Absorptive capacity of demand in sports innovation

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Abstract.

We propose a stylized and tractable Neo-Schumpeterian model of sectorial transformations in which demand side knowledge constraints inhibit innovation diffusion and industrial change, causing structural instability. Evolutionary competition in the model implies that innovation can overshoot the absorptive capacity of demand, leading to a slowdown in sectorial dynamism and even to structural collapse. Closed-form analytical results prove the existence of a unique stationary state in the dynamic model that is (globally) asymptotically stable. We show how the dynamic paths and the stationary rest-point depend on the trade-off between innovation and demand absorptive capacity parameters. To illustrate the plausibility and relevance of our results, we examine the Australian windsurfing industry in which diminished demand absorptive capacity (in the terms of the model) was a factor underlying sectoral collapse. We discuss how development of absorptive capacity of demand is a local public good and a collective action problem for an industry sector, and the role of demand side factors as constraints in industry and innovation policy.

Keywords: Industrial dynamics, sports industries, Absorptive capacity, Innovation models, Demand.

JEL Codes: L52, C62, O31, O33.

1. Introduction.

We propose a Neo-Schumpeterian model of sectorial transformations that draws on evolutionary economic modelling (Metcalfe 1998, Metcalfe et al. 2006). This stylized and tractable type of evolutionary framework is an effective way to study the role of knowledge and cognitive constraints from the demand side of a market as an inhibiting factor for innovation diffusion and industrial transformations. In our stylized model, innovation in an industry can overshoot the demand absorptive capacities, thus slowing-down (or even reverting) the rate and direction of sectoral technical change. This result emerges because of a coordination problem between market demand knowledge and supply-side knowledge.

Our approach recognizes the importance of demand-side *absorptive capacity* in innovative environments, but highlights several new issues for industrial dynamics when knowledge constraints come from the demand-side. We therefore combine two different Schumpeterian literatures—the theory of absorptive capacity (Cohen and Levinthal 1990), and the theory of innovation overshooting (Earl and Potts 2013, 2016), and we address the resulting mechanisms within a new Neo-Schumpeterian model. The purpose of this paper is to explore some of the consequences of unbalanced demand-supply knowledge in a highly stylized model, and extract new implications for innovation policy. We qualitatively verify the plausibility of our formal approach by applying it to a real case study in the context of technology driven sports industries—specifically, the Australian windsurfing industry (Thomas and Potts 2015).

The standard approach to innovation policy pioneered by Nelson (1959) and Arrow (1962) is essentially a supply-side/basic-science/technology-push approach (Arrow 2012). The policy prescriptions that follow from the Arrow-Nelson paradigm target innovation policy at the source of *market failures*. These include aligning private and social benefits from basic science; dealing with externalities and uncertainty; and creating strong incentives for R&D investment. As a complementary approach, which we develop in this paper, we might also consider that some *innovation failures* could also be explained with reference to the demand-side of the market. In this paper we explore coordination problems that arise when matching demand and supply in the context of increasingly complex consumer products, a complexity itself driven by Schumpeterian competition. We are specifically concerned with the dynamics of innovation adoption when a gap of knowledge and understanding opens up between creators (supply) and consumers/users (demand) of new knowledge. In order to analyse this problem, we present a stylized model of sectorial transformation using replicator equations (Metcalfe 1998, Hofbauer and Sigmund 1998), in which two varieties of a good co-exist and compete in the same sector. This is a common situation in Schumpeterian competition, where the older version is also an older technology, but will have a large established market share and will be familiar to consumers, and the newer version is also a newer technology, and will initially have a smaller market share of experimental users. A key difference that we want to focus on with our model is that the newer version, which is also a newer technology by definition known to producers, will also need to be learnt by the new consumers. This introduces the idea of demand-side absorptive capacity as a constraint on technological adoption.

We model demand-driven sectorial competition and growth –involving competition between the new and the old product varieties- through a replicator dynamics setting, and we end up obtaining a (non-linear) differential equation for the new technology market share, that is analytically tractable in continuous time. As we will see, we also obtain the evolution of the old technology as a tautological mirror of the new one. A *technological innovation* parameter represents the distance between the old versus the new varieties of the good. We also incorporate *demand absorptive capacity* as a key parameter that drives the evolution of market share. The dynamic analysis of this model of the evolution of demand (across the two product varieties) provides us with some closed-form results that show how, and under what conditions, demand absorptive capacity explains the expansionary pattern of the “new” version of the good and therefore the industrial dynamics of the sector. We also obtain certain indicators of speed of change and multiplier effects that have implications for industry coordination.

Section 2 introduces and develops the evolutionary model. Section 3 presents the dynamic analysis of the model which allows us to obtain some closed-form results. We present additional results in the Appendix which may be helpful in understanding the model dynamics. Section 4 draws on results from Section 3 to interpret aspects of the evolution of the Australian windsurfing industry as a case study. We conclude that demand-side absorptive capacity is a potentially significant and underappreciated factor affecting innovation diffusion and industrial dynamics.

2. The model

In this section, we propose a simple (highly stylized) evolutionary model that builds on the replicator dynamic approach developed by Metcalfe (1998) and Metcalfe et al. (2006). We use this approach to analyse in detail a particular mechanism in the evolution of industries with technological competition, in which the supply of innovative new products runs up against demand side absorptive capacity constraints. For simplicity, we focus in the evolution of a single sector in which two varieties of the sectoral good are produced. In the case study in Section 4 below, the sector is the Australian windsurfing industry, and the varieties are different technologies of board, sails and rigging. We distinguish between what we call an "old" (or well-established, traditional) variety "Y" of the sectoral product, whose market share at *t* is represented by $0 < y(t) < 1$, and a "new" (emergent) product variety "X" whose market share at any time is given by $0 < x(t) < 1$. We assume that both market shares are continuous and continuously differentiable functions of time (variable *t*). Likewise, since we just consider an "old" and a "new" product variety, it is clear that $x(t) + y(t) = 1, \forall t$. Therefore, once we obtain the dynamics of $x(t)$, we can also obtain the dynamics of $y(t) = 1 - x(t)$. Also note that as long as we are considering that "X" is the emergent-new variety, it seems sensible to assume that, initially, $x(0) \ll y(0)$. For the sake of formal simplicity, and because this assumption does not prevent us from studying the phenomena we are interested in, we assume just the above-mentioned two product varieties in the market, with no entry of new options as time goes by.

