Through the Red Queen effect

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Abstract

One of the important issues in the field of strategic management is to know the factors that explain why companies operating within the same sector have different performances. The evolutionary theory affirms that innovation could justify why certain firms remain in a prominent position in the market ensuring high yields. A scenario that explains the evolution of innovation among rivals is known as the Red Queen effect. In this scenario, an action carried out by a firm influences its performance and promote innovation among rival firms, affecting negatively the performance of the first. This paper is aimed to construct a system dynamic model capable of explaining the survival of two firms affected by the effect. To contrast the hypothesis on which the model is constructed, the innovation paths of two rival firms in a specific industry are examined. A simulation exercise tests the capacity of the model to replicate the creation of new products.

Keywords: Innovation, Competition, Duopoly, System Dynamics, Simulation

Introduction

The Red Queen is a character created by Lewis Carroll that appears in the book "Through the Looking-Glass". In a sequence of the story, the Red Queen runs hand in hand with Alice and cries "Faster! Faster!" During the race, Alice realises that, though she are running as fast as she can, neither they nor the neighbours around them never changed their places at all. An exhausted Alice asks the Red Queen the reason behind it and she answers: 'Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!'

The insight of the Red Queen concerning the need of continuous efforts to keep up has been the underlying idea used on distinct realms to explain different processes. The biologist Van Valen (1973) proposes the Red Queen scenario to explain why the probability of extinction for species and larger evolutionary groups bears no relation to how long it may have already existed. The economist Baumol (2004, p. 238) maintains that the Red Queen scenario describes one of the most powerful economic mechanisms in economic development and in history. He affirms that it underlies the exponential behavior of investment in innovation in at least the past century. Also, he offers historical examples of its existence and emphasizes its critical role in the origins of democracy and capitalism. From the perspective of rivalry between firms, Derfus et al. (2008) confirm the existence of the Red Queen effect after analyzing a sample of all the major competitors in eleven different industries across a broad spectrum of the US economy. The study finds over 4,700 actions justified by the scenario.

According to Baumol (p. 238), a "Red-Queen game" is a competitive scenario in which every player's success requires her to match or exceed the current efforts or expenditures of rivals, so that each is forced by the others to bid ever higher, and all participants find themselves required to run as quickly as they can in order to stand still. In a business context, Derfus et al. (p. 61) specify that the Red Queen can be seen as a contest in which each firm's performance depends on the firm's matching or exceeding the actions of rivals. Each firm is forced by the others in an industry to participate in continuous and escalating actions and development that are such that all the firms end up racing as fast as they can just to stand still relative to competitors. Rival firms are trapped, therefore, in a spiral of increasingly rapid responses. Schumpeter (1976) summarizes the consequences of the effect when affirms that the process of creative destruction entails an incessantly revolutionizes from within, incessantly destroying the old one, incessantly creating a new one (p. 83). Firms are in a constant process of creation; this is, they are in the “perennial gale of creative destruction” that ignores past achievements.

In the Red Queen game between rival firms, the innovation can be the excuse to play. It can be the tool on which firms play a game whose rules are dictated by the Red Queen. Innovation often supposes a competitive advantage, an opportunity to growth and a challenge for the competitors. In a Red Queen effect, the innovation of a firm boosts the others that will try to achieve a new innovation as fast as possible to reach the next predominant position in the market. Nowadays, in a world with many competitors in a same market, this process of continuous innovations appears in nearly all industries; think of, for example, automotive, mobile phone, pharmaceutical, food, or motorbike industry. Actually, a globalized word exacerbates the innovative impetus as the number of competitors in all industries increases. Figure 1 shows the evolution over time of patents in different regions confirming that innovation is faster than it was in the past. The fast increase of innovations might be explained by the modus operandi of the Red Queen to suit her environment: there are time intervals in which she runs fast, very fast, while she rests for other ones.

