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RESEARCH ARTICLE

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How fast to run in the Red Queen race?

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Summary

This paper creates a market ecosystem, via an agent-based model, that combines the dynamic features of the Red Queen effect with well-accepted business world performance indicators. Essentially, firms are tasked with remaining 'alive' by adapting to their environment through implementing a competitive response of innovating or imitating. An analysis of the firms' behaviours delivers a deep understanding of the drivers of innovative behaviour within the economy. The key findings of the paper are (1) that concentrated markets are not entirely detrimental to innovative behaviour, with the blend of firm type being a more important consideration, and (2) that the rate at which an innovation impairs existing markets affects the activity levels of the firms within the population. The model's results are validated against a matching study based on real-world data.

KEYWORDS

agent-based model, competition policy, creative destruction, innovation, Red Queen

1 | INTRODUCTION

Borrowing from the discussion between Alice and the Red Queen in Lewis Carroll's book *Through the Looking-Glass, and What Alice Found There*:

> *Now, here, you see, it takes all the running you can do, to keep in the same place.(Lewis Carroll, 1993: 124)*

Van Valen (1973) proposed the Red Queen effect as an evolutionary hypothesis. The hypothesis states that because of the continuous and escalating actions of competitors within an ecosystem, organisms must continually evolve if they wish to survive (Derfus, Maggitti, Grimm, & Smith, 2008). In doing so, species are running just to stand still; or, in other terms, they remain in the same relative position despite moving forward in absolute terms. While the hypothesis has its roots in biology, subsequently its application has expanded greatly and has been applied to economics and business as a possible explanation of the innovative dynamics of firms and markets. The direct relevance is that the performance of a firm will depend on its ability to successfully react to the actions of its competitors.

The goal of this paper is to develop an agent-based model (ABM) that explores the dynamics involved in the Red Queen effect, with the main objective being to explain how firms in an evolutionary market ecosystem must undertake self-preservation actions (innovate or imitate) to stay alive; that is, avoid bankruptcy and maintain a certain level of market share. To achieve this the model successfully implements an evolutionary landscape in which the firms exist and use financial performance indicators to inform their actions. After successfully implementing the model that contains these 'self-preserving' institutions, the model can in turn be used to explain why this occurs and its relevance to modern economics, including competition policy.

Section 2 consists of background information, which further explores the significance of the topic and reviews the papers that were utilized in the development of the model. Section 3 details the design of the model used in the paper, including the background to the model as well as the mathematics. The results follow in Section 4, in which the results for the various parameter sets are displayed and the results are tested against a set of hypotheses that are informed by those of Derfus et al. (2008). Finally, Section 5 discusses the implications of the model's behaviour, and the conclusions that can be drawn from that behaviour.

2 | BACKGROUND

Since the advent of evolutionary economics (Nelson & Winter, 2004), extensive research utilizing a multidisciplinary approach has been undertaken in an attempt to understand the economy as a dynamic and evolving system. One approach that is particularly relevant to this paper is to consider the economy, or certain parts of it, as a complex adaptive system (CAS). As outlined by Markose (2005), this approach has produced many promising results, yet it remains on the periphery of mainstream economics (Krugman, 1998). Within the realm of the CAS framework, Robson (2003) first suggested the relevance of the Red Queen effect to economics, and how it may be responsible for the emergence of innovative firms (Markose, 2005). The importance of understanding the dynamics surrounding the Red Queen effect is highlighted by Baumol (2004), who suggests that the Red Queen effect is the key mechanism for delivering economic development in a capitalist model. In addition, as reported in Derfus et al. (2008), the effect is capable of explaining founding rates (Barnett & Sorenson, 2002), failure rates (Barnett & Hansen, 2007), and competitiveness (Barnett & McKendrick, 2004).

A key paper that attempts to quantify the influence of the Red Queen effect in terms of more conventional economics is Derfus et al. (2008), in which the authors extend the framework of Barnett and McKendrick (2004). The paper analyses the actions of a focal firm and its rivals to confirm or deny the existence of the Red Queen effect. To achieve this, the authors propose a set of hypotheses relating to the effect that the concentration of the market, consumer demand, and the market position of the firms have on the rival actions, speed of these actions, and performance of the firms. A subset of these hypotheses are adapted and used in Section 4 to test the validity of the model presented in this paper. The general finding of the paper was supportive of the presence of the Red Queen effect, with the conclusion based on the finding that increased actions from a focal firm did increase performance of that firm but it had the side effect of increasing both the number and speed of the actions from rival firms, which would have a generally negative effect on the performance of the firm.

Rammel (2003) provides further theoretical support for the framework utilized in this paper by successfully arguing that an interdisciplinary approach to understanding the dynamics of innovations via the Red Queen effect is warranted. The key justification for this is that society needs to gain a greater understanding of the adaptive power of innovative diversity and must learn to compromise between short-term efficiency and long-term adaptability. The standard neoclassical economic theories are incapable of this explanation as they focus on a static and constant set of goods and services with the arrival of new goods and services treated as completely exogenous (Saviotti, 1996). This is to say they are introduced ex post; that is, after they have been innovated. By treating innovation as an ex-post event is to ignore key evolutionary aspects such as path dependence, uncertainty, cumulativeness, irreversibility and adaptive variations (Rammel, 2003). A consequence of this limited approach is that inflexible ‘lock-ins’ (as per Arthur, 1989 and David, 1985) are created under the neoclassical paradigm and the process of innovation becomes highly selective.

The process of ‘creative destruction’ (Schumpeter, 1942) is prominent in many theories of growth (Garcia-Macia, Hsieh, & Klenow, 2016), with its relevance to the Red Queen effect highlighted by Derfus et al. (2008). The process involves any existing market structure being ‘destroyed’ because of the successful innovation of a firm, with its significance being that it explains why firms are motivated to undertake new ‘actions’ to either improve their position or retain their position in response to the actions of their competitors. The ramification is that the system is in a perpetual state of change, making it vital to understand the dynamics involved in the process of innovation. The importance of understanding the implication of the ‘creative destruction’ process is seen in Garcia-Macia et al. (2016), where it was concluded that it was ‘vital for understanding job destruction and accounts for around one-fourth of growth’.

Given the ongoing evolutionary process within the Red Queen environment, there is a lack of a stable equilibrium, making the use of static analytical frameworks problematic. However, with an ABM, such as the one utilized in this paper, the dynamics of the Red Queen effect can be revealed, as they are not constrained by equilibrium conditions (Sornette, 2014) and they allow for the interaction of agents within a system. Agent-based models (ABMs) model a system from a bottom-up perspective, and their successful use in trying to uncover the dynamics of innovation is discussed extensively by Dawid (2006). In a further advance and proof of their utility, the SKIN model (Gilbert, Ahrweiler, & Pyka, 2014) is an all-encompassing ABM of innovation networks grounded in knowledge-intensive industries. The premise of the model is that each firm tries to improve its innovation performance and its sales by improving its knowledge base through adaptation to user needs, incremental or radical learning, and cooperation and networking. The model was designed and verified with empirical research and theoretical frameworks from innovation economics and economic sociology.

In terms of technical direction for the model in this paper, Teitelbaum and Dowlatabadi (2000) was the primary source. This paper discusses the ability to have multiple firm types in a model of innovation, which is a deviation from the norm of being constrained to a single representative firm type. The folly of the continued use of representative agents is detailed in Kirman (1992), with the main objection being that the utilization of a representative agent is a ‘convenient fiction’ used to provide micro foundations for aggregate behaviour with the sole intent of solving for stable and unique equilibria. Kirman (1992) also provides the impetus to consider the economy as a complex system, capable of delivering emergent outcomes, when he makes the point that ‘the sum of the behavior of simple economically plausible individuals may generate complicated dynamics’.

Teitelbaum and Dowlatabadi (2000) utilize an ABM to more accurately represent the interaction between multiple firm types within a competitive market by making use of two firm types—one focused on more radical innovation and one focused on only incremental innovation—and comments that ‘a synergy exists between firms of different types which allows heterogeneous populations of firms to earn more than homogenous ones’. This finding is significant because it could not be found using previous economic models constrained to a single representative firm. Important policy implications stem from this finding, including the idea that governments should attempt to foster diversity among the firms in its economy.

By using a similar framework to Teitelbaum and Dowlatabadi (2000), Araújo and Mendes (2009) employ an ABM to assess the effects of, and drivers of, innovation. The authors make an important point that ABMs, such as the one used in their paper and in this paper, have applications across several fields because of the interacting nature of the agents. Two models are reported in the paper, the first with producers and consumers, and the second with agents that extract a benefit from other agents, with different conclusions drawn from each model. The first model is further divided when adaptation is introduced with meaningful conclusions reached regarding the effectiveness of the innovation mechanisms. Of note is how the effectiveness related to the overall structure of the agents' environment and their relation to it. The second model produced results that show that even with simple interactions in a market there can be strong structures in agent-based societies.

