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How emergence conditions of technological clusters affect their viability? Theoretical perspectives on cluster lifecycles

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HOW EMERGENCE CONDITIONS OF TECHNOLOGICAL CLUSTERS AFFECT THEIR VIABILITY? THEORETICAL PERSPECTIVES ON CLUSTER LIFECYCLES

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Summary:

The widely studied concept of clusters has been usually treated as pre-established and successful structures. We argue that clusters are not pre-established but emerge through a double competition process of technological and regional nature. Moreover, faced to a changing environment they are not always successful. Their long-term evolution depends on their viability capacities. We show that viability is dependent on the emergence conditions, because different forms of emergence create clusters with different structures.

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Introduction

The uneven spatial distribution of economic activity has been, although marginal, an old concern for economists (Krugman, 1991a). Special attention has received the spatial concentration of firms in the same industry, so concepts such as industrial district, localised systems of production, innovative millieux… have multiplied. However, it is the porterian concept of "cluster", defined as "geographical concentration of interconnected firms and institutions in a particular field" (Porter, 1998), which has gained most attention from the academia and the political spheres in the last two decades. Nevertheless and in spite of its popularity this concept is problematic at different points (Martin and Sunley, 2003).

The literature has mostly focused on the comprehension of why clusters exist, how they can be characterised and which the reasons that make them successful are. But many dynamic aspects have been neglected. In fact, clusters are usually considered as isolated, pre-defined, pre-established and successful structures (Martin and Sunely, 2003; Bresnahan et al. 2001) that enhance the competitive performance of firms, innovation and regional growth. Contrary, not many studies focus on when and where clusters come to exist (Orsenigo, 2001; Brenner, 2004), and what makes some clusters survive in the long-term while others decline after a while (Menzel and Fornahl, 2010; Suire and Vicente, 2009a). This paper aims to fill this gap. We focus on genesis conditions of technological clusters, the viability conditions that determine their long-term dynamics and the link existing between both.

The definition of technological clusters as interconnected structures goes beyond their spatial considerations. They have a knowledge dimension too. For clusters to exist co-located actors should belong to the same field. Their interactions will conform a local knowledge structure that will be inserted in a larger network representing a technological field (Owen Smith and Powell, 2004). These relations between the cluster and the technological field go in both directions: the evolution of the cluster depends on the evolution the technological field, and the evolution of the technological field depends on the evolution of clusters specialized on it.

The aim of the paper is to analyse how the mechanisms at play for the emergence of technological clusters, influence its long-term viability. We explain that the viability of clusters depends on the combined strength of the regional process and the technological process, which are linked to the emergence conditions.

To do so, the next section defines the cluster as a result of a regional and technological dynamics traversed by different networks. Section 3 is concerned by emergence, so the conditions under which the double dynamics appears and develops. Section 4 focuses on how regional and technological dynamics are combined to ensure viability of this spatial structure in the long-term. Section 5 makes the link between the emergent conditions and the viability conditions and shows that both stages are interrelated.

2. Clusters: the cross-roads of double dynamics

We decompose the Porter's definition of cluster in its basic elements. The cluster's development from emergence to decline depends on the joint evolution of regional and technological dynamics. We firstly analyse the interplay between these two basic dynamics defining the cluster, and secondly we identify the main factors influencing them.

2.1. The nature of a double dynamics

Michael Porter's (1998) definition encompasses the basic frontiers of a cluster. They are technologically defined by the "particular field" on which "firms and institutions" develop their activities, and spatially by the "geographic concentration" of these actors in the same region. These two boundaries, although very elastic (Martin and Sunley, 2003), let us take the cluster out of its isolation and place it in the intersection of two dynamics: technological and regional. Moreover, actors in a cluster are "interconnected", so the evolution of these two dynamics is crossed by networks of different nature that influence their evolution.

Since actors develop their activities in different spheres, they belong to different (eventually) networks overlapping. Three types of networks with different structuring principles have been identified. Firstly, there are social networks of inter-personal nature (Grossetti and Bes, 2001). They account for the personal relations of human beings. Secondly, there are industrial networks. They are inter-organizational relations of productive nature on the production chain (Storper and Harrison, 1991). Finally, firms and institutions may be linked through R&D networks, i.e. networks linking actors in their exploration/examination phase to construct new products or application (Vicente et al. 2008). On the base of this conceptualisation and from the cluster's evolution perspective we can draw two basic hypothesis:

H1: *Cluster's evolution is driven by the interplay of regional and technological dynamics*.

Clusters are placed in the crossroad of technological and regional dynamics, so changes on the later will influence the evolution of the former. Networks and dynamics do not exist on their own, they become to exist through a sequential process of multiple decisions. Clusters are not pre-defined and pre-established structures, but they appear as a result of the individual evolution of each dynamics and their mutual interplay. From the long-term perspective, cluster's evolution is continuously exposed to the occurrence of endogenous and exogenous transformations affecting the regional and/or technological dynamics. Therefore, clusters are not always never-ending success stories.

