles certain patterns of the industry life cycle. As can be seen in those figures, the entry probability is not constant; rather, it is high during the initial phase of the industry, it grows a bit after that, and then, during the phase of industrial development, it falls drastically as firms enter and gain more stabilized positions. The initial growth (which is not always visible) is due to the fact that demand is still evolving and creating clusters, which makes the industry more attractive. Nevertheless, the probability of entry ends up falling since, as the clusters become consolidated and well attended by firms, the incumbent firms increase their brand image over time, and they improve it even more as compared to new entrants.

In Figure 9 we see how the parameter *r* influences the evolution of the entry probability. The higher the consumer insistence and inertias (low *r*), the more probable it is that unattended niches exist, which leads to a greater probability of entry. In general, the probability follows a decreasing trend; but if *r* is very small, the firms attending small clusters may not reach a mimium share and, then, they can exit, thereby opening space for new competitors. This the reason why we observe in Figure 9 that, when *r* is low, the entry probability is quite high, even in the state of industrial maturity.

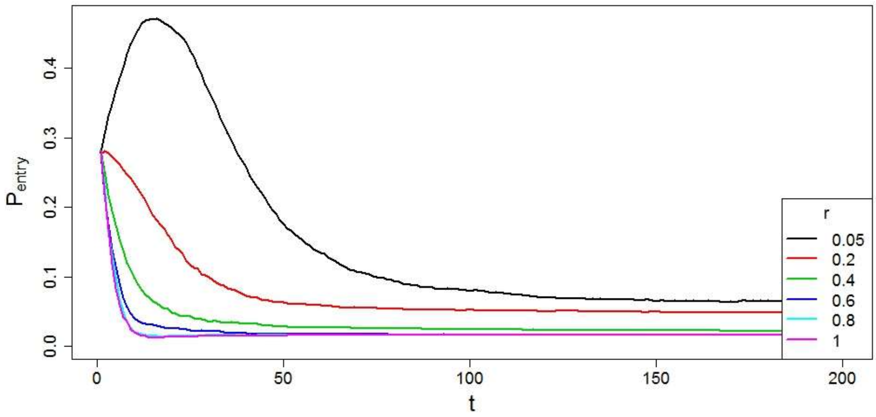

Figure 9. Time evolution of the probability of entry, for different levels of *r*

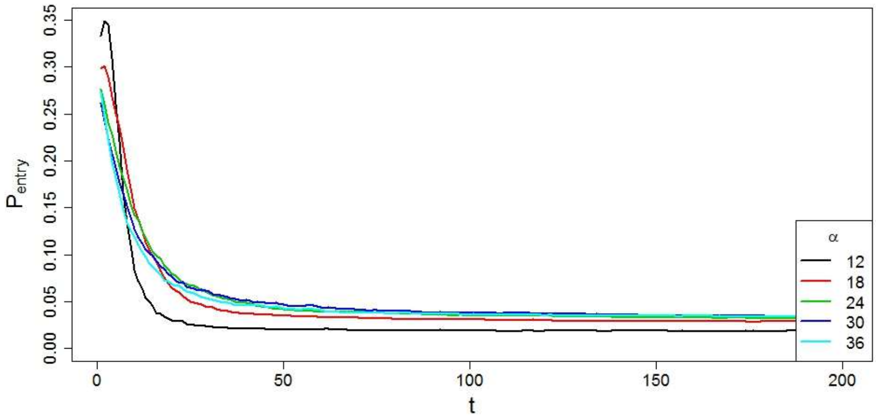

Figure 10. Time evolution of the probability of entry, for different levels of affinity