3 | MODEL DESIGN

3.1 | Model background

While there have been limited attempts to address the Red Queen effect in relation to innovation through an ABM, the model of Teitelbaum and Dowlatabadi (2000) provides sufficient insight into an acceptable modelling approach. The essence of their model is that products are represented by a binary bit string (BBS) of length *n*, with the process of innovation or imitation based on firms successfully altering the bit string. The justification of representing a product as a BBS according to Teitelbaum and Dowlatabadi (2000) dates back to Lancaster (1966). The alternative approach is to utilize a fitness landscape in which the firms would operate.

Existing product's BBS
[1 0 0 1 1 0 1 0 1 0]

Attempted Innovation by changing 5 bits (the bolded bits)
[1 0 0 **0 0 1 0 1 1** 0]
The Hamming distance in this example is 5, as 5 bits no longer correspond to BBS of the existing product.

Hamming Score of the attempted innovation is 5

FIGURE 1 An illustration of the calculation of a product's Hamming distance

The benefit of using the BBS approach is that any two products can be differentiated by calculating the Hamming distance (Schneeweiss, 1989) between them. Given the extensive use of a product's Hamming distance throughout the paper, Figure 1 is provided for illustrative purposes. While the example is trivial, given 5 bits are deliberately changed, the resulting Hamming distance between the two products is 5. The significance of the distance and how the bits are changed in this model are detailed in Section 3.3.2.

A high-level overview of how the model presented in this paper functions is provided in Figure 2, with detailed descriptions of the agent classes provided in Section 3.2 and each step described in Section 3.3. The core of the model is that there is an initial number of markets (which can be thought of as totally independent markets or segments within in a market), with firms making products available to consumers in each of these markets. New markets are opened as innovative firms successfully innovate, while imitative firms attempt to imitate and improve the product in an existing market. Consumers then choose which firm they will purchase a product from in each of the markets based on several factors, including whether the product is new, the differentiation of the product to the incumbent product,

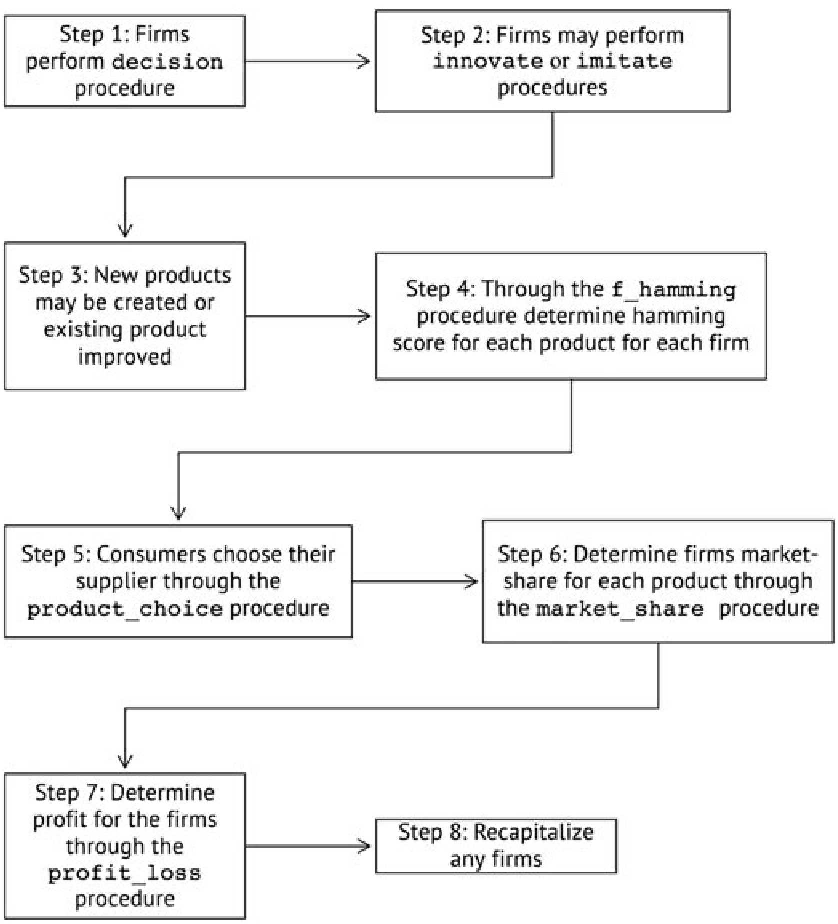

FIGURE 2 Flowchart of the Red Queen model

and their propensity to switch. Firms collect revenues based on their market share in each of the markets and then their profit for the period is determined after their cost of doing business (COB) and research and development (R&D) costs are removed. Any profits are then added to the capital of the firm. A firm will be bankrupted if its capital balance becomes negative, and it will recapitalize by issuing a new share.

The model is designed to capture the number of times a firm tries to innovate or imitate, the capital per share (CPS) of each firm at the end of the run, and the market share each firm captures. A firm takes actions by deciding to innovate or imitate; thus, the model is capturing how hard each firm is running in their Red Queen race. The CPS is the measure of the firm's success for participating in the race. The justification for the use of CPS, as opposed to total capital, is that the model allows a firm access to fresh capital when it is bankrupted, but the cost is that they must issue another share. Further earnings are then diluted among a greater number of shareholders. This approach will distinguish a firm that has continued to stay ahead—that is, it has not been bankrupted—against those that have been bankrupted at some point in the simulation.

The decision to follow the aforementioned process was based on keeping the number of firms consistent across the simulation. This approach is consistent with the models discussed in Section 2, with the exception being that they replaced the bankrupt firm with a fresh firm. This is somewhat at odds with Schumpeter's (1942) 'creative destruction', which suggests that an innovation will destroy the existing market structure and result in the innovative firm establishing a monopoly. To accommodate this the model does in fact allow for monopolies because the innovating firm will maintain a 100% market share until, if, and when the imitators catch up. Moreover, the addition of a new market leads to a deterioration in the size of the existing markets, as is detailed in Section 3.2.

3.2 | Agent classes

3.2.1 | Markets

The role of the market agent is to provide a space where the firms supply their products. New markets are only created when a firm successfully innovates a new product. In contrast, existing markets are 'improved' when a firm's imitation of an existing product is accepted. It should be noted that it is not the aim of a firm to imitate precisely an incumbent product, but rather it will try to improve on the existing product by changing the BBS, as detailed in Section 3.3.2, and having that new BBS accepted.

The model is initiated with the number of existing markets determined by the user. The complexity of the product offered in each market is equal across markets and is set by the user with the *bitmap_size* variable. At initiation, each market is allocated a unique BBS, which is in turn provided to each of the firms. This ensures that each firm has equivalent intellectual property at initiation. The BBS is also stored in a global list called *portfolio*. The role of this list is to track the incumbent product (as defined by the BBS) in each of the markets. As innovations occur, new product BBSs are added to the list; while when imitations occur, the existing BBS is replaced by the new BBS in the relevant position within the list.

Each market has a size as given by its revenue opportunity. The revenue of a market is shared among the firms based on its market share of the specific product (see Section 3.3.3 for the description of how this occurs). Each market is initiated with its revenue opportunity determined by the *revenue_per_market* variable, where it is assumed any new market has the equal revenue opportunity, as set by the user. Additionally, an innovation will negatively affect existing markets, with the revenue for each of the existing markets decaying as per equation 1, which is a straightforward discounting function:

$$\text{RPM}_i = \frac{\texttt{revenue\_per\_market}}{(1+\text{cdf})^n} \tag{1}$$

where RPM_i refers to the revenue of the ith market, cdf refers to the rate of creative destruction or the rate of decay of a market, and n refers to the number of markets in the economy; the user sets the cdf variable as float-point between 0.05 and 1. This feature assumes that, as the number of markets grows, the size of the existing markets declines based on the age of the market, with the rationale being to recognize that new markets are not entirely incremental and attract revenue from somewhere, with existing markets suffering as new products arrive. Section 4 explores the implication of adjusting the creative destruction factor.

3.2.2 | Firms

The model is specified such that the firms are responsible for much of the dynamics within this model, as they react to the changing environment. The goal of each firm is the same: to grow their capital base through improving revenue. It is assumed that margins, and therefore profits, are exogenous and are determined by the user. Within the firms' agent class there are two distinctive types of firms: innovators and imitators. Based on their class, their decisions and actions differ, as an innovative firm will try to grow capital by developing new products for new markets while imitators will attempt to grow capital through capturing market share in an existing market through improving upon an existing product. A more detailed explanation of the differences and how their procedures differ is provided in Sections 3.3.1 and 3.3.2.

