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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 presents 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 CLASSIFICATION
L52; C62; O31; O33

1. Introduction

In neo-Schumpeterian models of innovation-driven sectorial dynamics, the key explanatory and policy variables are all on the supply side. One reason for this is that firms and organizations are understood to be the locus of knowledge in economic production (Nelson and Winter 1982), and absorptive capacity constraints on innovation are also assumed to be on the supply side (Cohen and Levinthal 1990; Zahra and George 2002). A second reason is that the relevant supply-side market failures relate to investment in factors that are inputs into knowledge discovery and innovation (Arrow 1962). Because of this concentration on the supply side, neo-Schumpeterian formulations of innovation policy also focus on supply-side interventions (Arrow 2012).

In this paper, we develop a new approach to the study of innovation-driven sectorial dynamics that recognizes the significance of demand-side variables. It follows that innovation policy can also work through demand-side interventions. We model demand-side dynamics focusing on the knowledge and capabilities that consumers require when adopting an innovative new technology. This new concept of *absorptive capacity of demand* – which we then link to an evolutionary model of 'innovation overshooting' (Earl and Potts 2013, 2016) – is the central analytic contribution of this paper, and is the key mechanism driving our new evolutionary model of sectorial dynamics. The basic mechanism of our neo-Schumpeterian model is that innovation competition on the supply side (i.e. two firms competing for the market by investing in innovative new products, and

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thus simultaneously having old and new product lines) runs in to an absorptive capacity constraint on the demand-side (some consumers fail to invest in developing the absorptive capacity necessary to adopt the new product). This innovation overshooting, with attendant failure on the demand side to adopt, results in market collapse.

To analyse this problem, we present a stylized model of sectorial transformation using replicator equations (Hofbauer and Sigmund 1998; Metcalfe 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 an older technology, with a large, established market share and will be familiar to consumers, and the newer version is a newer technology that will initially have a smaller market share of experimental users. Our model pays attention to the newer version, which is a newer technology (by definition known to producers) that will need to be learnt by the new consumers. This introduces the idea that the ability or willingness of consumers to learn the new technology, which we identify as demand-side absorptive capacity, can constrain technological adoption.

Our replicator model of demand-driven sectorial competition and growth is used to obtain a (non-linear) differential equation for the new versus old technology market share that is analytically tractable in continuous time. 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.

Section 2 introduces and develops the evolutionary model in which a technological innovation parameter represents the distance between the old and the new varieties of the good, and in which *demand-side absorptive capacity* is the key parameter driving the evolution of market share and therefore sectorial dynamics. Section 3 presents the dynamic analysis of the model that allows us to obtain closed-form results. Additional results explaining the model's dynamics are in the Appendix. Dynamic analysis of the evolution of demand shows how, and under what conditions, absorptive capacity of demand 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 associated with absorptive capacity of demand that have important implications for industry coordination.

Drawing on these results, we illustrate our story in Section 4 with an empirical case study account of the evolution of innovation-driven competition in sports technology in the historical context of the windsurfing industry in Australia. We conclude that demand-side absorptive capacity is a potentially significant and underappreciated factor affecting innovation diffusion and industrial dynamics. We also conclude that this type of demand-side innovation problem presents a collective action problem for an industry in ensuring adequate investment in absorptive capacity of demand.

2. The model

Consider a simple and highly stylized evolutionary model that builds on the replicator-dynamic approach developed by Metcalfe (1998) and Metcalfe, Foster, and Ramlogan (2005). We will 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 on 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 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 $0 < x(t) < 1$. Assume both market shares are continuous and continuously differentiable functions of time (variable t). Likewise, since we will only 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 since '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 further 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. Consider λ as a measure of how much better '*X*' is over '*Y*' from the supply side, which foreshadows how much more knowledge and capability will be required on the demand side in order to adopt it. 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. 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 favour of the new variety*) by a constant level λ.

As is standard in replicator-dynamic formulations (Metcalfe 1998; Metcalfe, Foster, and Ramlogan 2005), 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 formalize 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:

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

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

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 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.

Observe that parameter α, which captures in the model what we call the *absorptive capacity of demand*, is a generic and aggregate representation of several aspects that usually appear as distinct factors in standard models. More precisely, note that absorptive capacity applied to consumer behaviour would include not only cognitive constraints, but perhaps also income, preferences for novelty vs traditional options, and 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 the formal representation as neat as possible. Thus, we use 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:

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

Because of the conditions that are required for the model to work well, the relevant interval for the *absorptive capacity of demand* is:

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

An interesting preliminary implication of our framework is that the model seems to require a relatively high level of absorptive capacity just to begin the analysis in an economic meaningful way. 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. A high level of absorptive capacity of demand seems to be needed for innovative industries to sustainably develop.