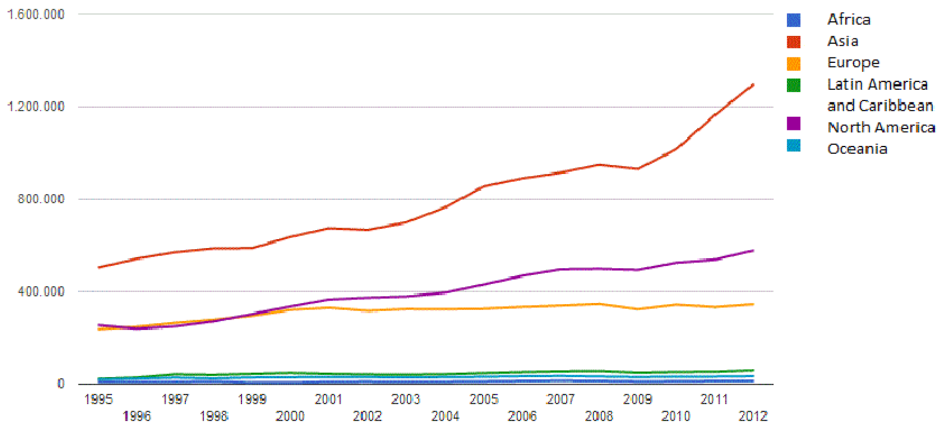


Figure 1: Total patent applications

Source: WIPO statistics database. January 2014

The actions and responses of firms affected by the Red Queen could help to explain the dynamics of innovations and, as a result, the differences performances of the firms involved in rivalry. System dynamics (SD) methodology can carry out the study. In fact, the Red Queen scenario is characterized by a spiral of interrelated causes and effects, which are at the core of SD, making, therefore, the Red Queen scenario a perfect subject for the SD approach. Indeed the methodology can be the best option to tackle the study in accordance with Gary et al. (2008, p. 422) who propose that SD is not only well positioned to identify how decision making drives dynamics and leads to performance heterogeneity, but also that it is better positioned to do so than many alternative research methods.

Building SD models for the study of competition in business strategies is not new. Oliva et al. (2003) in a SD model with multiple competitors examine a ‘get big fast’ (GBF) strategy whereby firms pursue to grow as rapidly as possible and pre-empt their rivals. These firms usually maintain very low prices, carry out heavy advertising campaigns and form alliances to build a market clout with suppliers and workers, deterring the entry of new players into the market. The strategy depends strongly on positive feedbacks that, in turn, could make the firms highly vulnerable. These loops can even lead them towards collapse as happened with dot coms companies. Using a simulation model of a duopoly case, Sterman et al. (2007) confirm that in more complex and dynamic environments—particularly those in which demand evolves quickly relative to capacity adjustment—aggressive strategies may lead to disaster, even when the conditions for success specified in the neoclassical literature have been met (p. 685). Strategies that promote growth but can end in disaster have also been examined by Forrester (1968).

Gaining market share and grow faster than the rivals are targets pursued for companies both following GBF strategies and those involved in the Red Queen race. However the tactics to achieve those targets differ. Unlike companies following GBF strategy, the firms involved in the Red Queen race must perform continuous innovations carried out by their research and development (R&D) departments. These differences suggest that the modellings should be different as well. When the Red Queen acts, it is essential to take into account the innovation process based on the formation of new ideas that replace the old ones in accordance with Schumpeter.

The aim of this paper is to construct a SD model to test if the Red Queen effect is capable to justify how innovation evolves in a duopoly and under a temporal horizon in the medium term. The model has to show the competitive evolution between the firms, including the speed of rival response. Nevertheless, the model will try to be parsimonious. In this regard, we can recover the message affirming that the benefits of simplifying system dynamics models and theories to more powerfully and persuasively communicate the key insights (Gary et al., p. 423).