The composition of the competitive landscape is determined by the user through the *num_firms* and *%_innovators* variables. Combined, these set the number of firms that are created and the percentage of those that are innovators and imitators (this being *1−%_innovators*). The class of the firm is identifiable through the innovator variable, which is set to true for an innovator and false for an imitator. The rationale for this design is supported by the models utilized by Teitelbaum and Dowlatabadi (2000) and Araújo and Mendes (2009), where both models allowed for differentiated firms, with varying dynamics, in terms of the number of actions and the performance of the firms emerging. Other variables that are set by the user are the firm's initial capital base (*f_endownment*), the minimum market share an innovator is willing to accept (*inn_ms_diff*), and the cost of undertaking innovation or imitation (*cost_per_innovation* and *cost_per_imitation*), which is a proxy for the R&D cost.

Regardless of whether a firm is an innovator or an imitator, the model tracks several values throughout the simulation. Table 1

TABLE 1 Key variables of the firms

Name	Type	Purpose
`portfolio`	List of lists	This list maintains the BBS for the products that the firm provides to each market. At initiation, each firm is provided the BBS for the incumbent products, but after that the list is filled with the product the firm is currently offering
`inn_att/im_att`	Variable	The occurrence of a firm undertaking an action (is either innovation or imitation depending on the firm type)
`revenue_per_product`	List	As part of step 8 in Figure 2 the revenue that a firm generates with each of its products is determined and stored in this list. It is then summed to provide the revenue per period for the firm
`profit_per_product`	List	The same as `revenue_per_product`, with the exception that the COB is removed.
`capital`	Variable	At initiation, each firm is provided an initial endowment and then at the completion of step 8 in Figure 2 the capital is updated by the profit for the period. If there was a loss, then the capital base is reduced, and if it becomes negative a firm will recapitalize
`capital_raisings`	Variable	Tracks the number of times that a firm was been required to recapitalize. Therefore, it is effectively the number of shares a firm issues, with this used in the calculation of the CPS value at the end of the simulation
`f_hamming`	List	When step 4 in Figure 2 is completed each firm records its Hamming distance for each of its products
`mkt_share`	List	As part of step 7 in Figure 2 the market share for each product is determined and then for each firm it is recorded in this list. The market share is used by the firm as part of the decision-making process about whether to attempt to innovate/imitate (step 1 in Figure 2)

summarizes these variables, and their relevance to the research question of this paper is detailed in Section 3.3.6.

3.2.3 | Consumers

The consumer class has the responsibility of deciding from which firm it will purchase products. The model is designed such that the consumers purchase a single unit from each market at each time step. Within this process it is assumed that consumers will also want to acquire any new innovative products, as described in Section 3.3.2, and they are not provided with a budget constraint. This process is in line with the modelling approach used in the models mentioned previously and is justified by the fact that an innovative or imitative action does not have a 100% chance of being a success (see Section 3.3.2 for greater detail); so, once it is deemed to be successfully introduced, consumers will demand it. Attempts to integrate other aspects of consumer behaviour towards innovation (e.g. Rogers, 1995), were not considered for this iteration of the model, as the objective of the model was to focus on the behaviour of the firms. The shortfalls of the abstract nature of the consumers' behaviour is discussed in Section 5.

The number of consumers is decided by the user via the *num_consumers* variable. When the consumers are initiated, their *purchase_from* list is populated with one of the *N* firms in the population. As imitation and innovation occur, this list is used to track from whom the consumer is buying each product in each of markets. The list is further utilized to determine the market share of the firms. The user has the option of having the market shares for the initial markets be either uniform or generated in a random fashion. The list is updated at each tick, as described in Section 3.3.3.

Despite the simplified nature of the consumer, a degree of heterogeneity in the consumer population is introduced through the agent's *switch_pro* variable. The variable provides a threshold that decides whether a consumer will switch to an improved imitation when it becomes available, with the consumers allocated their *switch_pro* value from a uniform distribution, where the value is a floating-point value between zero and an upper limit chosen by the user via the *con_tolerance* variable. The utilization of this variable occurs at step 6 in Figure 2, with the process fully described in Section 3.3.3. The inclusion of the *con_tolerance* variable was designed to distinguish consumers, as per a production adoption curve, with the basis being that if a consumer has a lower value for the *switch_pro* variable they are effectively be an early adopter because they have a low threshold in terms of switching to an imitated product. A higher value for the *switch_pro* variable means that the consumer is less likely to switch unless the product is highly differentiated from the existing product.

3.3 | Process flow

This section details the process flow for the model. It is important for the reader to recognize that the process that a firm undertakes differs in minor but important ways depending on whether the firm is an

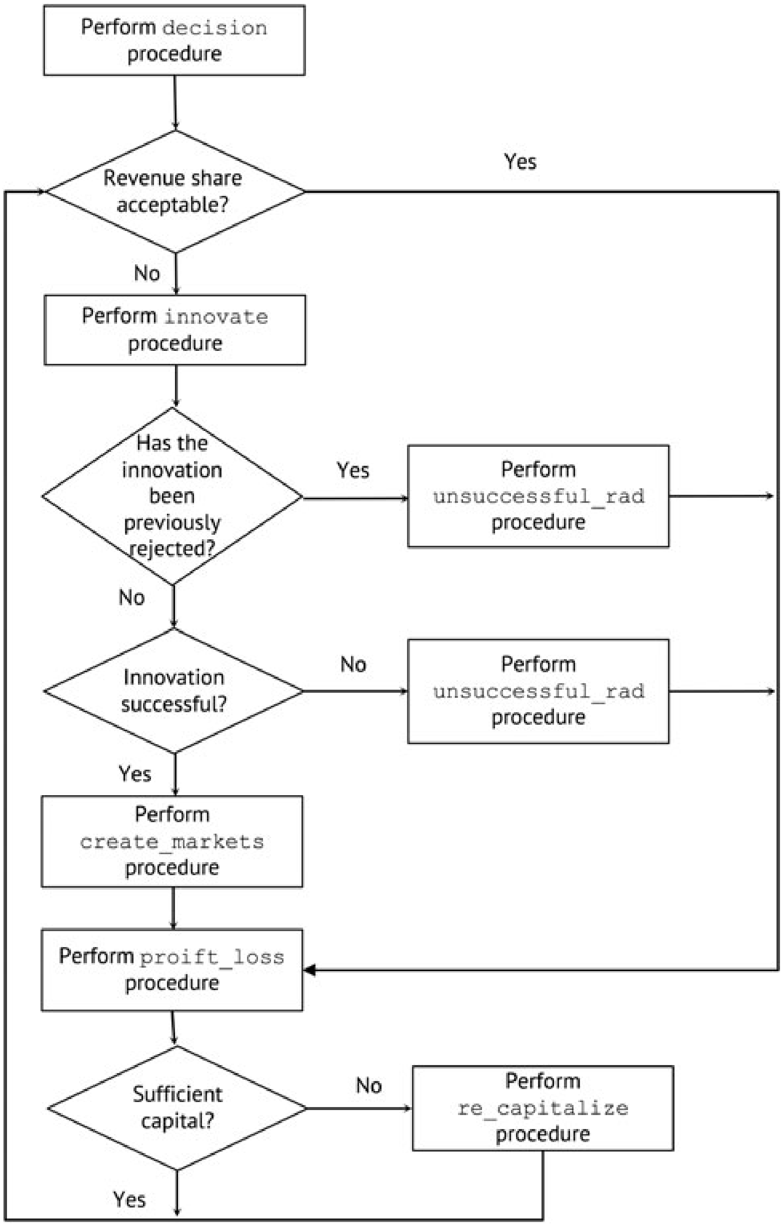

FIGURE 3 Flowchart for an innovative firm

innovator or an imitator. To illustrate the differences, Figures 3 and 4 have been provided. Where appropriate, each of the following subsections will highlight the differences.

3.3.1 | The decision procedure (step 1)

At the start of each time period the firms decide whether to act or not (step 1 in Figure 2). The process starts with the firm generating a revenue forecast by multiplying its market share in each of the existing markets by the revenue available for the relevant market. As per Section 3.3.4, readers should be aware that markets, while they are initiated at the same size, diminish as new markets are created through the innovation process. The ramification is that a firm with a high market share in older markets will have a lower proportion of total revenue than a firm with equivalent market share in newer markets. It is this component of the model that is vital for understanding the Red Queen effect, because if a firm stays in its existing markets as other firms keep 'running' by undertaking innovation or imitation, the inactive firm falls behind as their environment deteriorates.

Once the firms establish their revenue forecasts they compare them with a benchmark level that they endeavour to achieve. For the innovative firms, their benchmark is the total revenue opportunity across all the markets, divided by the number of firms, and multiplied by the user-defined *inn_ms_diff* variable. The interpretation of this variable is that if an innovative firm demands (accepts) a premium (discount) in terms of market share as a return for carrying out innovative behaviour the variable's value will be greater (less) than one. In reality, the level of market share that the innovator is willing to accept will be tied to the profits they can generate in the market and their business strategy; for example, Apple was willing to maintain a market share well below 50% in the personal computer market yet generated sufficient returns. Alternatively, Amazon's business strategies are based on achieving and maintaining a dominant market share in the online space.