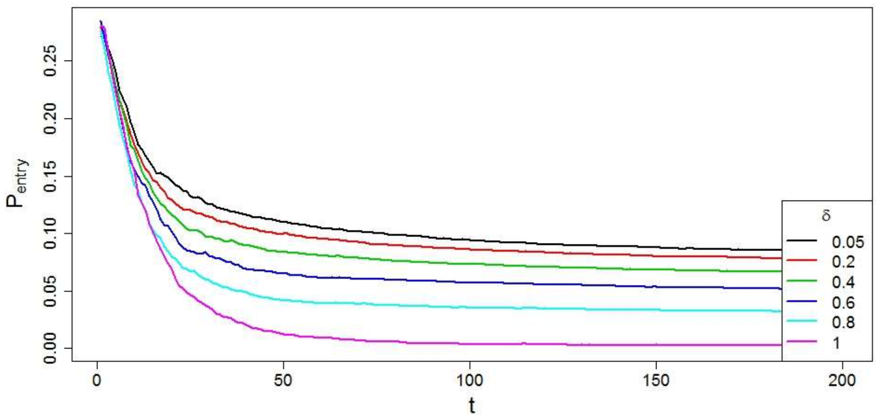

Figure 11. Time evolution of the probability of entry, for different levels of loyalty

Now, looking at Figure 10, we can affirm that the probability of entry only depends on α during the initial industry stage, and it gets almost independent of α after that. Logically, if α is low (low level of locality –low degree of homophily- in consumer learning), almost all of the clusters that emerge are sufficiently large and attractive for firms to enter. As α increases, small niches begin to appear, which diminishes the attractiveness of entry. If α were so large that no representative clusters could exist, then the probability of entry would be zero.

Figure 11 shows how δ influences the probability of entry, even when the level of adoption is high (industrial maturity). In so far as all of the market is attended, high values of δ lead to a lower probability of entry; this is so since the higher the consumer loyalty to the incumbent firms, then the narrower the windows of opportunities for new entrants.

3.2.2. Level of adoption

Figure 12 shows how the level of adoption dynamics. Some parameters can slow down the convergence to market saturation, and even reduce the level of adoption finally reached by the industry. If consumers are very insistent and inertial in habits (low *r*), producers take longer to adapt to their demand desires; in this case the level of adoption grows more slowly, and some extreme niches, which are of low comercial interest, are never attended.

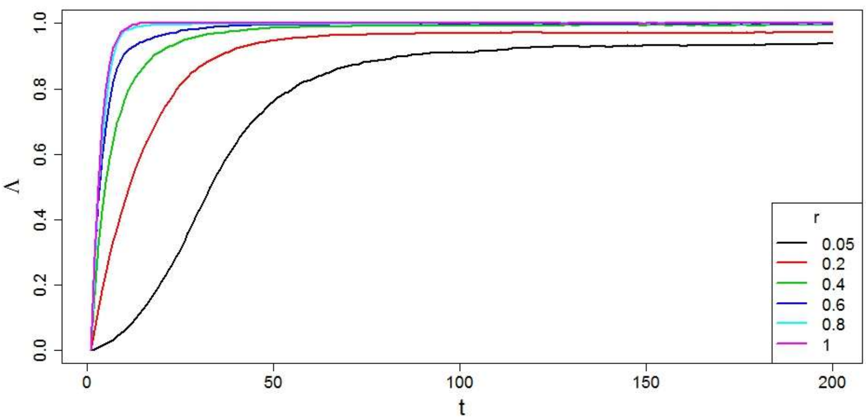

Figure 12. Time evolution of the rate of adoption, for different levels of *r*

In Figure 13 we present a surprising result: consumer loyalty has no influence neither in the speed of adoption, nor in the level of adoption that is reached. Just like *r*, parameter α influences the speed of diffusion, but not the market potential (Figure 14). The reason is that a less fragmented demand, which can be atended by a standard firm, facilitates diffusion.