Now we can start combining the previous assumptions to arrive at a tractable global expression for the model dynamics. Notice that, from Equation (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

$$\dot{x} \equiv \frac{\mathrm{d}x}{\mathrm{d}t}. \tag{3}$$

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:

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

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 use them in Section 4 to reflect on the historical evolution of the windsurfing industry.

Apart from this analytical strategy, we also undertake a second type of formal exploration. Simple algebraic manipulations allow 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 (Equation (4)) which are $x_1^* = 0$ and $x_2^* = (\alpha(1+\lambda) - 1)/\lambda$. The first one, $x_1^* = 0$, is unstable and irrelevant under the assumptions adopted, and the second one, $x_2^* = (\alpha(1+\lambda) - 1)/\lambda$, is globally asymptotically stable.* ∎

Proof: By applying the definition of stationary state, we consider in Equation (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 $x_2^* = (\alpha(1+\lambda) - 1)/\lambda$.

Let us notice that, if we do not impose the condition (established in (2) above) $(1/(1+\lambda)) < \alpha < 1$, the second state $x_2^* = (\alpha(1+\lambda) - 1)/\lambda$ 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 $(\mathrm{d}\Phi/\mathrm{d}x)(x_1^* = 0) = \alpha(1+\lambda) - 1 > 0, x_1^*$ 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 $(\mathrm{d}\Phi/\mathrm{d}x)(x_2^*) = 1 - \alpha(1+\lambda) < 0$, x_2^* is locally stable. Additionally, it is easy to see that $\Phi(x) > 0$, $\forall x \in (x_1^*, x_2^*)$, and $\Phi(x)$ are strictly concave $\forall x \in (0, 1)$; therefore, we can assure from what we have said that $x_2^* = (\alpha(1+\lambda) - 1)/\lambda$ 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 $x_2^* = (\alpha(1+\lambda) - 1)/\lambda$. 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 $\partial x_2^*/\partial\alpha = (1+\lambda)/\lambda > 1$.*
(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: $\partial x_2^*/\partial\alpha = (1+\lambda)/\lambda > 1$, and $\partial x_2^*/\partial\lambda = (1-\alpha)/\lambda^2 > 0$. 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 $\partial x_2^*/\partial\alpha = (1+\lambda)/\lambda > 1$, 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 Equation (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 $(x_t-x_2^*)/(x_0-x_2^*)\approx e^{-(\alpha(1+\lambda)-1)t}$, this would allow us to calculate, for example, 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: $t^c\approx 0.7/(\alpha(1+\lambda)-1)$.

(1) 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: $\partial\partial x_2^*/\partial\lambda\partial\alpha=(\partial/\partial\lambda)(1-\alpha/\lambda^2)=(-1/\lambda^2)<0$.

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 $x_2^*=\overline{x,}$ we can obtain that: $\alpha=(1+\lambda\bar{x})/(1+\lambda)$. If we derivate this expression with respect to λ, we obtain: $\partial\alpha/\partial\lambda=(\bar{x}-1)/(1+\lambda)^2<0$. 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 increased speed and scope of industrial transformation in favour 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. This occasional phenomenon has been identified and explained in the innovation overshooting literature (Earl and Potts 2013, 2016). 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 Equation (4) and we re-write the differential equation as follows (details in the Appendix):

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

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):

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

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 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.

4.1. 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 programme, 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 ($\lambda = 0.4$), and a relatively high absorptive capacity of demand ($\alpha = 0.75$), 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.

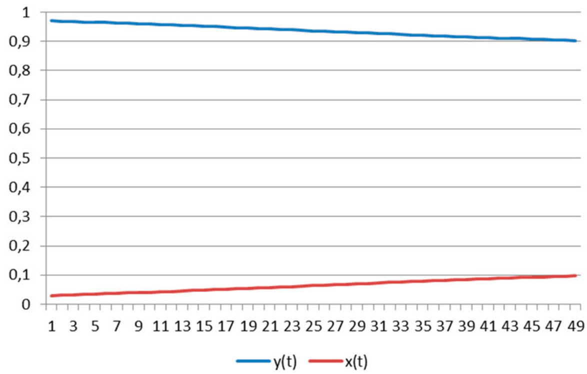

Figure 1. The emergence of the sector, $\lambda = 0.4$ and $\alpha = 0.75$.

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; Figure 1).

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).

4.2. 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 (e.g. 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 Figure 1). But, now, we fix a high rate of innovation ($\lambda = 0.8$), high distance between varieties, and a high level of absorptive capacity of demand ($\alpha = 0.75$). 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.