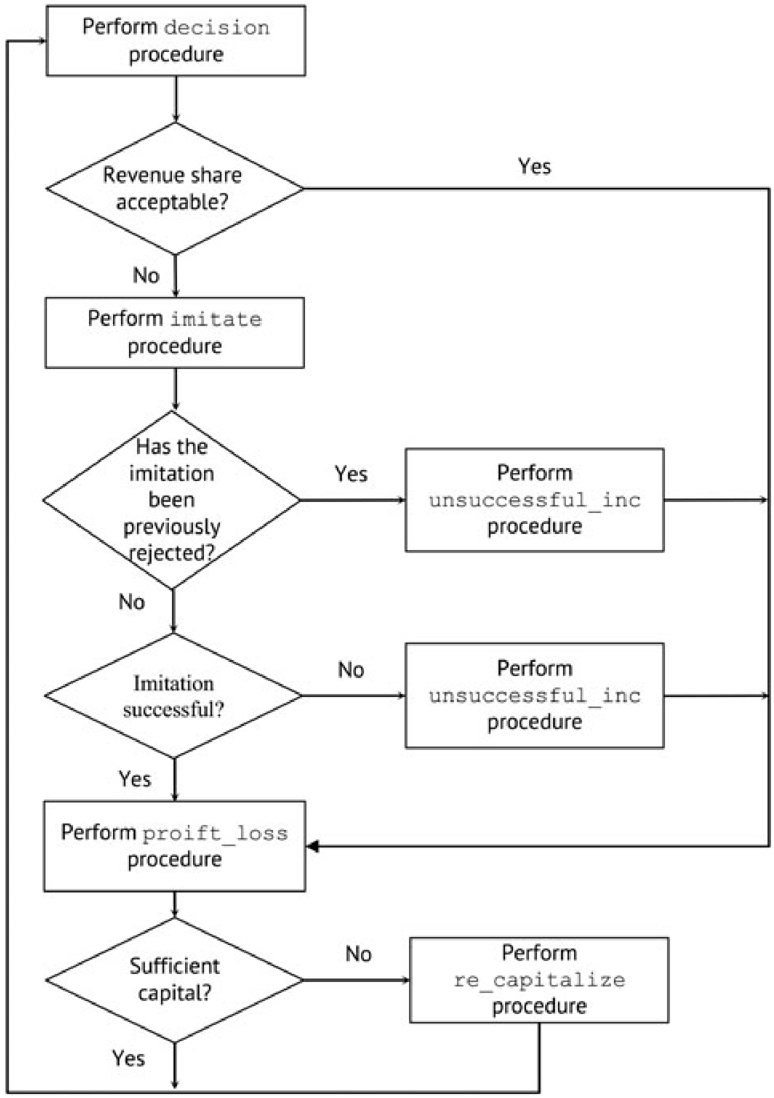

FIGURE 4 Flowchart for an imitative firm

For the imitative firms, their expectation is to secure an equal share of revenue divided by the *inn_ms_diff* variable. This design feature is done solely to maintain a degree of symmetry in the model. A value greater (less) than one feature assumes that the imitative firms are happy (unhappy) to sacrifice revenue to avoid carrying out imitative behaviour. If the firm's revenue forecast is below its benchmark, they will decide to undertake an innovative or imitative action, depending on their agent class.

3.3.2 | The innovation or imitation processes (steps 2 and 3)

Having decided to act, a firm will call the appropriate procedure (innovate for innovators and imitate for imitators). The procedures are slightly different and reflect the inherent differences in strategies of the two firm classes.

For the innovation process the firm will access the BBS of the newest product on the market. This process is equivalent to a competitor acquiring an existing product and reverse engineering the product to understand the new technology. The firm will then choose the number of bits it will attempt to change. The number is given as a random number between one and the length of the BBS. In a similar process as illustrated in Figure 1, the firm will randomly choose the bits it wants to switch and will switch them from zero to one or vice versa. The firm's capital account is then debited by an amount equal to the number of changes made times the *cost_per_innovation* as set by the user at initiation, thus capturing the level of R&D spending.

The next step is to determine whether the new product, as given by the BBS, has been tried and failed before. To do this the firm accesses the failure list and calculates the Hamming score of the new product compared with all the previously failed products. If a score of zero is returned for any of the comparisons, then the new product fails because a score of zero means the product is identical to a previous one. The failure list is initiated with a BBS of all zeros, which therefore prohibits a BBS of all zeros being a legitimate product. If the product has not failed beforehand, the Hamming distance of the new products is calculated in comparison with the existing product. The Hamming distance is then converted into a probability via

$$\mathtt{inn\_pro}_i = \frac{\exp[(\text{Hamming score}/\mathtt{bitmap\_size}) \times 0.4]}{100} \quad (2)$$

Once the probability is calculated it is compared with a random float (rf) drawn from a uniform distribution between zero and one. In the instance that the product is a failure, when the inn_pro_i is less than the rf, the BBS is added to the failure list. If the inn_pro_i is greater than the rf the product is deemed a success, and a new market is created via the *successful_rad* procedure. The reader should note that at this point it is implicitly assumed that consumers will want the product. A discussion regarding the limitations of this approach is held over to Section 5. As part of this procedure, the new BBS is installed as the incumbent product as well as being added to the portfolio of the firm before consumers have their *purchase_from* list updated with the identification of the firm that just successfully innovated. This step ensures that the firm will have 100% of the new market until an imitator successfully improves the product via the steps detailed in the following paragraph. In addition, to ensure consistent list lengths, the portfolio list of the non-innovating firm (that is, all imitators and the innovative firms who did not create the new product) is updated with a BBS of all twos. This step simply ensures that these firms return a maximum Hamming distance in various other procedures, which is to say consumers cannot consider their product.

The process for imitation is not dissimilar to the innovation process. One exception is that when determining the number of switches, the range of the random number is half that of an innovative firm. The rationale for this feature is that the aim of the imitator is to make a minimal amount of changes to the existing product, thereby making a smaller investment, in an attempt to have their product accepted. This design does not preclude an imitator switching more bits than an innovator, but on average this process should see innovation being more intensive. The firm's capital account is then debited by an amount equal to the number of changes made times the *cost_per_imitation* as set by the user at initiation:

$$\mathtt{im\_pro}_i = 0.4 - \left(\frac{\text{Hamming score}}{\mathtt{bitmap\_size}}\right)^2 \tag{3}$$

By contrasting equations 2 and 3, it can be seen that the function for innovative success is an increasing convex function: the higher the Hamming distance of the new product, the higher its relative probability of being a success. Alternatively, the probability of imitative success is a decreasing concave function, meaning that the farther the product is from the existing product the lower its chance of being a success is. This approach was taken to remain consistent with that of Teitelbaum and Dowlatabadi (2000).

If the imitation process is successful there are further differences; namely, the process is that the BBS of the imitation replaces the existing BBS in the list of existing BBSs (as opposed to adding to it), and consumers do not update their *purchase_from* value for the existing product at this point, as this is held over to the *consumer_product_choice* procedure (step 6 in Figure 2).

3.3.3 | Determining market share (steps 4, 5 and 6)

Following the possible introduction of new products and the updating of existing products, it is necessary to determine which products the consumers will buy. The first step in this process is the *f_hamming* procedure. This procedure asks each firm to cycle through its portfolio list (which contains the BBS for its product in each market) and compares their BBS with the BBS of the incumbent product in each market. The purpose of this is to calculate the Hamming distance for each of its products. After each firm's Hamming distances are determined the *min_hamming* procedure is called, which cycles through the Hamming scores for each product and finds the minimum Hamming distance. Once it has found the minimum score it updates the *lowest_ham1* list with the identification of the firm that recorded the lowest Hamming distance. This is important, because it has been assumed that a consumer, if they are to switch providers, will switch to the one with the lowest Hamming distance, since this is the newest imitation in an existing market. Note: this is not relevant for innovations.

Next, the consumers check to see whether they want to change products (note that this only occurs for a product that has been imitated and not for a new innovation). For this to occur, the consumer calculates the Hamming distances of the products they are currently purchasing against that of the improved product introduced to an existing market. As per

$$\frac{\mathtt{currentHamming}}{\mathtt{bitmap\_size}} > \mathtt{switch\_pro} \tag{4}$$

the consumer then sees whether the Hamming distance divided by the length of the BBS is greater than their *switch_pro* value. If this is the case, then they will switch to the newest imitation because the product they are currently purchasing is too far away from the newly accepted product. Consumers with a high *switch_pro* value will be less likely to switch. In the instance that the condition to switch is met, the consumer will access the *lowest_ham1* list to find the firm with the lowest Hamming distance. Having discovered this, the consumer will update their *purchase_from* list to reflect from whom they are purchasing the product, noting that consumers purchase a single unit from each market at each time step.