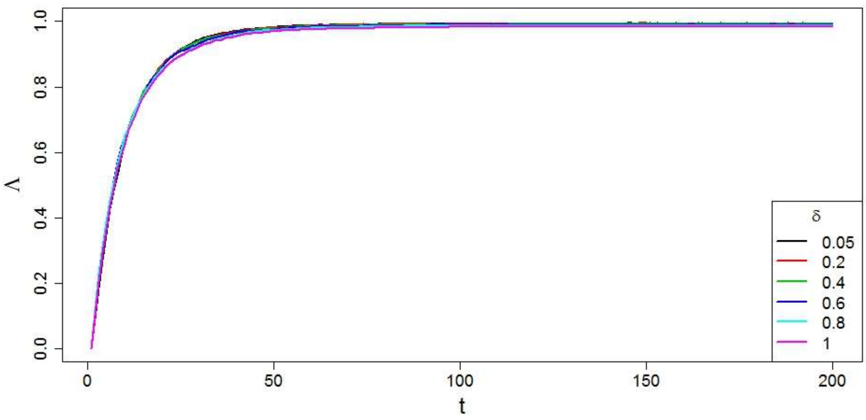

Figure 13. Time evolution of the rate of adoption, for different levels of loyalty

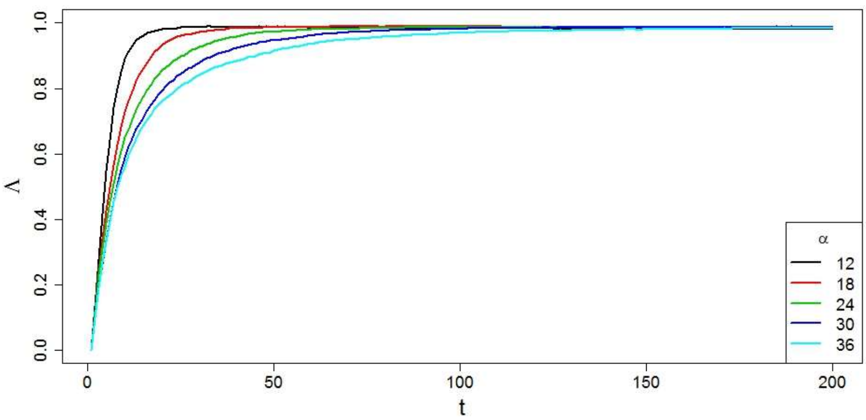

Figure 14. Time evolution of the rate of adoption, for different levels of affinity

3.2.3. Number of producers

We now turn to the evolution of the number of producers. In Figure 15 we can see how the parameter r not only influences the number of producers in the stationary state, but it also determines the velocity of maturity. As has been mentioned above, there are different ways to reach a given (or similar) stationary state. For example, a small radius like $r = 0.2$ and a very large radius like $r = 1$ both converge to a similar result; however, they would follow very different transition processes. In our model, the industry reaches maturity slowly if the consumers are highly active and phrone to try new options (high r), which in principle might seem to be counter-intuitive. The explanation is that, the higher the activity of consumers in trying new things, the longer the time during which firms keep actively competing and innovating, and the industry remains fully alife.

The change in the speed of the industry life cycle is not linear. There is a sudden change in phases after which the speed slows down drastically, as is shown by the late arrival of maturity for $r \geq 0.6$. The reason for this can be found in the divergence that happens between the firms' expectations and what actually occurs when the market is global (very high r). In such a case, all the firms can gain access to any consumer cluster, and a gap occurs between the set of consumers that are expected, and those (many more) that actually end up purchasing. Since firms enter the market depending on expected demand, there is not much of an incentive (in principle) and firms enter slowly. Nevertheless, those firms that enter the market find, to their surprise!, that they sell much more than expected, and they can survive without being expelled from the market. This attracts and increases the number of firms, as shown in Figure 15.