Assume the "new" product variety "X" embodies an objective rate of improvement (in normalized performance/price terms) equal to λ, $(0 < \lambda < 1)$ as compared to the normalized performance/price of the "old" variety "Y" (which we assume is equal to "1"). This is a typical assumption in relative-fitness evolutionary models (Hofbauer and Sigmund, 1998). In general terms, we may consider λ as the *innovation jump* (or objective advance in embodied functionalities) of the new product variety, as related to the old sectoral-good version. Thus, we can denote by

$f_y(t) = f_y = 1$ the normalized fitness of the old version "Y", and by $f_x(t) = f_x = 1 + \lambda > 1$, the relative (objectively improved) fitness of the new product version "X"[1].

As usual in Metcalfe-type (1998; 2006) formulations, we propose a demand-driven evolutionary model of sectoral transformation in which the overall growth rate of sectoral supply and demand is constant (and exogenous) equal to $g \in (0,1)$, and the growth rates of (supply and demand) for, both, the "old" and the "new" varieties, vary with respect to the overall (average) rate depending on the relative levels of performance/price normalized fitness. We assume that firms (let us say, a continuum of firms) are temporarily distributed between the manufacturing and supply of both varieties, and they may gradually shift (or not) to produce the alternative variety depending on the evolution of demand. It is crucial in the model the gradual transformation of demand –as consumers being used to consume the "old" variety, gradually discover and understand (or not, or partially so…) the "new" variety. Thus, we consider that the continuum of firms may gradually adapt the growth rate of sectoral production to the evolution of demand for both varieties, "X" and "Y" , and they do it according to the respective demand growth of both varieties.

We can formalise the key mechanisms in our demand-driven model for the alternative product varieties (old and new) as follows:

(1) The demand growth rates of both varieties "X" and "Y" of the sectoral good are given (respectively) by:

$$g_x(t) = g + \left(\alpha f_x - \bar{f}(t)\right), \qquad g_y(t) = \frac{g - x(t) g_x(t)}{1 - x(t)} \qquad (1)$$

$$\bar{f}(t) = x(t) f_x + y(t) f_y = 1 + \lambda x(t)$$

so that $x(t) g_x(t) + y(t) g_y(t) = g$. This assumption combines the well-known Metcalfe-type approach to sectoral evolutionary growth (with demand driven ongoing structural transformation), and our relative fitness approach to old/new varieties-competitiveness in normalized performance/price ratios. Note that $\bar{f}(t)$ is the average

[1] Notice that this assumption can be interpreted, either as a unique *innovation jump* allowing for a new variety which is objectively superior to the old variety with a distance λ, or as, both, the old and the new varieties improving their functionalities at a constant common rate, but being separated (*in favor of the new variety*) by a constant level λ.

fitness (or average competitiveness level) in the market that endogenously changes as time goes by.

(2) The α parameter in (1) represents what we call the *absorptive capacity of demand*, that is to say, the cognitive ability of consumers/users to understand, to use, and to acquire, the "new" variety "X". Clearly, the higher the value of α, the higher the *absorptive capacity of demand* regarding the improved performance/price (relative fitness) of the new variety.

Let us notice that parameter α capturing in the model what we call the *absorptive capacity of demand*, is a generic and aggregate representation of several aspects which usually appear as distinct factors in standard models. More precisely, note that (e.g.) absorptive capacity applied to consumer behaviour would include not only cognitive constraints, but perhaps also income, preferences for novelty *vs* traditional options, and –of course- cognitive elements such as the ability to handle new devices or equipment, learning capabilities, cost and time to learn, and so on, with all these factors being crucial in determining the diffusion of innovations. Since our model is a first step in addressing demand absorptive capacity in a tractable evolutionary framework, we have decided to keep (for the time being) the formal representation as neat as possible. Thus, we have chosen the use of an aggregative parameter α instead of proposing explicit micro-foundations. In this way, we can convey the new arguments and results in a powerful and easily understandable manner.

As it is shown below, for the sake of economic meaning regarding market shares, we must assume that:

$$\left(\frac{1}{1+\lambda}\right) < \alpha < 1\,, \qquad \text{with} \qquad 0 < \lambda < 1. \qquad (2)$$

It is interesting to mention that, because of these conditions (which are essential for the model to work well), the relevant interval for the *absorptive capacity of demand* is:

$$\frac{1}{2} < \alpha < 1.$$

This is an interesting (very preliminary) implication of our framework. We believe that it is remarkable since the model seems to require a relatively high level of absorptive capacity, just to begin the analysis in an economic meaningful way!. In our opinion, this condition anticipates the crucial role that demand absorptive capacity is going to have in what follows. Nevertheless, as we will show in the analysis and in the case-related simulations, a value of α just above 0.5 is not enough to assure a viable industry evolution. Therefore, as we will show, not just a relatively high absorptive capacity, but a high! absorptive capacity of demand may be needed for innovative industries to develop in a sustainable way (more on this, later).

Now we can start combining the previous assumptions to arrive at a tractable global expression for the model dynamics. Notice that, from eq.(1), it is straightforward that the rate of change of the market share for the “new” variety "X" is:

$$\frac{\dot{x}}{x} = g_x(t) - g = \alpha f_x - \bar{f}(t).$$

with the expression $\dot{x}$ denoting $\dot{x} \equiv \frac{dx}{dt}$. (3)

Once we have in (3) the dynamics of the “new” variety’s market share, it follows that the dynamics of the “old” variety share is $y(t) = 1 - x(t)$. Therefore, if we focus our attention on studying the dynamics of $x(t)$, we fully capture the essence of industrial change in the model. Note that as soon as we arrive at the ordinary autonomous differential equation driving the dynamics of $x(t)$, the model is fully amenable to formal treatment and will be completely specified. Then, we proceed to obtain this fundamental differential equation and in Section 3 we will analyse the dynamic properties as well as certain further results.

Let us obtain, first, the fundamental equation of the model. If we combine (1) and (3), and taking into account the previous definitions of the main variables, it is straightforward to conclude that the dynamics of the model can be analysed through the following first-order (non-linear) ordinary differential equation:

$$\dot{x} = \Phi(x(t)) = x(t)[\alpha(1+\lambda) - 1 - \lambda x(t)] \qquad (4)$$

If we will keep in mind the economic meaning of $x(t)$ as the market share for the “new” product variety, and recall the constraints on the parameters stated in (2), then this equation (4) is the fundamental equation of the model that drives its dynamics. Now we turn to explore the properties of (4) and develop a closed-form solution for the equation in Section 3.