To manage complexity, our approach considers a duopoly and a temporal horizon adjusted to avoid possible unwanted long-term consequences of the Red Queen effect: new competitors, exits, bankruptcies, merges or acquisitions. Consequently, both firms will keep in continuous competition so that each successful response determines a new challenge for the rival. The competitive advantages are only temporary and the success reached in the past does not matter. The two firms continue playing, keeping alive the Red Queen. But, if the firms will play this difficult game why they do that? In this regard, it is assumed that the motivation of the firms to keep in the scenario is consequence of the positive causal relationship between its innovation successes and its share of market, which directly influence on its performance. This assumption would justify performance differences with similar arguments to those exposed in the evolutionary theory of Nelson and Winter (1982). Nevertheless, the assumption about the motivation could be controversial as some examples confirm. An exemplification is the case of Apple and Samsung that, many times, their market share is consequence of good advertisement campaigns more than authentic innovations.

The paper is organized as follows. The second section debates what elements take part in the causal structure and why they have been selected to explain how the effect performances. The third section constructs a simulation model taken as reference two leader firms in a particular industry. The Red Queen race could justify the evolution of their new products and a simulation will try to replicate such behaviour. Finally, the most relevant results are emphasized and some consequences are explored.

Modeling leadership

In a duopoly in which a focal firm and its rival take part, Figure 2 illustrates a causal diagram that explain how these firms play the Red Queen race during a definite temporal horizon. The model focusses on three internal processes of each firm and the feedback between them: creativity, innovation and the organization's reaction to the success of its rival. Other aspects of the firms, such as marketing, finances, production, etc., are not considered. The diagram contains six loops; four of them are reinforcing loops and the rest negative ones. The negative loops balance the reinforcing loops and the model describes an endogenous growth for both firms.

The loop R1 outlines the share market of each firm. The share depends on the number of products that each firm has in the market though the model does not explain how the new products spread in the market (Milling (1996, 2002), Maier (1998)). The structure of this loop is simple as the market is shared by the two firms: the gain of the focal firm entails the loss of the rival and vice versa. Two types of products are considered: new products capable of shaking up the market and products that are improvements to existing products. It seems clear that new products appear in the market at a slower pace than improvements to existing ones. The product improvements are the most frequent innovations in the majority of industries: software, mobile phones, televisions, food, etc. Both kind of products may be considered separately as done in Sterman et al. (1997), but given that the model does not take into account the individual impact of each product innovation on the market, the distinction between both innovations is not relevant.

Obsolescence decreases the number of innovative products of each firm. At this point, various theories coexist on how the process works. For example, Sterman et al. (1997) consider an average product life to product discontinuation; Buera et al. (2013, p. 218) assume that products die with a constant hazard rate and are immediately replaced by a new one that arises following a Pareto distribution. Smith et al. (1992, p. 44) claim that product life cycles have shortened and continue to shrink nowadays. Moreover, they indicate ten areas in which R&D managers can help to shorten the cycle time for new products and projects. This widespread assertion is justified because firms quickly introduce new products in the market, causing the obsolescence of rival products. Based on an empirical study, Bayus (1994, p. 305) affirms that the product life cycles depends on several factors such as innovativeness, price and necessity. Although certain economic conditions such as population growth or lifestyle can also affect to the cycles. Nevertheless, this author upholds that competitive interactions can shorter the life cycles of certain products although, in a general context, the affirmation cannot be accurate.

The reinforcing loop R2 describes knowledge creation and the application of this knowledge to generate innovations. Each firm is only involved in its particular processes, although both firms are connected due to the information that one absorbs from the other.

Regarding the first aspect, the number and frequency of innovations are subjects to different points of view. Repenning's model (1999, p. 8) considers that new products are introduced in previously established deadlines taking as example the automotive industry. However, other industries behave in a different way such as pharmaceuticals, medical care or animal health industries that quickly introduce innovations into the market. Grossmann et al. (2013) assert that new products get into the market as soon as the ideas are developed. These authors affirm that the ideas are generated according to a differential equation, which involves labor input in the R&D sector and existing ideas. The equation takes into account two externalities: it is harder and harder to innovate when the number of preceding innovations is high and rivals may work on the same idea causing R&D redundancy in the market.