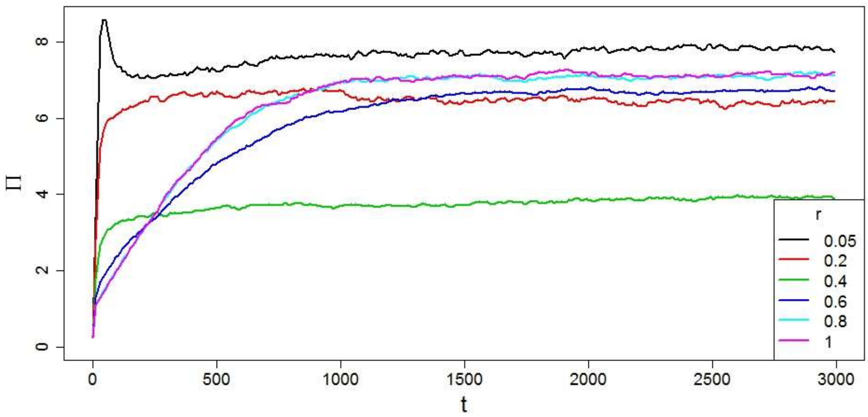

Figure 15. Time evolution of the number of producers, for different levels of *r*

Regarding the parameter δ, there is nothing special other than what has already been mentioned with respect to the stationary state. As regards the locality of learning, we only note that a low α is another way in which industrial maturity may be delayed (Figure 16).

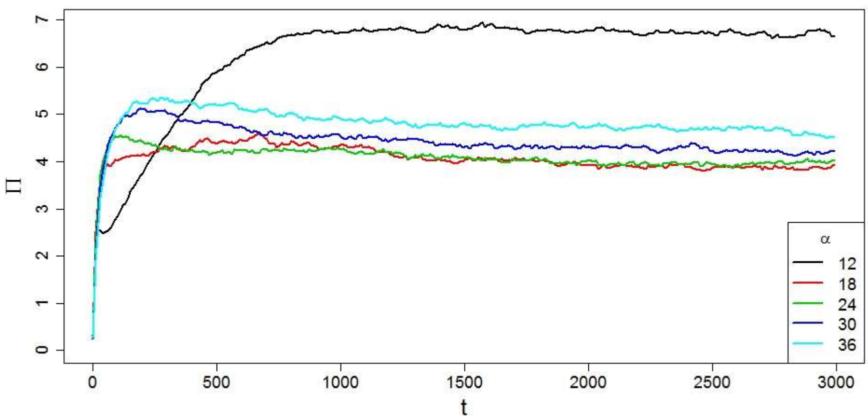

Figure 16. Time evolution of the number of producers, for different levels of affinity

3.2.4. Industrial concentration

Finally, we present Figure 17 in which we can see the evolution of the level of industrial concentration and its sensitivity to *r*. Recall that when *r* was high, the number of firms underwent a gradual growth. Now we see that, as the number of firms increases, the industrial concentration decreases. For large radii (highly active consumers) specific firms' advantage disappears, and even the latter competitors have opportunities in the market. For that reason the level of industrial concentration falls. These results appear for all values of α that were considered and for $\delta \leq 0.9$; if $\delta > 0.9$ then there is a tendency towards a monopoly.