3. Dynamic Analysis

We follow two complementary strategies to analyse the dynamics arising from equation (4). First, we will analyse in global-general terms – see propositions 1 and 2 (below) – the existence and number of rest points (stationary states) for the dynamics, and the stability properties of each stationary state (Gandolfo 2009). These results allow us to characterize the properties of the stationary states in terms of the corresponding parametric values. From here, we can obtain multiplier effects around the relevant stationary state and propose a measure of the speed of convergence to the post-innovation structure of the sector. As we will see, these results have interesting economic interpretations related to the role of demand absorptive capacity in innovative industries discussed above. These results can be applied to assess the evolution of very different industries; for example, we will use them in Section 4 to reflect on the evolution of a real sport industry.

Apart from this analytical strategy, we also undertake a second type of formal exploration. Simple algebraic manipulations allows us to re-write equation (4) in a way that resembles a specific version of the logistic differential equation (Hofbauer and Sigmund 1998, Gandolfo 2009). This result (see proposition 3) allows us to obtain the general integral of the fundamental equation as a solution that completes and extends propositions 1 and 2. Furthermore, this suggests some simulations that illustrate our subsequent case-based analysis. Let us also note that since propositions 1, 2 and 3 provide a full and general closed-form analysis of the model, the simulations that we show in the next section (Section 4) are for illustrative purposes when appreciating some real features of a specific industry (the Australian windsurfing industry). Thus, a sensitivity analysis of the simulations is not needed in the current model, since propositions 1, 2 and 3 below fully characterize the dynamics and the properties of our modelled industry. Furthermore, propositions 1 to 3 make it possible for the reader to check all the interpretations and simulated paths that we will present in Section 4, and they open the way to explore new results. Now, all the aforementioned is clearly stated and proved in the following three propositions:

Proposition 1: *There exist two stationary states (resting points) in the model* (*eq.*(4)) *which are* $x_1^* = 0$ *and* $x_2^* = \frac{\alpha(1+\lambda)-1}{\lambda}$. *The first one,* $x_1^* = 0$, *is unstable and* *irrelevant under the assumptions adopted, and the second one,* $x_2^* = \frac{\alpha(1+\lambda)-1}{\lambda}$*, is globally asymptotically stable.* ■

Proof: By applying the definition of stationary state, we consider in eq.(4) $\dot{x} = 0$. Then, we obtain: $x(t)[(\alpha(1+\lambda)-1)-\lambda x(t)] = 0$; there are two roots for these second order equation which are the two stationary states: $x_1^* = 0$ and $x_2^* = \frac{\alpha(1+\lambda)-1}{\lambda}$.

Let us notice that, if we do not impose the condition (established in (2) above) $\left(\frac{1}{1+\lambda}\right) < \alpha < 1$, the second state $x_2^* = \frac{\alpha(1+\lambda)-1}{\lambda}$ does not have economic meaning as a market share. Therefore, we assume that the condition holds.

Now, let us analyse the stability characteristics of both stationary states. Regarding $x_1^* = 0$, considering (4) and the parametric constraints, since we obtain that $\frac{\mathrm{d}\Phi}{\mathrm{dx}}(x_1^* = 0) = \alpha(1+\lambda) - 1 > 0$, x_1^* is unstable and, therefore, irrelevant for our analysis. It is irrelevant because, apart from being unstable, we will always consider (at least at the initial stages of the industry) that both (new and old) varieties co-exist, so that their initial market shares are never null. Therefore, $x_1^* = 0$ is irrelevant.

On the other side, regarding x_2^*, the relevant resting point, as long as we see that $\frac{\mathrm{d}\Phi}{\mathrm{dx}}(x_2^*) = 1 - \alpha(1+\lambda) < 0$, x_2^* is locally stable. Additionally, it is easy to see that $\Phi(x) > 0, \forall x \in (x_1^*, x_2^*)$, and $\Phi(x)$ es strictly concave $\forall x \in (0,1)$; therefore, we can assure from what we have said that $x_2^* = \frac{\alpha(1+\lambda)-1}{\lambda}$ is globally asymptotically stable.

■

Thus, we have proved that the stationary state x_2^* is the point towards which, for any initial condition given, the market trajectory will always tend asymptotically. That is to say, for any $x(0) = x_0$, as closer to "0" as we want from the right-side, the system tends towards a "new" variety market share equal to $x_2^* = \frac{\alpha(1+\lambda)-1}{\lambda}$. Let us note that the value of x_2^* , (which is always positive and lower than 1 in the model), allows us to define the “old” variety market share as: $y_2^* = 1 - x_2^*$. Observe also that both shares and, therefore, the limit-market structure of the sector, depend crucially on the main (demand-side, and supply-side) parameters (α, λ). With these fundamental results on the model dynamics, let us now turn to analyse in the following proposition the role of these two fundamental parameters.

Proposition 2: *From equation* (4)*, and from the results obtained in Proposition 1, we can state that:*

1) *The stable state x_2^* depends positively on both the absorptive capacity of demand, "α", and on the “jump” in sectoral innovation "λ".*
2) *There is a multiplier effect operating in the sector around x_2^* according to which, an increase of 1 percent in demand absorptive capacity, generates a higher than “one to one” effect on the “new” variety-final market share. This multiplier effect of absorptive capacity is exactly $\frac{\partial x_2^*}{\partial \alpha} = \frac{(1+\lambda)}{\lambda} > 1$.*
3) *The parameters (α, λ) not only determine the limit-structure of the sector in the stable state x_2^*; they also determine the speed at which the sector evolves towards its limit-structure. More precisely, they affect positively the speed at which the new variety gains market share, and also the speed at which the sector converges to its steady state.*
4) *There exist compensatory effects between α and λ regarding, both, x_2^*, and the speed of convergence to this stationary state. This result suggests that there may be alternative ways (even alternative industrial policies) to transform and reinvigorate a sector.* ■

Proof:

1) From the results obtained in Proposition 1 and the assumptions of the model, it is easy to prove that: $\frac{\partial x_2^*}{\partial \alpha} = \frac{(1+\lambda)}{\lambda} > 1$, and $\frac{\partial x_2^*}{\partial \lambda} = \frac{1-\alpha}{\lambda^2} > 0$. Therefore, the higher the value of both parameters, the higher the limit-market share for the “new” variety within the industry.