Regarding the second aspect, the factors that influence creativity are accepting almost unanimously. Grossmann et al., claim that existing knowledge is a basic element for new knowledge. This same idea is stated by Brockman et al. (2003, p. 390) that, additionally, asseverate that entrepreneurship fosters new product innovativeness. Su et al. (2013) provide additional elements to foster new knowledge; they not only consider firms 'own knowledge but also external knowledge that firms have to assimilate in the spirit of Cohen and Levinthal (1990). In addition to capture and assimilate external knowledge, firms could stimulate the creation of new knowledge by developing strategies to promote it (Amabile et al. (1996) p. 1156). In that sense, one of the main objectives of the organizational strategy would be to motivate innovation and to support creativity. It should be taken into account that creativity requires resources, especially time, and likewise, management must allow research teams to have certain autonomy to foster creativity.

Our interpretation supposes that each firm's new knowledge causes its new products. The new knowledge is quantified by means of a production function, Cobb-Douglas style, with decreasing returns on account of hardness of creativity. The number of new products is a random function in accordance with Aghion (1990, p. 3) and innovations arrive during the current unit of time according to Poisson process. Therefore, the new knowledge affects the number of new products and its frequency, though both aspects are random.

The reinforcing loops R3 and R4 capture the formation of new knowledge for each firm. The loops explain that for each firm existing and external knowledge foster new knowledge, catching a standard "standing on shoulders" effect. External knowledge indicates knowledge created elsewhere. Nevertheless, given that, the model examines a duopoly, external knowledge must be provided by the innovations of the rival. The model does not take into account, as Grossmann et al., that both firms could be developing the same research that, obviously, would be prejudicial to the slower firm. Following Grossmann et al., the causal diagram assumes that R&D sector influences directly on new knowledge; however, unlike these authors this influence is consequence of the commitment of the R&D department to the current project (Repenning (2000), Hilmola et al. (2003), Tu et al. (2009)).