The final step in this process asks each firm to cycle through each of the consumers for each of the markets to establish whether the consumer is purchasing the product in the queried market from them. Firms undertake this step to determine their market share in each of the markets with the information used in their revenue forecasting process (as described in Section 3.3.1). The information is also used in Section 3.3.4. The procedure works on the basis that if the queried consumer is purchasing the product for the market in question from the querying firm, then that firm updates their *mscount* variable by one, with the market share for the relevant market being the value of the *mscount* after all consumers have been queried. This process is repeated for each product with the results stored in the *mkt_share* list for each firm. It should be assumed that if the market share of any product is zero then the firm does not produce any goods for that market.

3.3.4 | Determine profit and loss

The first step in determining the profit and loss for each firm for each period is to determine the size of each market as per equation 1. The significance of the equation is that the introduction of a new market will see the existing markets decline in size. Each firm establishes the revenue for each market, after which it is multiplied by its market share its market share, as determined in Section 3.3.3, for each market by its size to establish its revenue for that market/product. The results for each market are then stored in the firm's *revenue_per_product* list.

Profit per product for the firm is then calculated by subtracting the COB from revenue for each product and updating the *profit_per_product* list. The COB for a given firm, for a given market, is calculated by multiplying one minus the margin (as set by the user) by the size of the market in question before dividing this by the relevant firm's market share for that market. It is therefore assumed that the margins that the firms achieve is homogeneous, a limitation discussed in Section 5. If the firm's market share for a product is zero, then the profit is assumed to be zero as there is no COB.

The final procedure sums the *profit_per_product* list, with resulting capital added to the capital account for the firm. If the firm made a trading loss, it may be of such a size that the firm is now required to recapitalize (see Section 3.3.5). Alternatively, the capital account may have been already pushed into the negative because of excess innovative/imitative activity, as described in Section 3.3.2. The model assumes that all profits are retained by the firm and are not distributed as dividends to the shareholders.

3.3.5 | To recapitalize a firm

If, after the updating of the capital levels of the firm, a firm is found to have a negative capital value, it will recapitalize. The process of recapitalizing involves increasing the firm's capital by the value of the *f_endowment* setting and increasing the recapitalize counter by one. The latter is the equivalent of issuing another share.

3.3.6 | Model outputs

The ABM utilized in this paper captures data at the micro level of the agent, firm type (innovator or imitator), and at the macro market level. This flexibility allows for multiple relationships to be assessed. In terms of the key performance indicators (KPIs), the following variables are the ones that have been selected for this paper:

1. The number of successful innovations are tracked via the *product count* of the system, with the number of successful innovations being the product count at the end of the run, minus the number of initial products.
2. The number of times innovators attempt to innovate is captured by the *innovation attempts* variable. This value is utilized to establish a per innovator KPI, obtained by dividing its value by the number of innovators.
3. The total number of successful imitations is recorded by the *imitations* variable. Again, this can be divided by the number of imitators to determine a per imitator KPI.
4. The number of times imitators attempt to imitate is tracked via the *imitation attempts* variable. The result is divided by the number of innovators to establish a per imitator KPI.
5. Rather than simply capturing the capital of each firm, the model captures *capital per share*, which is the capital of a firm divided by the number of shares it has issued, which is given by the number of times a firm has had to recapitalize.

This latter step was taken to penalize a company for having to recapitalize and equalizes the capital level of the firms. The number of times firms have been forced to recapitalize is captured by the *recapitalization* variable. This KPI will provide an indication of the destructive nature of the competition within the model. At each step the model tracks the total revenue and profit of each firm with the intent of establishing who is winning the race.

4 | RESULTS

4.1 | Validation

While ABMs provide researchers great flexibility to implement models of varying breadth and degrees of complexity, to be of use to the broader community their results require a level of validation. Validation of a model, according to Axtell and Epstein (1994), can fall into one of four categories, ranging from a caricature of reality through to being in quantitative agreement with empirical microstructures. While the model presented here retains a high degree of abstraction, the objective was to attempt to establish a degree of quantitative validation using existing research data. The specific goal was to find a level of agreement and/or disagreement with a translation of the work of Derfus *et al*. (2008). The justification for this approach is that the models reported in Section 2 lacked any attempt at validation against real-world data, and it was deemed reasonable to translate/modify a number of the findings from Derfus *et al*. (2008) into the framework presented by the current model. The benefit is that in the event of establishing a baseline validation the model can then be extended and matched to more specific data, as per the discussion in Section 5.

4.2 | Hypothesis

The primary goal of the ABM implemented in this paper was to find a level of agreement and/or disagreement with an interpretation of a number of hypotheses put forward in Derfus *et al*. (2008), who distinguished firms as either focal or rival firms, with a focal firm defined as the firm undertaking actions in a given market, with the rival firm defined as those firms in the same market that will respond, or not respond, to the action of the focal firm. The rationale for this distinction is the desire to explain the motivations for actions and reactions (Derfus et al., 2008). In making this distinction the authors did not identify the actions of the firms as innovative or imitative; therefore, there is not a direct translation into the innovating and imitating firms in the model presented in this paper. However, using several assumptions, and basic economic principles, it is justifiable to make several translations to form a set of hypotheses that could be used to add validity to the model.

Table 2 provides the hypotheses that were adapted and tested in this paper. The key translation was to assume that focal firms are responsible for starting the competitive race, and they do this by innovating, thereby creating a new market, rather than undertaking imitative behaviour in an existing market; hence, the focal firm was replaced by innovators. This step can be further justified on the basis that in an environment of 100% imitators no actions would take place as the imitators are satisfied with their place in the market, a point implied by the assumptions of perfect competition in the neoclassical economic paradigm. Therefore, it was assumed (and

TABLE 2 Hypotheses to be explored via the parameter sweep

Subset	Number	Hypothesis
Concentration	C1	Industry concentration positively moderates the relationship between an innovators actions and its performance
	C2	Industry concentration positively moderates the relationship between an innovators' actions and imitators' actions
	C3	Industry concentration negatively moderates the relationship between imitators' actions, the speed of those actions and the performance of the innovators
Actions	A1	As the number of innovative attempts increase, the performance of the innovative firms should increase
	A2	As innovation increases, imitation attempts should increase
	A3	As success imitation increases, the performance of the innovators should decrease

justifiable) that there must be at least one innovator in the system to start the competitive process.

The translation of rival firms to imitators was based on two assumptions. The first is that the imitative firms are not provided with the capability to innovate (i.e. to create a new market), therefore restricting their actions to those of a rivalrous (reactive) nature, as they attempt to gain a satisfactory share of the revenue from existing markets. The second is that an incumbent innovator is not a direct rival to the other innovators as they do not compete in the same markets. The implication is that the primary reason that an innovator decides to act is that the actions of the imitators (their direct rivals) have diminished their market share in one of their markets beyond an acceptable level causing them to react by undertaking the innovative process. It should be noted that innovators are indirect rivals to each other, as the opening of new markets is ultimately detrimental to the other innovators.

4.3 | Parameter settings

A parameter sweep utilizing several possible variables was undertaken to achieve the research objective of assessing the changing behaviour of firms within the Red Queen environment. The settings for the various variables are outlined in Table 3. The justification for keeping several of the variables constant was that the model was initially calibrated to derive a baseline model utilizing the figures employed.

TABLE 3 Parameter sweep settings

Variable	Parameter settings
Number of firms	2, 4, 6, 8, and 10
Percentage as innovators (%)	0.25, 0.5,0.75, and 1
Initial firm endowment	100
Revenue per new market	500
cdf	0.05, 0.10, 0.15, 0.20 and 0.25
Margin (%)	5, 10, 15, 20 and 25
Innovators market share advantage	1.1
Cost per innovation	10
Cost per imitation	8
Bitmap size	10
Initial markets	2
Number of consumers	100
Switch tolerance	1

In addition, to avoid generating an overly complicated set of results, the variables selected to be varied were assumed (and tested) to be the ones most relevant to testing the various hypotheses.

By way of further justification in terms of the *inn_ms_diff* variable, tests were run to ascertain the sensitivity of the results to changes in this variable. It was found that unless the value was moved to an extreme—such as 0.5(2.0), which means that an innovator is prepared to accept 50% less (or they sought 200% more) than their warranted market share—the results remained robust for a setting around one. The final setting of 1.1 is justified by the fact it would be expected that in a competitive environment, and with no ability to charge a premium, an innovator would prefer to maintain some premium in terms of market share as reward for their actions. The shortfall of this approach is discussed in Section 5.