2) Let us show that the expression $\frac{\partial x_2^*}{\partial \alpha} = \frac{(1+\lambda)}{\lambda} > 1$, can be obtained as the sum of the infinite terms of a geometric progression, with initial value $(1+\lambda)$, and common ratio $(1-\lambda)$ which is positive and lower than one, so that the progression is convergent. Formally:

   $S_\infty = [(1+\lambda) + (1+\lambda)(1-\lambda) + (1+\lambda)(1-\lambda)^2 + \cdots] = \frac{1+\lambda}{1-(1-\lambda)} = \frac{1+\lambda}{\lambda}$.

   This way of obtaining the *multiplier of demand absorptive capacity* allows us to see that, whereas the increase in α has an immediate increasing effect on the new variety-market share (reflected in $(1+\lambda)$), it also increases (indirectly) the average market competitiveness in eq.(1), thus stealing additional market share from the "old" variety, recalling that average fitness is:

$$\bar{f}(t) = 1 + \lambda x(t)$$

3) We prove point 3 in Proposition 2 by obtaining, and solving, the Taylor first-order series expansion of (4) in a neighbourhood of x_2^*, which leads to:

$$x(t) \approx (x_0 - x_2^*)e^{-(\alpha(1+\lambda)-1)t} + x_2^*$$

   with $(\alpha(1+\lambda)-1) > 0$ being the speed of convergence to x_2^*. Thus, this value is our indicator of the speed at which the "new" variety gains market share. Let us note that, by estimating the value of $(\alpha(1+\lambda)-1)$ in a specific industry, since $\frac{x_t - x_2^*}{x_0 - x_2^*} \approx e^{-(\alpha(1+\lambda)-1)t}$, this would allow us to calculate (e.g.) the time t^c that would take the market to cover half-way of the distance from x_0 to the limit market share of the new variety x_2^*. More precisely:

   $t^c \approx 0.7/(\alpha(1+\lambda)-1)$.

4) From Proposition 1 and part 1) of this proof, it is easy to show the expression of the second partial derivative of x_2^*, first with respect to λ, and then, with respect to α, That is: $\frac{\partial \partial x_2^*}{\partial \lambda \partial \alpha} = \frac{\partial}{\partial \lambda}\left(\frac{1-\alpha}{\lambda^2}\right) = \frac{-1}{\lambda^2} < 0$.

   Additionally, if we consider $x_2^* = \bar{x}$ -with $\bar{x}$ being a fixed value for the stationary state that we fix exogenously-, from the expression of x_2^* and being $x_2^* = \bar{x}$, we can obtain that: $\alpha = \frac{1+\lambda\bar{x}}{1+\lambda}$. If we derivate this expression with respect to λ, we obtain: $\frac{\partial\alpha}{\partial\lambda} = \frac{\bar{x}-1}{(1+\lambda)^2} < 0$. These two latest results prove the existence of a certain compensatory relationship between both parameters. ■

The interpretation of these results will help us to interpret the evolution of a specific real industry in Section 4 below. However, in general terms, they state that in any industry characterized by a relatively low level of λ (the 'innovation jump' between varieties of the product), the existence or development of a high level of demand absorptive capacity (α) would lead to a speed and scope of industry transformation in favor of the "new" variety, which could be analogous to the one obtained with a much higher innovation rate. This is an intuitive result – demand side innovation adoption is constrained by not only consumer budgets (prices and income) but also by the skills and abilities of the consumers to understand and effectively use the new technology, a measure that we have identified as demand absorptive capacity (α). But this notion has not to date been a particular target of policy thinking nor analysis. Demand-side strategies to facilitate consumer or user learning and capabilities suggest a new target for innovation and industry policy. Moreover, as the replicator model shows, demand-side innovation policies may engender multiplier effects and may compensate for low innovation opportunities in the sector due to such factors as a narrow knowledge base or low cumulativeness that would otherwise retard supply-side growth. On the other side, an industry with high innovative potential due to fertile technological prospects can nevertheless still stagnate due to failures of demand absorptive capacity. The implications for innovation policy are once again relevant, a theme we return to in conclusion.

Now we complete the formal exploration of the model dynamics with proposition 3.

Proposition 3: *It can be shown that the model fundamental equation* (4)*, can be interpreted and solved in a closed-form way as a logistic-type differential equation. The general close-form solution (or general integral) can be studied and simulated for any specific initial condition and parametric values.* ■

Proof: We depart from eq. (4) and we re-write the differential equation as follows (see more details in the Appendix):

$$\dot{x} = (\alpha(1+\lambda)-1)x(t)\left[1-\frac{x(t)}{\frac{\alpha(1+\lambda)-1}{\lambda}}\right] \qquad (5)$$

Let us note that this is a variant of a logistic-type equation such as (Gandolfo, 2009):

$$\dot{z} = rz(t)\left[1-\frac{z(t)}{D}\right]$$

It is possible to obtain the general integral (close-form solution) of this differential equation for any initial condition $z(0) = z_0$, and the parametric values, so that we have:

$$z(t) = \frac{Dz_0}{z_0 + (D - z_0)e^{-rt}}$$

In our model, for any possible initial condition (initial share of the "new" variety) $x(0) = x_0 > 0$, and considering just the relevant stationary state x_2^*, and specific parametric values, the close-form solution of (5) would be (see Appendix):

$$x(t) = \frac{(\alpha(1+\lambda)-1)x_0}{\lambda x_0 + (\alpha\lambda - \lambda x_0 + \alpha - 1)e^{-(\alpha(1+\lambda)-1)t}} \qquad (6)$$

■

It is clear that different patterns can emerge from (6) depending on the initial condition x_0 and the industry-specific parametric values. Likewise, taking into account that $y(t) = 1 - x(t)$, it is clear from (6) that we can run illustrative simulations for different parametric values and initial conditions that will allow us to reproduce industry-specific patterns and speeds of overall sectoral transformation. The simulations may represent alternative industry evolutions from specific settings, and although simulations are not needed to explore this model since propositions 1, 2 and 3 fully capture the model dynamics, they can help the reader to better understand the formal results. The simulations also allow us to qualitatively check the model's plausibility by observing real case studies (as in section 4 next) in the light of our formal results.