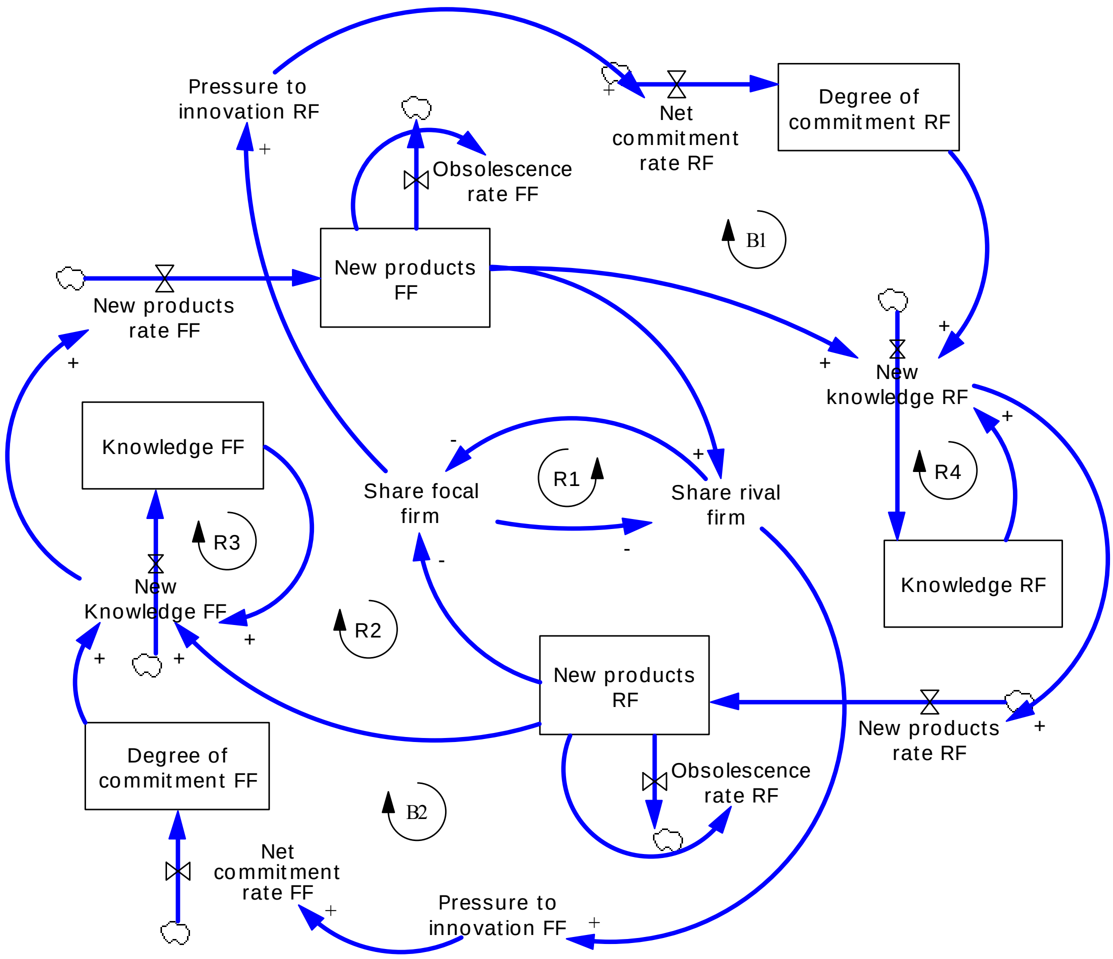


Figure 2: Competitiveness in a duopoly

The negative loops B1 and B2 describe how the success of a firm forces its rival to adopt similar strategies in order to achieve the next innovation. These loops take into account management practices, workforce, knowledge and innovation. The connections between all the aforementioned elements could be summarized as follows. When a firm has a new product in the market, the rival firm presses its workforce to draw another new creation. This pressure should result in a greater involvement of workforce, implying a higher likelihood to achieve a new product. The loops work alternatively between both firms: at each period of time, the highest pressure is focused on a firm and when it is successful, the pressure moves to its rival. The existence of pressure is justified because the implication of all organization in creativity is not spontaneous, at least to certain degree. The research teams will be focused on their projects but the management will press them when the results of its rival firm become evident. The effect of management's pressure on creativity is generally accepted as positive on the condition that the pressure is not excessive. In contrast, too much pressure could cause the opposite effect and undermine the research. Amabile et al. suggest that the pressure from the organization must be assumed by the teams as the urgency of an intellectual challenge more than a way for control.

The pressure is exerted in the R&D department because the research teams are vital to creativity and, as a result, they are responsible for the firm's competitiveness. The effect of the pressure is commitment to the project and in accordance to Sterman et al. (1997, p. 509), its quantification could follow the differential equation:

$dC/dt = \theta (C^*-C) + \omega C (1-C)$.

The first term reflects the result of the management's effort to improve the commitment among the members of team. The second term captures the effect generated by successful results: the more people are involved in creativity efforts, the more they will communicate their enthusiasm to others through word of mouth. The commitment C, which is a variable between zero and one, is the average commitment of the workforce in the R&D department; C^* indicates the commitment that the management wants to reach; θ sets the gradual increase of commitment towards its target C^*. The word of mouth effect ω can have either a positive or negative impact on commitment because it joints tree aspects: the impact of results, the impact of the adequacy of management support and the impact of perceived job security and stability.