In terms of the cost of imitation remaining less than the cost of innovation, as the imitative process involves reverse engineering an existing innovation, a discount in terms of the cost is warranted. The use of 100 consumers and a bitmap size of 10 are consistent with the model of Teitelbaum and Dowlatabadi (2000).

To generate the results, which are detailed in Section 4.4, 100 runs of each parameter setting with each run lasting 101 steps, with all possible combinations of the parameter settings, as per Table 3, were used. The number of runs was decided upon utilizing the methodology put forward by Lee *et al*. (2015); that is, that the coefficient of variation for a number of variable showed sufficient stability (0.05) after 100 runs.

4.4 | Results presentation

To understand the factors influencing the actions of the firms in the model, the results are presented using three techniques: a principal component analysis (PCA), boxplots, and a linear regression. The PCA has been used as a preliminary tool to identify the factors affecting the volume of innovative and imitative actions taken by the firm, while the other two techniques formalize and test the relationships for their statistical significance. The reader should note that Derfus *et al*. (2008) used the Herfindahl index (HHI) as their measure of concentration, whereas the analysis in this paper is done solely on the number of firms, which is effectively the inverse of the HHI, so the sign of any coefficients will be the opposite for this paper.

The PCA was designed to identify the variables that had the greatest effect on the volume of innovative actions undertaken by

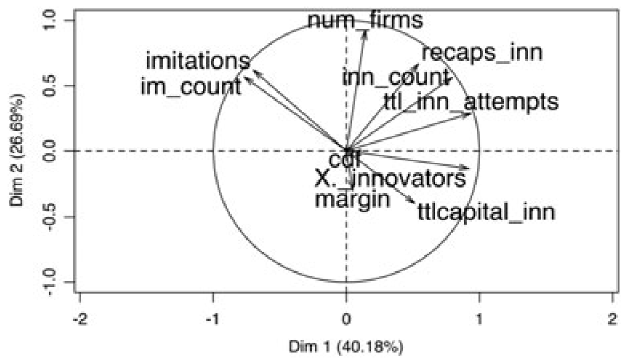

FIGURE 5 Biplot resulting from the PCA into the factor influencing innovative behaviour

the innovators with the economy. The resulting biplot is seen in Figure 5. The first two components explain over 75% of the variation of the model, with the first component explaining 45%. The first component is positively influenced by the percentage of innovators in the population (*X._innovators*) and the total number of innovators, while the number of imitators and their actions contribute negatively. For the second component, the total number of firms (*num_firms*) is the largest contributor. Margin does not have a significant effect on the volume of actions undertaken by the firms, but this could have been expected given that the decision to undertake an action was based purely on a firm's revenue share. The creative destruction factor also does not have a significant influence on the outcome of the model.

Having established that the percentage of innovators and the total number of firms affected the number of innovative actions per innovators, it was assumed that the same variables would also materially affect the number of imitative actions per imitators. The relationship between these variables and the allowable margin (though margin was deemed to have a minor effect through the PCA, for completeness the results have been separated) for the innovative firms are seen in the boxplots in Figure 6. The reader should pay attention to the layout of the plots. Each of Figures 6–8 is designed such that each facet/tile has been determined by the number of firms in the sample, with the *y*-axis representing the number of actions per innovative firm (or the like). The *x*-axis marks the interaction between the margin and percentage of innovators (margin·% firms as innovator) in the population; that is, a label of 0.05·0.50 should be read as the results from a combination of a 5% margin and a population consisting of 50% innovators. The reader should be aware that when the number of firms is two and the percentage of innovators is 25%, the model rounds up the number of innovators to one rather than rounding down. The scenario of 100% imitators is not included because this setting results in the system instantly finding a steady state that sees no actions undertaken by the imitators. This finding supports the validity of the model, as this result is consistent with the theory of perfect competition, where innovation does not (and cannot) occur because firms have no incentive to innovate as they have no ability to generate a profit (a point raised previously in Section 4.3). The first conclusion that can be drawn is that as the percentage of innovators within the population increases for a given population size this has a positive effect on the volume of actions undertaken by innovators. In addition, the total number of firms in the population has a limited effect on the level of innovative behaviour.

Figure 7 provides the dynamics relating to how market concentration and the percentage of innovative firms in the population affect the actions of the imitators. The main impression is that as the number of firms in the population increases so too does their average number of actions, which was not the case for innovators.

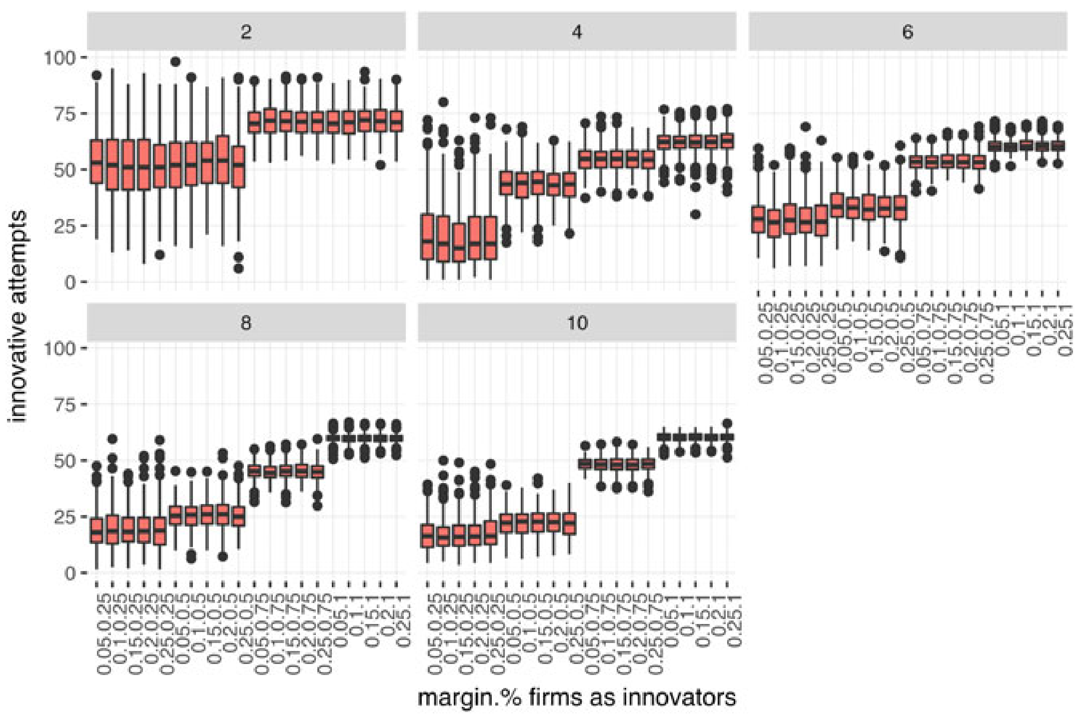

FIGURE 6 Boxplots illustrating the number of 'actions' per innovative firm varied by the number of firms in the population (given in the title box for each chart), the allowable profit margin, and the percentage of innovators (given by the *x*-axis)

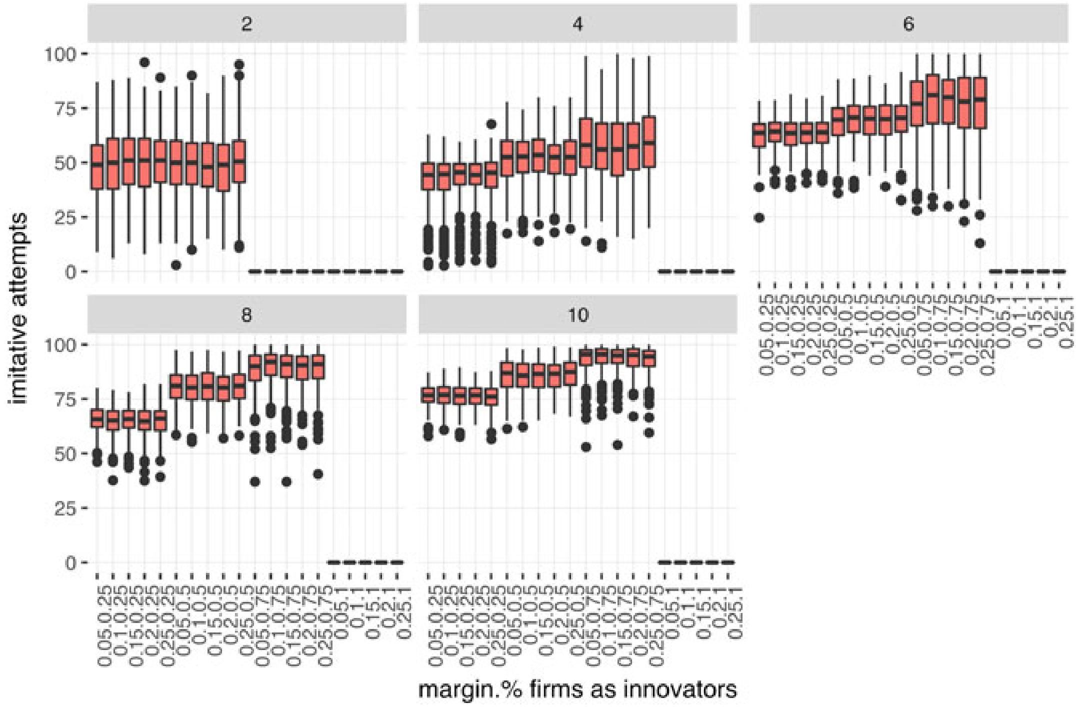

FIGURE 7 Boxplots illustrating the number of 'actions' per imitative firm varied by the number of firms in the population (given in the title box for each chart), the allowable profit margin, and the percentage of innovators (given by the *x*-axis)