4. Innovation and absorptive capacity in windsurfing

Drawing upon the case-study elaborated by Thomas and Potts (2015) we briefly describe the case of the Australian windsurfing industry in three stages: the emergence of the industry; the sectoral consolidation; and its decline or innovative reversion and lack of dynamism. We focus on the role that forces akin to the two fundamental parameters of our model – the innovation rate (λ) and the absorptive capacity of demand (α) – could have played in the real case and we reproduce (in a stylized and qualitative way) these patterns in the simulations. The model cannot replicate the eventual collapse of the sector and many other features of the real story; this is not our aim with such a simple and stylized framework, but our formal representation does shed new light on the destructive innovation dynamics observed in this sector. From the model's point of view, there are three key trajectories: only the "old" survive, only the "new" survive, or the two varieties live together. Nevertheless, the model can represent the situation at which the "new" disappears after a period of previous coexistence with the "old" variety. We will interpret this latest event – in terms of our model – as the collapse of the sector.

Stage 1: The emergence of the sector (1970-1980)

The windsurfing industry traces its origins to 1968 when Americans Hoyle Schweitzer and Jim Drake achieved a grant of US patent for the "sailboard" – a contraption consisting of a surfboard-like board, with a sailing rig attached via a universal joint. With their patent secured, Hoyle and Scweitzer embarked on ambitious licensing program, primarily in the USA and Europe, to encourage manufacturers to take up production. Windsurfing struggled initially to gain credibility in countries such as Australia and the USA that had strong surfing and watersports traditions, but in places like Germany, France and Holland that had no strong surfing culture it very quickly became a 'cool' sport. Boardsailing (as it was then known) became the world's fastest growing sport (Thomas and Potts, 2015). In terms of our model, we can represent this stage assuming that, as an emergent sport, it presented a medium-low innovation rate (λ=0.4), and a relatively high absorptive capacity of demand (α=0.75), since demand was formed by highly skilled and motivated people who aimed at training and involving, through building-up specific capabilities to the sport, other consumers/users.

As we show in Figure 1 the simulation reflects a slow initial phase of gradual diffusion of the "new" (red path), whereas the "old" variety (blue path) still remains dominant. The sport has first to consolidate before differentiating and improving the products. The initial market share for the "new" material is 0.03 (initially-small share for novelty; Fig.1).

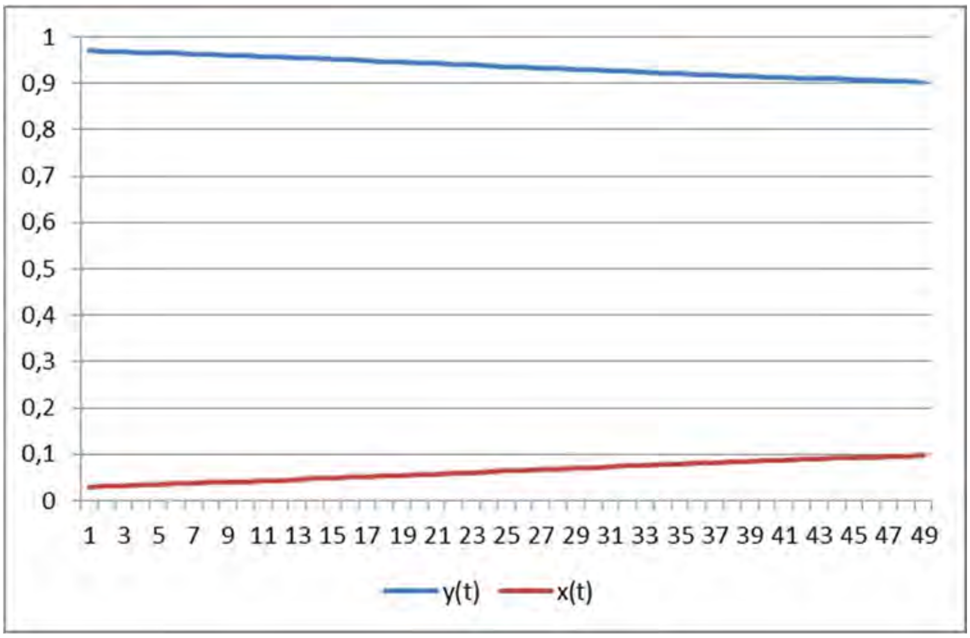

Figure 1: The emergence of the sector, λ=0.4 and α=0.75

While the equipment and its application remained relatively static in Europe, from the mid-1970s users in other parts of the globe, including Hawaii and Australia began to modify their equipment to exploit and explore local conditions (waves and wind). The pioneer manufacturing firms for windsurfing equipment emerged largely as a result of early user-innovators forming commercial concerns to manufacture and distribute their versions of equipment, in response to demand from aspirational users (Lüthje 2004, Shah 2006, among others)

Stage 2: The consolidation of the sector (1980-1985)

As the popularity and participation of the sport grew, the innovation paths broke down clearly now into two very different strands: one strand developed a high performance-based sport equipment that was oriented to an elite of athletes (the Hawaiian user-innovators) and a growing cohort of aspirational participants willing to follow them; the other strand focussed on the populist-route, maintaining the equipment in the simple and low-cost traditional level (primarily in Europe). It was finally the elite who led the rate and direction of the inventive activity in the windsurfing equipment. In a relatively short span of time (3-5 years) the equipment design became highly technical, and with the advent of new materials and manufacturing processes (eg, kevlar and carbon-fibre sandwich methods), more expensive and with a high-cost, high performance entry-level for new comers. Innovation was being led by manufacturers, who, responding to the demands of their high profile, sponsored elite athletes seeking to sail faster, jump higher and otherwise push the performance boundaries of the sport.

We represent this second stage in our model departing from the already established share of the "new" version of sport-good (equal to 0.1 in the previous stage; see Figure 1, and check the initial conditions in Figure 2 which continue the paths from Fig.1). But, now, we fix a high rate of innovation (λ=0.8), high distance between varieties, and a high level of absorptive capacity of demand (α=0.75). As we show in the graph, under these conditions the two varieties survive sharing the market, both the "traditional" mode that still catered to entry-level users and new and advanced material find their place in the market.