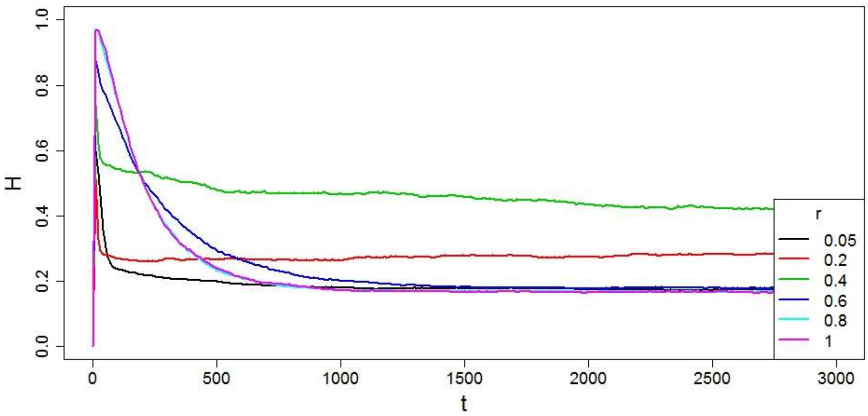

Figure 17. Time evolution of market concentration, for different levels of *r*

4. Industrial structures and demand-supply co-evolution

A continuum of industrial structures emerges from the model when two aggregate variables– the number of producers and market concentration – which emerge from the co-evolution of supply and demand in the market, are considered against one another. We would like to briefly highlight in this section that the model can endogenously generate an infinite number of emerging industrial structures; thus, as a subset of the continuum, we find the traditional structures of monopoly, oligopoly with a dominant firm, conventional oligopoly and other structures. Thus, as we will suggest later on, the fact that supply-demand co-evolution in our ABM generates such a large range of industry structures –which are clearly dependent on the specific settings we present-, is a result which may guide future efforts in empirical research.

4.1. Industrial structures during maturity

By taking discrete points along the continuum, we can present a brief summary of the emergent industrial structures. This is done in Tables 1 and 2. The structures that we consider, from lower to higher degree of competition are: monopoly, transition to monopoly (T), oligopoly with a dominant firm (D), conventional oligopoly (C), competition, and maximum competition (M). The stochastic nature of the model does not allow us to establish exactly when a monopoly is reached, since the number of firms is the average of many simulations. Then, in Tables 1 and 2 we just illustrate, in an orderly way, how the model generates changes in emergent industrial structures as a function of the key parameters.

Table 1. Industrial structures according to insistence and loyalty

		Insistence of consumers		
		Extreme	High	Low
Loyalty	High	Oligopoly (C)	Competition	Competition (M)
	Moderate	Monopoly (T)	Oligopoly (C)	Competition
	Low	Monopoly	Competition	Competition (M)

Table 2. Industrial structures according to fragmentacion and loyalty

		Fragmentation of demand		
		Extreme	High	Low
Loyalty	High	Oligopoly (C)	Competition	Competition (M)
	Moderate	Monopoly (T)	Oligopoly (C)	Competition
	Low	Monopoly	Competition	Competition (M)

The model also reproduces an industrial situation that, because of being quite atypical, has traditionally not been of great interest: markets that are unattended by suppliers. The model suggests that such a structure appears in two extreme cases: firstly, it appears when demand is extremely fragmented; in this case no niches are representative, and therefore the industry lacks commercial attractiveness for potential entrants. Secondly, if fragmentation is high, even though not extreme, then firms can enter and survive only if consumer insistence is not too high. If we relax demand fragmentation and consumer insistence, then we obtain structures with a supply that is considerably smaller than demand (markets with supply constraints).

4.2. Industry evolutions

Real industries do not maintain the same market structure during the entire life cycle; rather, they may evolve from a monopoly of the pioneer to other industrial structures that, in general, depend on specific sectorial characteristics. Our study has detected three demand-side factors that crucially affect industry evolution. In our model, almost all of the industrial evolutions emerging from different parametric ranges start off as a monopoly (the pioneer), which is then transformed into other (more competitive) structures (greater number of competitors and/or lower industrial concentration). This is due to the progressive entry of new firms. This process continues until the sector reaches the structure that, depending on the characteristics of the industry, emerges at the maturity stage (see the previous sub-section).

However, certain parametric ranges can lead to atypical industry evolutions, that is to say, to evolutionary paths that we would not expect to appear if we were just considering the mature structure. This happens when the level of insistence is so high that the market becomes global, or demand fragmentation is so low that there is a single niche. In both cases we get the same outcome: initially, the industry has a structure that is less competitive than expected, although when it reaches maturity, it becomes even more competitive than usual. This is due to the late arrival of maturity; thus, the industry evolves slowly towards more competitive structures (see section 3.2 above). Thus, a low level of insistence and/or a low demand fragmentation promote competition at maturity.

Furthermore, the scenarios which end up in unattended markets can also lead to atypical evolutions. Thus, when demand fragmentation is extremely high, we know that firms do not enter, the industrial structure does not evolve, and the market gets unattended. However, when we increase demand fragmentation just a little, some firms enter, and if the level of insistence is very high, they get easily expelled from the market. This temporary sojourn in the market leads to an erratic evolution of the industrial structure that fluctuates randomly between the pioneer's monopoly, oligopoly (when several firms co-exist before being expelled), and a total lack of supply.