Simulation model

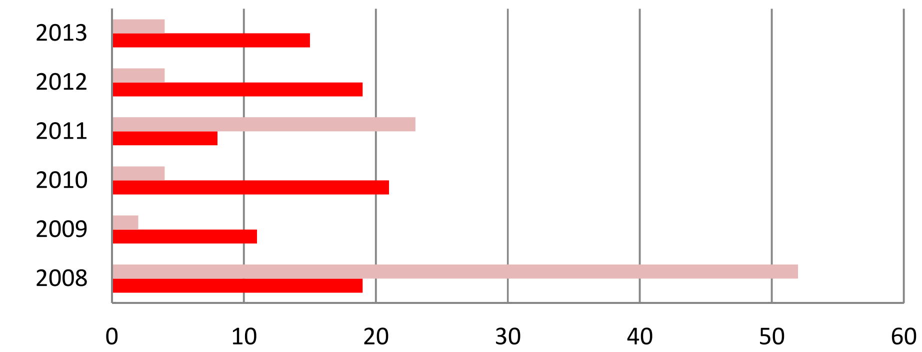
In the sector of a specific electric device for personal cleanliness, there are two firms that share over 60% of European market. The rest of market is distributed by other four or five firms. The data about new products and innovations of leading firms can be found in the Internet advertisement pages of both firms. However, the data for both firms are not analogous. Whereas one of the firms (firm A) publishes launch date (month/year) of its new products, the firm B does not and as a consequence the identification of the launch month for its products is hard. Given that they have problem to provide the data, a solution is to distribute proportionally by month in case the monthly comparison between firms was necessary. Another difference is related to the obsolescence of new products. The oldest product for a firm A was born in 2008 and for firm B in 2007. Unfortunately, these data does not allow obtaining the average life of the products.

The struggle for market dominance characterized by the Red Queen effect is confirmed by the evolution of new products for these two firms. The year of introduction of these products is shown by Figure 3. Observing this yearly distribution of new products, it is clear how the Red Queen effect works between them. At the end of 2008, firm B dominated the market. Therefore, all the pressure was for firm A that at the end of 2010 managed to reduce the gap between them. When firm B notices the loss of market share, it pressures itself in order to achieve good results, managing to do so at the end of 2011. Once again, all the pressure is for its rival the firm A that, at the beginning of 2014, had 83 products in the market while the firm B had 89 products.

Our aim with the simulation exercise is to replicate the observed pattern. The temporal horizon of the model is six years (2008-2013) and the unit of time is a month. The model is symmetric for the two firms since both are involved in parallel processes. To obtain the number of arrivals of new products, a

Monte-Carlo procedure is used. The procedure generates a sequence of numbers that are distributed following a Poisson process with an average equal to the new knowledge rate. The seed used for the generation of the random numbers varies for each run of simulation (50 different runs have been made). Two random numbers for each firm are used; every random number specifies the number of arrivals of new products and, then, the maximum number of new products for a year is 36.

Obsolescence of new products is not considered due to the difficulties to calibrate this fact in accordance to data. However, it is assumed that a certain fraction of the knowledge of each firm will become unnecessary. This assumption is based on the length of the temporal horizon: the fraction of the new knowledge that is used to obtain the new products cannot be used in the immediate future. Nevertheless, it can be used later but the model does not take into account this fact due to the temporal horizon.