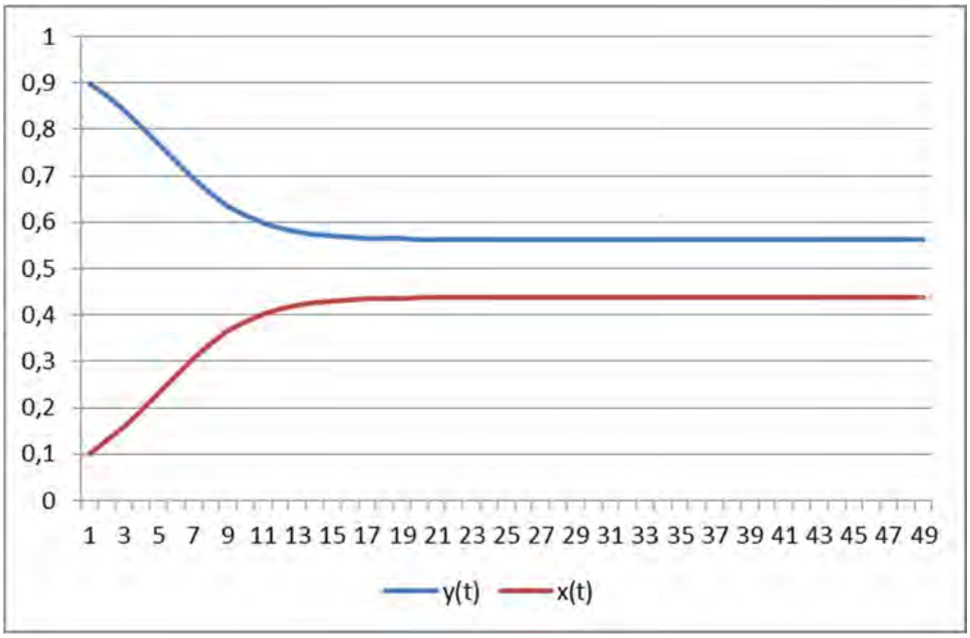

Figure 2: The consolidation of the sector, λ=0.8 and α=0.75

Stage 3: The decline of the sector (1985-2000)

Together with the change in the performance level, another significant change occurred in the sector by the end of the 80s. An early feature of the 'industry' was the existence of windsurfing schools, born of the fact that while the early equipment and use was *relatively* simple, there was still some investment in skills acquisition needed to enjoy the sport. A natural progression of these schools was to sell equipment to their clients and as equipment became more expensive (and higher-margin) many of these businesses became retailers and neglected their school operations and the windsurf schools were progressively closed down. Motivated by higher profits with less effort, from selling more technical, more expensive products with higher retail margins, they left aside training activity that was crucial to developing an entry-level pipeline of new users. As equipment evolved further in sophistication, materials and expense, for aspirational participants and recreational and social users it became increasingly difficult to keep up with their peers, leading to technical overshooting where the pace of innovation exceeds the absorptive capacity of the user community (as in Earl and Potts 2013, Potts and Thomas 2016). Many recreational users and aspirational participants abandoned the sport and without a pipeline of entry level users to replace them, the absorptive capacity of the demand side of the market began to taper off, and we observe with it a decline of the sector dynamism (mostly regarding new varieties of the sport) and ultimately, many firms went bankrupt (Thomas and Potts, 2015).

We simulate this stage assuming that we continue from the already reached initial market share for the "new" equal to 0.437 (compare Figures 2 and 3), and we fix a high innovation rate (λ=0.8) (as in Figure 2), but now we shift towards a relatively low absorptive capacity of demand (α=0.6) (see results in Figure 3). We show in Fig. 3 how the market share for the "new" variety (red) declines almost to zero.

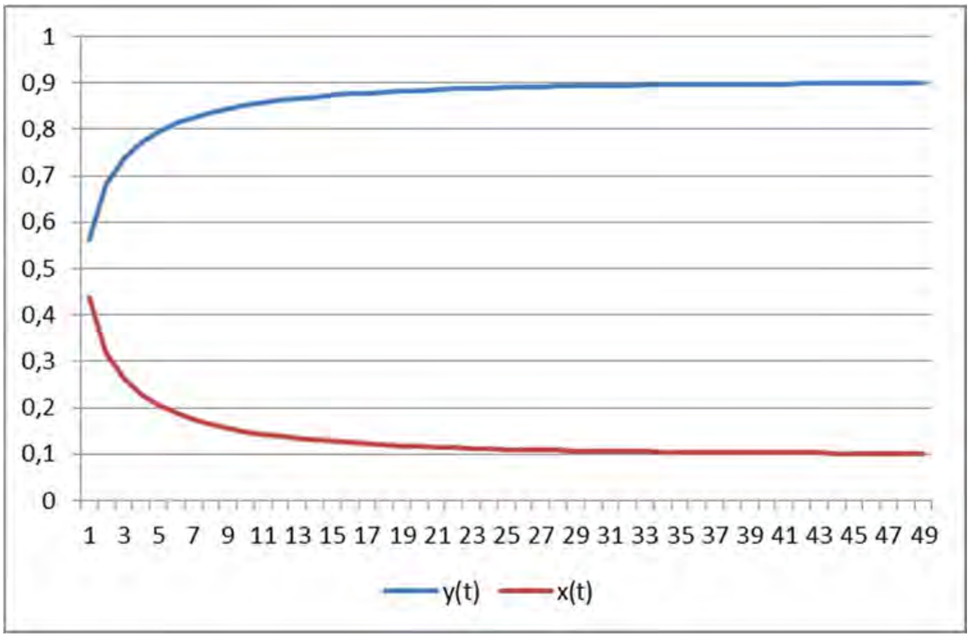

Figure 3: The decline of the sector, λ=0.8 and α=0.6

As a preliminary conclusion, we can establish that a wide potential for innovation in a new activity (e.g. in an emergent sport industry), is not a sufficient condition for said activity (i.e. the sport industry) to prosper, develop, and consolidate in a successful way. As the model shows, the demand-side of the market must be able to absorb the new innovations; that is to say, demand must be able to understand novelties, and effectively use the new options (products) in order to buy them. Otherwise, the innovation potential cannot develop. This is indeed what the model analyzed in Sections 2 and 3 predicts. In order to sharpen and reinforce this result, we show in Figures 4 and 5 two examples of industry evolution paths in which the absorptive capacity of demand is high enough for a "new" variety of the sectoral good to consolidate (or even to surpass) against the "old" variety.

In Figure 4, we maintain the initial conditions at the beginning of the industry (x_0=0.03) and a high value of λ, but we increase absorptive capacity. We show the resulting paths and the industry evolution in the Figure 4. We can observe in the simulation how, in this case, the "new" variety surpass the "old" one and ends up being the dominant option in the market.