5. Conclusions

In this paper, we have developed an agent-based model that, starting out from mechanisms of consumer social-learning and firm innovation, allows us to analyse important aspects of industrial dynamics with emphasis on the endogenous evolution of demand. The results suggest that there are, at least, three novel demand factors which play an important role in the dynamics of certain sectoral characteristics (such as the rates and rhythms of adoption, the number of firms, industrial concentration, and aspects of the industry life cycle). The three demand factors (insistence of consumers, locality of social-learning which determines demand fragmentation, and consumer loyalty) determine the appearance and relative importance of certain firm advantages that produce non-linear patterns of behavior.

In that way, e.g., a low level of consumer insistence (that is to say, a high taste for ongoing novelty on the part of active consumers), and/or a low level of demand fragmentation (relatively few alternative niches), can delay the industrial maturity phase. Likewise, as a general rule, a moderate level of insistence, an intermediate level of fragmentation and a greater level of loyalty, favor the emergence of oligopolies. It is remarkable that the intertemporal positive feedback linking high consumer loyalty, with the early existence of firms capable of detecting and satisfying the topology of consumer needs in the initial industry stages, fosters *the advantage of a few pioneers*.

Likewise, the model generates a *continuum of industrial structures*. The emergence of one type of structure or other crucially depends upon the three demand parameters (insistence, locality of learning and loyalty), as opposed to the standard industrial economics analysis which most often focuses mainly on the supply-side (technological, strategic or institutional factors). In our model, the co-evolution of demand with supply can explain an infinite number of industrial structures, among which we find -as a subset of the continuum- the traditional structures of monopoly, oligopoly with a dominant firm, conventional oligopoly, etc. Other atypical structures, such as markets that are partially or totally unattended, appear.

To close the paper, we would like to suggest some directions for future empirical search:

For instance, our model suggests that when consumers are very insistent (inertial, with strongly delineated tastes and not too permeable to novelties) then, many similar firms can coexist, but they are not direct competitors; competition operates at the level of clusters. This could be the case, e.g., in high-quality wine sectors, where each consumer may accurately know what he/she wants, and many wineries coexist. Notice how a specific pattern of firm behavior (intra-cluster competition) emerges in co-evolution with a demand characterized by a precise consumer profile (in this case, inertial consumers with solid tastes).

On the other side, if consumers are moderately insistent (thus being more prone to new experiences in a highly active way), the market tends towards an oligopoly in which different suppliers target their products to several niches at once, although not in an indiscriminate manner. This could be the case of the medium-sized automobile industry. In that market, the firms that are able to simultaneously satisfy the desires of a diverse set of consumers may enjoy an important advantage. Again, specific firm behaviors (targeting several niches at once) emerge in a co-evolutionary way with demand, mostly driven (in this case) by permeable consumers.

Finally, when the market shows a lack of consumer insistence (perhaps because tastes are still to be formed, and active consumers -in the sense of Bianchi (1998)- are highly open to learn new things), then each firm directs his/her product to all of the consumers. It could be a worthwhile attempt trying to check these suggested links in future empirical works.

Finally, let us suggest future empirical directions of search for the cases of extreme structures: on the one hand, in markets which are just partially attended (with areas of unattended demand), research may look for (demand-side) entry barriers due to high demand fragmentation (leading to the emergence of hardly-detectable latent zones of needs which firms do not discover; or we may also see easy firm-exit resulting from strict consumer insistence). On the other hand, when consumer loyalty is very high, we should find oligopolic structures, or even monopolies if consumers are not very insistent. Clearly, this is the case (as we have seen) for very high levels of loyalty -combined with the early detection of needs by firms- which leads to “the advantage of the pioneer” overcoming any other type of competitive advantage.

Disclosure statement

No potential conflict of interest was reported by the authors.

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