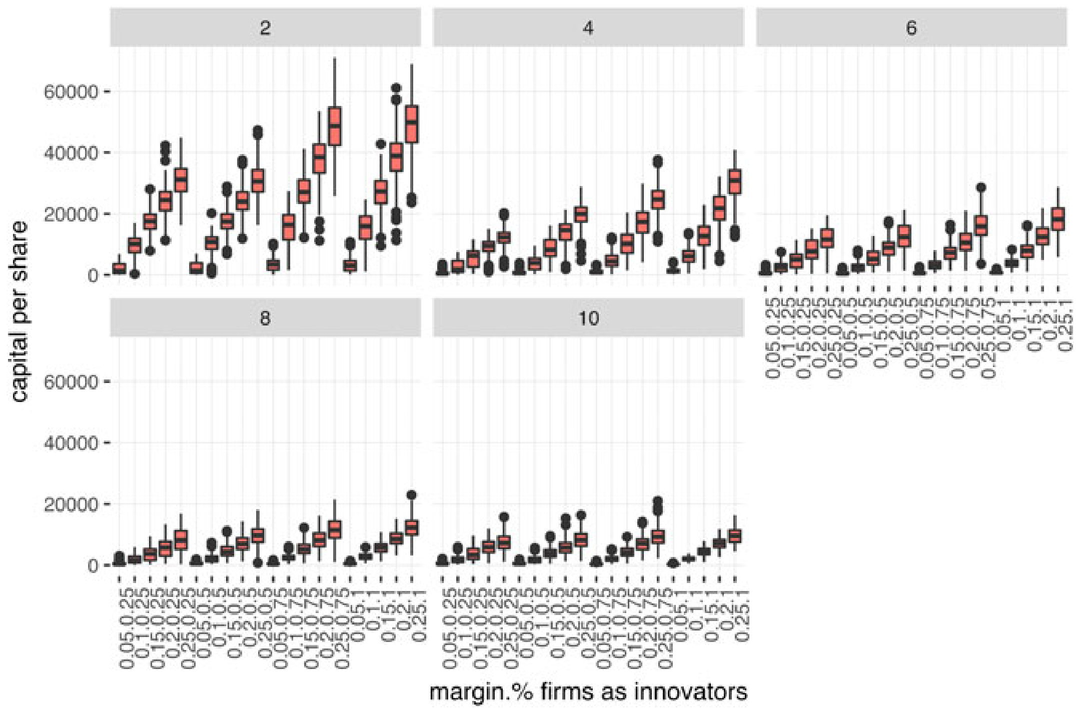

FIGURE 8 Boxplots illustrating the CPS per innovative firm varied by the percentage of innovators in the population (given in the title box for each chart), allowable profit margin, and the number of firms (given by the *x*-axis)

The volume of actions decreases as the percentage of imitators in the population increases (or the percentage of innovators increases), which is in line with what occurred with the innovators. The findings are consistent in part with the hypothesis C3 in Table 2; namely, that a higher industry concentration has a negative effect on the level of imitator actions.

To test the validity of the aforementioned observations outlined, linear regressions were performed with the results and the model specification presented in Table 4. The adjusted R^2 of the innovators model was 75.6% and the imitators model was 67.9%. To obtain the results for the imitator model, data points where there were no imitators in the population were removed.

TABLE 4 Linear regression results for firm actions

	Variable	Estimate	SE	t	Pr(>|t|)
Innovator actions/ attempts	Intercept	38.908	0.352	110.37	<0.01
	`Num_firms`	−0.782	0.115	−6.79	<0.01
	% of Innovators	34.250	0.463	73.91	<0.01
	Imitations	−0.243	0.006	−38.88	<0.01
	cdf	1.070	0.779	1.37	0.17
	`Num_firms`: % of Innovators	−0.699	0.122	−5.752	<0.01
Imitator actions/ attempts	Intercept	27.304	0.517	52.80	<0.01
	`Num_firms`	3.694	0.077	47.85	<0.01
	% of Innovators	−1.432	1.034	−1.38	0.166
	Innovations	0.482	0.015	32.40	<0.01
	cdf	46.298	1.044	44.34	<0.01
	`Num_firms`: % of Innovators	1.158	0.176	6.58	<0.01

SE: standard error.

The variables that negatively affect the number of actions by innovative firms as per Table 4 are the number of firms in the population and the number of successful imitations by the imitative firms, which are both statistically significant. The percentage of firms that are innovators in the population and the creative destructive factor positively affect the number, with the latter not statistically significant. Significantly, the interaction term of the number of firms and the percentage of innovators, which is statistically significant, is negative, indicating that, as these terms increase, the combined effect is detrimental to level of innovation. Therefore, if the markets become more competitive, greater innovation only occurs if the population contains a higher proportion of imitators, because it is the imitators, not other innovators, that cause the greatest loss of market share for the innovators.

For the imitators, the regression model suggests that the volume of imitative actions is positively influenced by the number of firms (and the interaction term of the number of the firms, and the percentage of the population that are innovators), the creative destruction factor, and the number of successful innovations. In turn, imitative behaviour is negatively affected by the percentage of innovators in the population, although this is not statistically significant. The first observations support both hypothesis C2 in Table 2 (at least in terms of actions undertaken by the firms) and hypothesis A2 in Table 2. A likely explanation of the last finding is that as the number of successful innovations increases, thus growing the total revenue available in the economy, it forces the imitative firms to attempt to produce new items for the new markets at a faster rate because their share of the total revenue of the population has declined below an acceptable level at a quicker rate. In a significant finding, this dynamic is accelerated even farther when the creative destructive factor increases, because the imitative firms cannot sit still as their existing markets are eroded at a quicker rate and they are forced to continue running to maintain their position.

There are several conclusions that can be drawn regarding the dynamics from these results in terms of the Red Queen effect. The first is that innovators are forced to run harder if they are racing firms like themselves. This is a direct consequence of the creative destruction factor (the impairment of an existing market), because a successful innovation has a greater negative effect on revenue share than the loss of market share in an existing market caused through a successful imitation. However, as the number of firms increases, and therefore competition increases, the innovators do not need to run as hard because the negative effects of lost revenue share from new innovation are shared across a greater number of firms.

For the imitators, they do not imitate (i.e. they run slower) when, for a given population, there is a greater proportion of imitators. This is because after a bout of imitation they will find a quasi-steady state that is only interrupted by the creation of a new market after a successful innovation. This, in turn, results in the dilution of the imitators' existing revenue share. However, as there are more entrants, imitators must run harder to keep up because they are fighting harder over a smaller pie. This issue is amplified by the innovators reducing their activity as the market becomes less concentrated, thereby not providing greater opportunities for the imitators to reclaim their targeted share of revenue.

Turning to the performance of the firms (or the reward for their running), Figure 8 presents the boxplots of the CPS for the different levels of innovative firms, using the same graph template as Figures 6 and 7. CPS has been taken as the proxy for performance as it measures the accumulation of profits normalized by the amount of times a firm was forced to recapitalize. With the scales being the same across each of the sub-plots in Figure 8, it is immediately evident that the industry concentration has a positive effect on the performance of the innovative firms (consistent with hypothesis C1 in Table 2). Given that the level of financial performance is likely to affect the level of innovative behaviour, it is not a large leap to suggest that concentrated markets are better suited to innovative activity. It is also evident that margin has a positive influence on CPS. The final observation is that as the percentage of innovators increases within a given population then the performance of the innovators increases. This is no doubt a result of the model's functionality, where innovators are responsible for creating new markets rather than reclaiming market share in an existing market. The consequence is that, as the percentage of innovators increases, an innovator is under less threat of losing market share (in the case of 100% innovators, they will maintain 100% market share of any new market) in any of the new markets that they create. However, the size of the market that the innovator establishes will eventually decline as the other innovators create other new markets, causing the loss of revenue share. It is this outcome that will force the innovator population to remain 'running' to maintain their share of the revenue.