	2008	2009	2010	2011	2012	2013
Firm B	52	2	4	23	4	4
Firm A	19	11	21	8	19	15

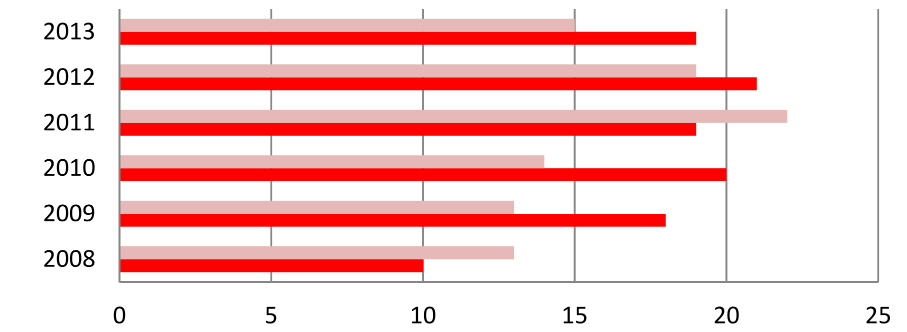
Figure 3: Distribution of new products by year of introduction

The transformation of knowledge (dimensionless) in products (units of product) and vice versa requires introducing in the model more auxiliary variables than those considered in Figure 3. Moreover, the model considers that both firms have a set of resources that are used when the rival is obtaining too successes. For example, the firm with lower market share has to use these resources if the firm with high market share produces during two consecutive years more products that it. The issue is that the model considers that a firm can increase the number of new products by changing the color, the size of previous products or by modifying little characteristics of other products, which, moreover, is quite common in the selected market.

The model is dimensionally correct (Rahmandad et al. (2012)) and reacts properly to extreme situations. Figure 4 displays the new products launched per firm and year. These values are the average value of the 50 simulations according to different sequences of random numbers that influencing the rate of new products. As it is possible to check the simulation results follow the pattern shown by the real data. However, from a quantitative view, the model provides values that do not adjust totally to the real data. A statistics analysis of the divergence between real and simulated results is not representative because of the series are too short.

Final remarks

As far as we know, system dynamics has not addressed the causal analysis of the Red Queen effect in any field where it may arise. This one aspect alone would make the topic interesting to the SD community. In this regard, the topic broadens the literature to incorporate the effect in a context of rivalry between firms. In addition to this, the modelling contains other contribution that the literature has not yet considered: the creation of new knowledge driving by the R&D departments, the management and the knowledge captured from the rival firm. These relationships are both easy to understand and to implement establishing a new perspective to explain the dynamics of the innovations.



	2008	2009	2010	2011	2012	2013
Firm B	13	13	14	22	19	15
Firm A	10	18	20	19	21	19

Figure 4: Distribution of new products by year of introduction (simulation results)

The selection of the SD methodology allows us to examine and learn about the Red Queen effect. Instead of examining isolated cases of one-time responses to innovations, SD can check how the innovations evolve over time. Indeed, SD can explain how the Red Queen effect works. For example, is it possible to think that the effect is not happening because the response of a firm is not as fast as it should be on account of the data? Simulations confirm that maybe due to technological, strategic or R&D workforce factors, a firm could have slower responses than expected during certain intervals. However, this does not imply that the firm leaves the market that is infected by the effect: the firm runs as fast as it can. This possibility is checked by the simulation exercise, highlighting the importance of SD models to test mental models.

The model can support different variants such as the introduction of delays or exogenous elements, the modification of functional settings or the adaptation to other sectors. However, the results achieved by the model seem to follow the behavior patterns of the selected industry. A complete or total replication of the behavior of both firms is not possible due to lack of information. Also, the model can be extended in several directions. For example it could incorporate multiple competitors, enriching both the modelling and the dynamics. Likewise, the model could include other areas of the firms or other rules for the actors.

References

[1] Aghion P. 1990. A model of growth through creative destruction. *NBER Working Paper 3223*.

[2] Amabile T.M., Conti R., Coon H., Lazenby J., Herron M. 1996. Assessing the work environment for creativity. *Academy of Management Journal*, **39**(5), 1154-1184.

[3] Baumol W.J. 2004. Red-Queen Games: arm races, rules of law and markets economies. *Journal of Evolutionary of Economics*, **14**(2), 237-247.

[4] Bayus B.L. 1994. Are product life cycles really getting shorter? *Journal of Product Innovation Management*, **11**, 300-308.