4.3. Stage 3: 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 1980s. An early feature of the industry was the existence of windsurfing schools,

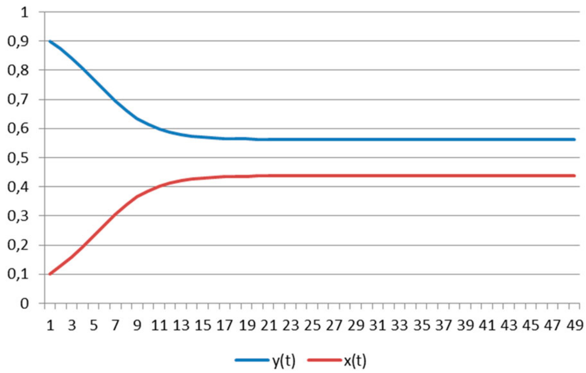

Figure 2. The consolidation of the sector, $\lambda = 0.8$ and $\alpha = 0.75$.

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 ($\lambda = 0.8$) (as in Figure 2), but now we shift towards a relatively low absorptive capacity of demand ($\alpha = 0.6$) (see results in Figure 3). We show in Figure 3 how the market share for the 'new' variety declines almost to zero.

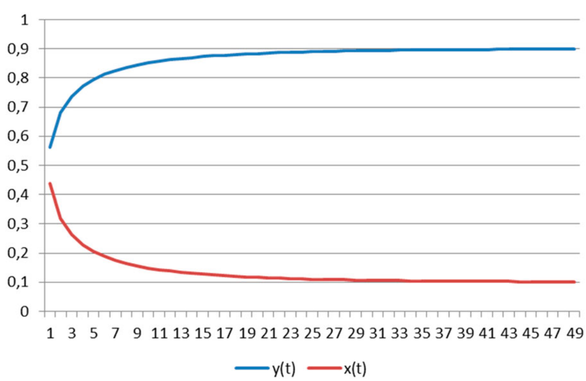

Figure 3. The decline of the sector, $\lambda = 0.8$ and $\alpha = 0.6$.

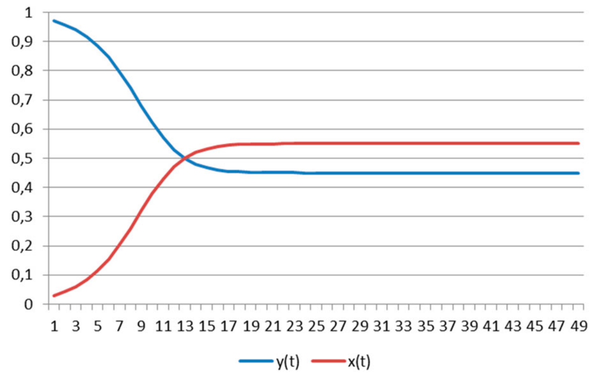

Figure 4. Industry evolution, $\lambda = 0.8$ and $\alpha = 0.8$.

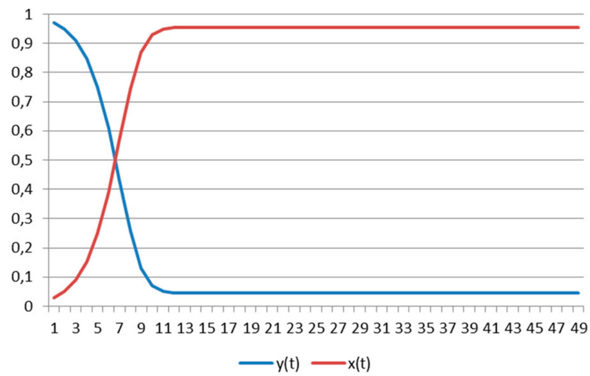

Figure 5. Industry evolution, $\lambda = 0.8$ and $\alpha = 0.98$.

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. Consumers, both new and existing, must be able to understand novelties and be able to effectively use the new products in order to buy them. Otherwise, the innovation potential cannot develop. This is indeed what the model analysed 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 surpasses the old variety to become the dominant option in the market.

Now, if we increase even further the absorptive capacity of demand, we obtain the result in Figure 5 (for $\alpha = 0.98$), where the 'new' variety practically dominates the whole sports 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.

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 for example 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 2015) 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, Mischke, and Ocasio 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 1990s 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, 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. The role of industry associations seems particularly relevant in developing and enforcing such 'policy' solutions.

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 analysed 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. A further 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. This suggests that building absorptive capacity of demand can be an effective innovation policy.

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: namely 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 favour 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.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix

Let us clarify how we obtained 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 present some useful intermediate results here. 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 $\lambda x(t)/(\alpha(1+\lambda)-1)$ by the parameter λ, we can arrive at Equation (5) in the main text of the paper (Section 3, Proposition 3) written as follows:

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

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 Equation (6) Section 3 as follows:

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