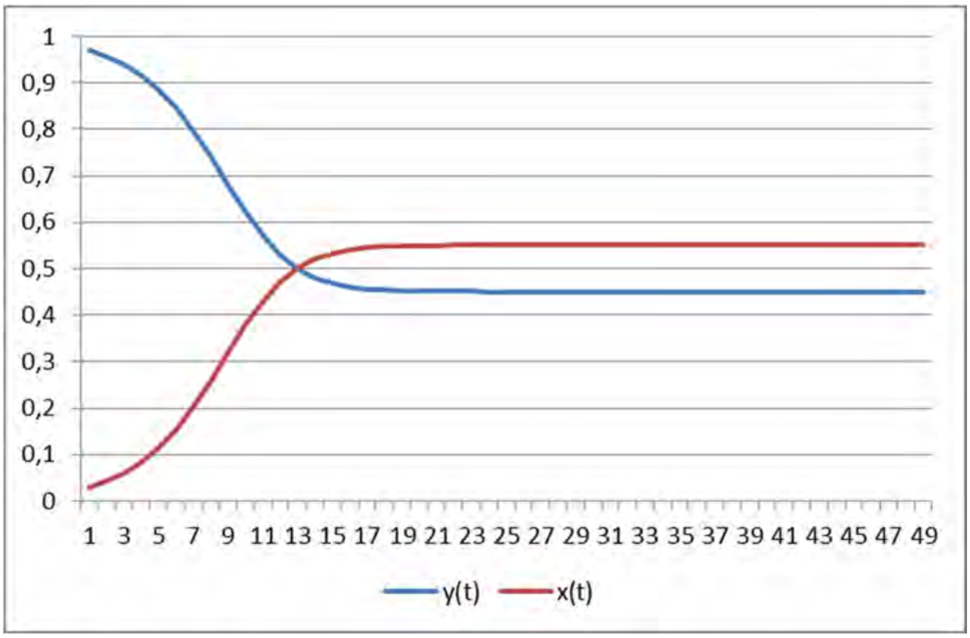

Figure 4: Industry Evolution, λ=0.8 and α=0.8

Now, if we increase even further the absorptive capacity of demand, we obtain the result in Figure 5 (for α=0.98), where the "new" variety practically dominates the whole sport industry. In Figure 5 we show a complete leadership shift (together with a full market transformation) because of high innovation and high demand absorptive capacity.

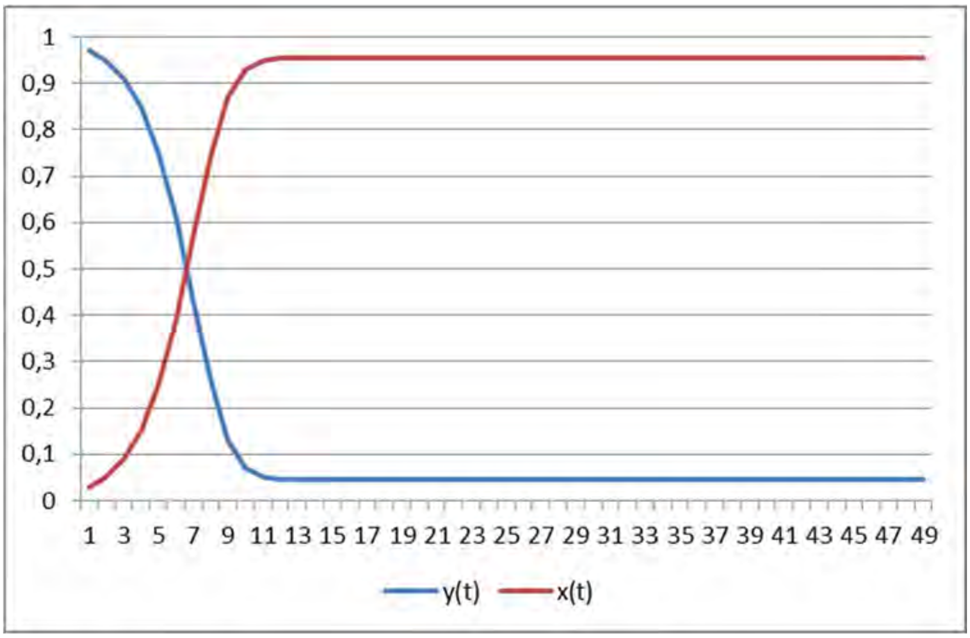

Figure 5: Industry Evolution for λ=0.8, α=0.98

Clearly, the simulations and the interpretation of certain aspects in the case study support the propositions presented in Sections 2 and 3. Given the explicit formal expressions obtained (e.g.) in propositions 2 and 3, a calibration with real data for different industries (case-studies) would be possible, suggesting a potentially rich vein of future research.

5. Demand absorptive capacity as a collective action problem

An interesting implication of our model, as in Earl and Potts (2013) in which Schumpeterian competition leads to innovation overshooting, is that the resolution of the diagnosed economic problem necessarily occurs at the sectoral or industry level. This is not strictly considered a problem for industry policy or innovation policy at the macroeconomic level because the coordination failure is specific to a particular regime of technological competition in a particular sector. Furthermore, the problem is also not solved at the micro level of the individual firm, unless that firm is a secure monopoly, because the benefits accrue to the entire market, and thus in competitive equilibrium we would expect underinvestment in demand-side absorptive capacity. Therefore, an efficient level of investment in demand-side absorptive capacity is an industry-level (meso-level) problem. It is therefore also a collective action problem, or a 'social dilemma' that if left entirely to a competitive market will likely fail.

Of course one such mechanism is monopolistic control of the market in order to internalize the externality. Plainly, if a single firm controls access to some bottleneck stage of the production process (e.g. equipment or clothing, or media, Potts and Thomas, 2016) they can recover the costs of investing in demand side absorptive capacity through rents at that point. The monopolist will invest at a level that maximizes industry revenues and growth. However, the very existence of rents at that point will induce competition, so unless there is a mechanism to protect those rents (for instance, intellectual property, or licensing) this outcome is expected to be unstable under contestability.

A different mechanism is through industry level organization through some association or club in order to internalize the externality by using the club as a kind of local government to create industry level public goods (Foray 2003). The association would then level fees (i.e. taxes) on suppliers, and direct these to the provision of absorptive capacity training. The association for example may organize and fund marketing campaigns and training schools. This would still require some additional mechanism to incentivize suppliers to join the industry association, ranging from additional benefits (such as industry newsletters or conferences) through to legislative mandate (Sako 1996, Barnett et al 2000). In many instances geographic or cultural concentration of an industry makes provision of such local public goods easier, as it lowers the transactions costs of monitoring contributions and free-riders, and also raises the effectiveness of punishment through low cost mechanisms such as gossip and exclusion from insider groups.