[5] Brockman B.K., Morgan R.M. 2003. The Role of Existing Knowledge in New Product Innovativeness and Performance. *Decision Sciences*, **34**(2), 385-419.

[6] Buera F.J., Moll B., Shin Y. 2013 Well-intended policies. *Review of Economic Dynamics*, **16**, 216-230.

[7] Carroll L. (2006). *Alicia en el país de las maravillas. A través del espejo.*Ediciones Valdemar. 4ª Edición. Madrid.

[8] Cohen W.M., Levinthal D.A. 1990 Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly*, **35**(1), 128–152.

[9] Derfus P.J., Maggitti P.G., Grimm C.M., Smith K.G. 2008. The Red Queen effect: Competitive actions and Firm performance. *Academy of Management Journal*, **51**(1), 61-80.

[10] Forrester J.W. 1968. Market growth as influenced by capital investment. *Industrial Management Review (MIT)*, **9**(2), 83–105.

[11] Gary M.S., Kunc M., Morecroft J.D.W., Rockart S.F. 2008. System Dynamics and Strategy, *System Dynamics Review*, **24**(4), 407-429.

[12] Grossmann V., Steger T., Trimborn T. 2013. Dynamically optimal R&D subsidization. *Journal of Economic Dynamics and Control*, **37**(3), 516-534.

[13] Hilmola O.P., Helo P., Ojala L. 2003. The value of product development lead time in software startup. *System dynamics Review*, **19**(1), 75-82.

[14] Maier F.H. 1998. New product diffusion models in innovation management- a system dynamics perspective. *System Dynamics Review*,**14**(4), 285-308.

[15] Milling P.M. 1996. Modeling innovation processes for decision support and management simulation. *System Dynamics Review*, **12**(3), 211-234.

[16] Milling P.M. 2002. Understanding and managing innovation processes. *System Dynamics Review*, **18**(1), 73-86.

[17] Nelson R.R., Winter S.G. 1982. *An evolutionary theory of economic change*, Belknap Press. Cambridge, MA.

[18] Oliva R., Sterman J.D., Giese M. 2003. Limits to growth in the new economy: exploring the 'get big fast' strategy in e-comerce. *System Dynamics Review*, **19**(2), 83-117.

[19] Rahmandad H., Sterman J.D. 2012. Reporting guidelines for simulation-based research in social sciences. *Systems Dynamics Review*, **28**(1), 396-411.

[20] Repenning N.P. 1999. Resource dependence in product development improvement efforts". Descargado de Internet en agosto 2013.

[21] Repenning N.P. 2000. A dynamic model of resource allocation in multi-project research and development systems. *System Dynamics Review*, **16**(3), 173-212.

[22] Schumpeter J.A. 1976. *Capitalism, socialism and democracy*. George Allen&Unwin. London.

[23] Smit P.G., Reinertsen D.G. 1992. Shortening the product development cycle. *Research Technology Management*, **35**(3), 44-49.

[24] Sternan J.D., Henderson R., Beinhoker E.D., Newman L.I. 2007. Getting Big too Fast: Strategic Dynamics with Increasing Return and Bounded Rationality. *Management Science*, **53**(4), 683-696.

[25] Sterman J.D., F. Repenning N., Kofman F. 1997. Unanticipated Side Effects of Succesful Quality Programs: Exploring a Paradox of Organizational Improvement. *Management Science*, **43**(4), 503-521.

[26] Su Z., Ahlstrom D., Li J.,.Cheng D. 2013. Knowledge creation capability, absorptive capacity, and product innovativeness. *R&D Management*, **43**(5), 473-485.

[27] Tu Y., Wang W., Tseng Y. 2009. The essence of transformation in a self-organizing team. *System Dynamics Review*, **25**(2), 135-159.

[28] Van Valen L. 1973. A new evolutionary law. *Evolutionary Theory*, 1, 1-30.