Figure 9 presents the findings of the imitative firms, with little to differentiate them from the innovative firms. One noticeable difference is that the general level of profitability in the imitative community is lower than for the innovative. This is a direct result of the imitators not being able to create new, more profitable markets and not having immediate access to the new markets once they are opened.

The results of the linear regressions used to understand the relationship between the firms' performance, as given by CPS and selected variables, are provided in Table 5. Margin was added as an explanatory variable based on the evidence of its effects as seen in Figures 8 and 9, while innovation attempts/imitation attempts were included because they measure the amount of actions/running by each of the firms. These variables were used instead of the number of successful actions because they capture the intent of the firm, which is important because it does not rely on the probabilistic outcome of the innovation/imitation process (see Section 3.3.1). If the model is correctly

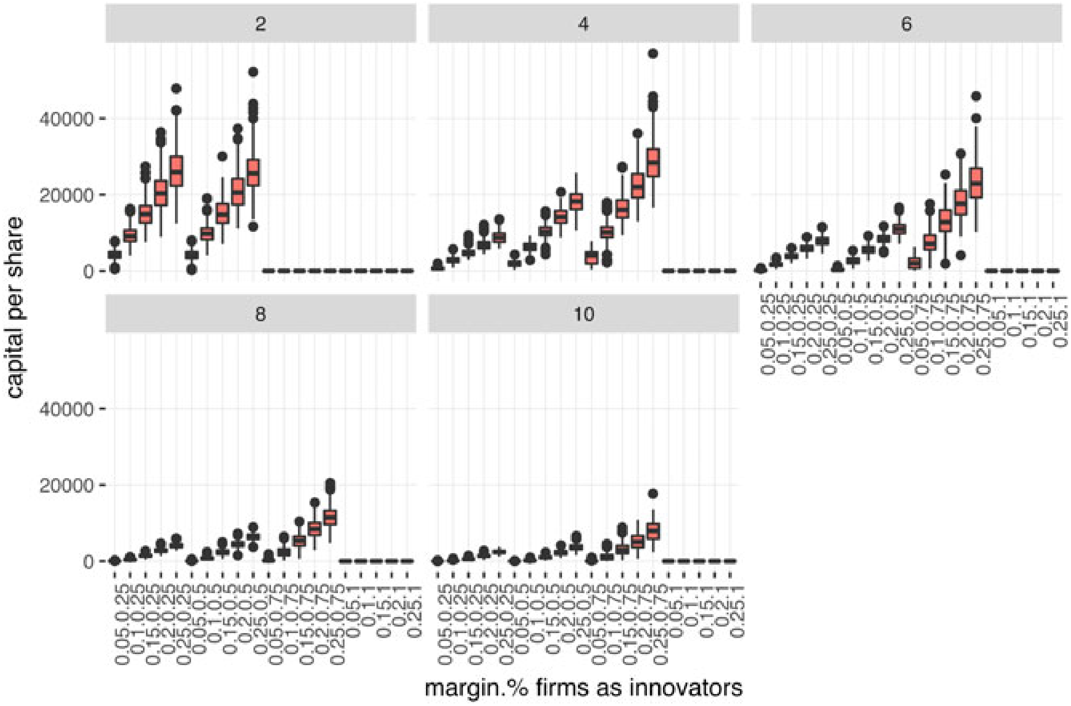

FIGURE 9 Boxplots illustrating the CPS per imitative firm varied by the percentage of innovators in the population (given in the title box for each chart), allowable profit margin, and the number of firms (given by the *x*-axis)

TABLE 5 Linear regression results for firm performance

	Variable	Estimate	SE	t	Pr(>| *t*|)
Innovator CPS	Intercept	−4,098.20	235.85	−17.38	<0.01
	Num_firms	−2,480.65	20.49	−121.04	<0.01
	% of Innovators	11,306.44	257.46	43.91	<0.01
	Imitations	115.166	2.41	47.82	<0.01
	Margin	90,205.26	495.67	181.99	<0.01
	`Innovation_attempts_per_inn`	103.817	3.72	27.90	<0.01
	cdf	−3,067.63	497.84	−6.162	<0.01
Imitator CPS	Intercept	4,562.07	153.79	29.66	<0.01
	Num_firms	−1,722.52	15.52	−110.98	<0.01
	% of Innovators	8,123.94	266.51	30.48	<0.01
	Innovations	93.71	4.80	19.51	<0.01
	Margin	60,770.9	388.07	15.60	<0.01
	`Imitative_attempts_per_inn`	−29.70	2.56	−11.59	<0.01
	cdf	6,265.01	405.79	15.44	<0.01

specified, then the sign of the action coefficient should be positive, which it is, as it indicates that the innovative/imitative actions have a positive influence on capital accumulation. If this were not the case, then there would be no value in undertaking these actions.

The explanatory power of the aforementioned models was not as high as the previous models, with the adjusted R^2 reported as 68% and 73.6% respectively. Table 5 highlights that margin has a large positive effect on the performance on capital accumulation for both types of firms. Given the margin was exogenously set and is constant, this result was expected and somewhat irrelevant. Future iterations of the model could look to correct this by making the margin endogenous as part of making firms consider the return on investment on their actions. The effect of creative destruction is more evident in this analysis, with it negatively affecting capital accumulation. The straightforward interpretation is that if new innovations decay existing markets at a higher rate, then the detrimental effect of capital accumulation will be greater. The effect is larger for the innovators, no doubt because of their market positions.

Both the number of successful imitations (innovations) by imitators (innovators) and the number of innovation (imitative) attempts has a positive effect on the capital accumulation. The first finding is inconsistent with hypothesis A3 in Table 2, while the second is consistent with hypothesis A1 in Table 2. The explanation for these relationships is straightforward but extremely insightful. Without imitation or innovation occurring, innovators lack the incentive to innovate and open new markets, which in turn leads to greater profit opportunities. For the imitators, a similar relationship exists, in that once their revenue share falls below the critical value because of the opening of new markets, they want to catch up, and this has a positive reward. Consistent with hypothesis C1 in Table 2, we see that as the number of firms increases (concentration decreases) the performance of the innovators (and for that matter imitators) decreases.

5 | CONCLUSION

The findings from the model are generally supportive of the translations made from Derfus *et al*. (2008), therefore providing a level of validation for the model. In addition, the model provides meaningful insight into the dynamics that bring about the results, such as the race begins in earnest as innovators, who can be thought of as the instigators, set out to maintain their share of the revenue when faced with more of their kind. The imitators, who are quite unmotivated by nature, are then forced to try to keep up the best they can, preferring an environment where there are fewer firms in total and fewer of their kind. These findings are all meaningful contributions to understanding the dynamics of the Red Queen effect.

This paper also provides numerous clues for policy makers in terms of encouraging innovative behaviour. Consistent with the thoughts of Schumpeter (1942), regulators should not be concerned with highly concentrated markets if they are made up of innovative firms, as it is more conducive to innovative activity. One only needs to look at companies such as Google and Apple or Boeing and Airbus to see the truth in this statement. Regulators should be more concerned if the firms in a concentrated market are imitators; they should encourage greater competition, in which case only a small number of innovators is sufficient to force the existing imitators to start running faster. The situation would be akin to Tesla, or Southwestern Airlines, who disrupted industries with low levels of innovative behaviour, causing a surge in activity from the incumbent firms. However, given the lack of empirical validity of the model, the policy implications stemming from this model are somewhat speculative.

The model in this paper has provided a solid foundation on which to investigate the Red Queen effect. By removing several of the somewhat subjective assumptions and design features with more empirically based ones, the validity and utility of the model will be enhanced. The prime change would involve the achievable margins of the firms. With margins currently being homogeneous—meaning that there is no first-mover advantage in terms of production costs, and production costs exhibit constant returns to scale—there are numerous avenues available to enhance the model. In addition, the age of a market, and the number of firms within it, could also affect the achievable margin. Combining these changes with firms targeting a share of the available profits rather than revenue has the potential to produce a rich set of results. In a similar manner, a firm's decision to undertake an action could be based on a return on their investment. Finally, the ability of the innovator to charge (and maintain) a premium is something that should be considered given that the premium is another way in which the innovators' returns could be enhanced.

The opportunity also exists to increase the role of the consumer in deciding whether an innovation or imitation is accepted in the market. This step is likely to require a significant redesign of the model; but given the early results of the model, this would be a worthwhile pursuit.

The utility of moving away from the traditional use of representative agents and towards are more dynamic and adaptive view of how the economy works has been effectively demonstrated in this paper. The utilization of an ABM has been central to this achievement, and as the growth of this form of analysis grows, more insights into how the economy truly operates will be revealed.

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