As noted in the previous section, in the windsurfing case, there were, at least in the early and consolidation phases of the industry's development, schools that facilitate skills acquisition and development for new and aspirational participants, which, to a point, served to build the absorptive capacity of demand. When manufacturer-led competition subsequently drew firms' attention to more lucrative pursuits (selling high-margin equipment to existing users rather than selling lessons, as shown in Thomas and Potts, 2015) the absorptive capacity reached its peak and subsequently declined.

Sports industries offer some useful insights into how collective action by user groups or industry self-regulation might manage this potentially destructive dynamic. In the case of Swimming, which faced elite/manufacturer-led equipment development in the form of the introduction of (expensive) hydrodynamic swimsuits. Recognizing the potential of new and expensive swimsuit technology to increase the cost of competitive equipment, the world governing body for swimming, FINA, banned the use of the suits in competition. This was not so much an action to support or build absorptive capacity among participants, rather a regulatory response designed to limit equipment development to match the (perceived) constraints of absorptive capacity of users (Potts and Thomas, 2016). In a similar vein, the sport of cycling faced similar risk of technical overshooting in the late 1990's with the advent of new materials such as carbon fibre and kevlar allowing more exotic, aerodynamic bicycle design. These new materials and designs led to competitive equipment becoming more specialized and expensive, potentially limiting users' access to competitive equipment. The governing body for the sport, the Union Cyliste Internationale (UCI), took steps to constrain the design parameters of bicycles for the purposes of recognized competition. Again, equipment development was artificially constrained by regulation to match the perceived absorptive capacity of the user community. By contrast, and unlike swimming and cycling, the sport of windsurfing did not have a unifying, global governing body with power to impose similar constraints on equipment design.

6. Conclusion

This paper has developed a neo-Schumpeterian model of sectorial transformation in which knowledge constraints from the demand-side can constrain innovation and transformation in an industry or sector. In our model of Schumpeterian competition, technological innovation in product complexity can overshoot the absorptive capacities of demand and slow or inhibit industrial innovation. We have captured the evolution of a single sector in which two varieties of the sectorial good are produced: an "old" (well-established, traditional variety), and a "new" (emergent) variety. Both varieties are represented in the model by respective evolving market shares. We formally analyzed the model's dynamics showing the existence and the asymptotic stability of the relevant industry steady state in terms of the market share for each variety. We also obtained closed-form expressions for the industry dynamics, and measurable indicators of speed and convergence time. Our main result was that the market share of the "new" variety depends positively on both the innovation rate of the sector and the absorptive capacity of demand. An implication was that demand absorptive capacity has a multiplier effect, such that relieving absorptive capacity constraints can drive further innovation by raising the marginal value of investment in innovation. Additionally, we found some compensatory effects between the two factors, the innovation rate and the absorptive capacity of demand.

The purpose of the theoretical model was to show how Schumpeterian competition could be unstable (producing overshooting, resulting in industry decline, Earl and Potts 2013) and how the key part of this process occurs on the demand side through absorptive capacity constraints. To illustrate our results we used our model to simulate the evolutionary path of a specific sport: viz. the Australian windsurfing industry, and compared this with a previous case study that showed very high levels of innovation but also evidence of overshooting caused by demand-side absorptive capacity constraints (Potts and Thomas 2015, 2016). This illustration, together with our formal results, suggests that innovation policy would benefit from taking into account the demand-side of innovation competition. This result seems to be crucial for the case of knowledge intensive sectors. Likewise, since, as we have shown formally, some compensatory effects exist between the innovation rate and the absorptive capacity, a policy-mix can be designed. For example, in a sports industry characterized by a relatively low rate of innovation, the promotion of a high level demand absorptive capacities through mechanism such as promoting training or schools, and would lead to a speed and scope of industry transformation in favor of "new" and progressive varieties of the sport, which could produce results analogous to the ones obtained with traditional industry policies aimed at promoting higher innovation rates. However, the main implication we emphasized was the industry specific public good character of demand absorptive capacity, and therefore the important role placed by industry associations in organizing governance mechanisms to undertake these investments and therefore internalize the externality. Innovation policy of this sort requires the industry itself to solve this collective action and governance problem, and the differing capabilities of different sectors to do this may be an unexplored contributing factor in industrial dynamics.

Appendix

We devote this Appendix to clarify how to obtain some of the formal results in the paper. In order to keep the reasoning process as neat as possible in the main body of the text, we have decided to present some useful intermediate results in this Appendix. Thus, we will depart in this Appendix from the first-order (non-linear) ordinary differential equation (4) which drives the model dynamics. The equation (4) in Section 2 is expressed as follows:

$$\dot{x} = \Phi(x(t)) = x(t)[(\alpha(1+\lambda)-1) - \lambda x(t)]$$

It is possible to extract the term $(\alpha(1+\lambda)-1)$ out of the brackets, in such a way that equation (4) can be re-written as follows:

$$\dot{x} = (\alpha(1+\lambda)-1)x(t)\left[1 - \frac{1}{(\alpha(1+\lambda)-1)}\lambda x(t)\right]$$

If we manipulate this expression just by dividing the intra-bracket quotient $\frac{\lambda x(t)}{(\alpha(1+\lambda)-1)}$ by the parameter λ, we can arrive at equation (5) in the main text of the paper (Section 3, proposition 3) written as follows:

$$\dot{x} = (\alpha(1+\lambda)-1)x(t)\left[1 - \frac{x(t)}{\frac{\alpha(1+\lambda)-1}{\lambda}}\right].$$

Let us notice that this differential equation is a variant of the logistic-type equation (see e.g. Hofbauer and Sigmund, 1998; Gandolfo, 2009):

$$\dot{z} = rz(t)\left[1 - \frac{z(t)}{D}\right]$$

As we show in the proof of the proposition 3, it is possible to obtain the general integral (close-form solution) of this differential equation, which, for any initial condition $z(0) = z_0$, can be expressed as follows:

$$x(t) = \frac{(\alpha(1+\lambda)-1)x_0}{\lambda x_0 + \lambda\left(\frac{\alpha(1+\lambda)-1}{\lambda} - x_0\right)e^{-(\alpha(1+\lambda)-1)t}}$$

More simply, we can express this solution as in eq. (6) Section 3 as follows:

$$x(t) = \frac{(\alpha(1+\lambda)-1)x_0}{\lambda x_0 + (\alpha\lambda - \lambda x_0 + \alpha - 1)e^{-(\alpha(1+\lambda)-1)t}}$$

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