Most of the works about cluster's evolution make an unidirectional association between product or industry/technology life cycle and the cluster life cycle. They either stress on the product maturation and the conquest of mass consumption markets (Vernon, 1966), or on the product maturation and the standardization process (Scott, 1983) to explain clusters' evolution. In this sense, Arhtur (1989, 1990) modelled how a technological monopoly and a regional monopoly can independently emerge by the generation of externalities. However, since we consider that the technological and regional dimensions are bi-directionally interlinked, the cyclical outcomes of emergence and viability are not so straightforward. The evolution of the technology depends on what happens at the regional level, and similarly what happens at regional level depends on the technological dynamics. Such relations will alter the emergence process and the lock-in conclusions.

H2: *Cluster's viability conditions depend on its emergence conditions.*

The success and fail from the emergence perspective requires the capacity to generate the right synergies between technological and regional dynamics in order to succeed in the double competitive process generated after a technological shift. While the aeronautics/aerospace in Toulouse region (Dupuy and Gilly, 1999) may illustrate the success, the case of biotechnological activities in Lombardy (Orsenigo, 2001) illustrates the failure. However, from the long-term perspective, what is relevant is the capacity of the cluster to maintain the regional conditions to sustain and follow the growth of the technology (Suire and Vicente, 2009b), and be able to dissociate from it when the technology declines. The sustaining and dissociation capacities depend on cluster's structure mostly defined at the emergent stage, which has created networks and technological and regional processes of dissimilar strength. Although regional and technological dynamics are interlinked they are neither symmetric nor influenced by the same determinants. That is why some clusters, such as Silicon Valley, maintain their innovative nature while the technology and the industry entered their mature stage (Saxenian, 1994), while others, such as Silicon Sentier (Paris), decline while the industry is still growing (Vicente and Suire, 2007).

From this perspective successful and performing clusters have the capacity to maintain as a location norm and overcome the different threats they face. Hence, Silicon Valley is successful not only because of its innovative performance but also by its viability. This explains its successive shifts from defence to integrated circuit, personal computer, Internet, biotech and cleantech. Each wave, responding to different external shocks such as cutbacks of defence spending or price competitive challenges (Saxeninan, 1994), has created a growth period transforming the Valley.

Consequently, clusters are composed by several interactive actors conforming complex structures. They appear in the crossroads of technological and regional dynamics. However, these two dimensions are not independent because social, industrial and R&D networks mutually traverse them. It is the interplay among them that defines the evolution of clusters from the emergence to the eventual renewal or decline.

2.2. Factors influencing the regional and techno-industrial dynamics

We review here the static and dynamic factors that influence the regional and technological dynamics as well as their interconnection through different networks.

The static views of location underline the relevance of geographical endowment, transport possibilities and firms' needs, to explain the resulting industrial spatial pattern. More recent approaches have nuanced these deterministic views by introducing indeterminacy generated by endogenous agglomeration forces (Krugman, 1991b; Arthur, 1990), and adaptive instead of static environment (Scott and Storper, 1987). Although they point to chance, locational capabilities and externalities to explain agglomerations, initial conditions cannot be completely ignored. Firstly, the very early entrants do not profit of external effects and take their location decisions on the base of existing initial conditions. Secondly, the dependence on a particular resource only accessible in certain locations can make emerge a cluster by pure necessity. From the long-term perspective the nature of resources influences the viability of the cluster by locking-in the choices of actors due to their non-contestability and alternative potential uses. The technological counterpart of these location deterministic views takes the form of intrinsic performance. The users adopt a technology based on its performance without considering the potential feedbacks. Consequently, viability depends on the relative better intrinsic performance of a technology with respect new and old alternatives, and the size of switching costs.

Under the presence of positive feedbacks chance becomes important and path dependency trajectories appear (Arthur, 1989). Chance is conceptualized as random small-events (adoption decisions or location choices) that probabilistically occur in a sequence of time, however not everything can happen because the probability to occur it is not the same for all events (Boschma, 1997). However, admitting the importance of chance does not mean that each actor takes its own decision regardless of parameters such as performance, regional conditions or available information. Arthur (1989, 1990) synthesizes it in two variables: private preferences and externalities imposed by previous decision-makers. This combination of chance and externalities magnifies early small-events and make location and adoption processes path-dependent and unpredictable.

Externalities can adopt the form of informational signals, agglomeration economies or network externalities. Informational signals are important in uncertain contexts with incomplete information about technological and regional features. They create a particular process of location and adoption with relevant consequences for cluster's viability. Adoption and location decisions are subject to uncertainty and incomplete information because some relevant particular features are only observable a *posteriori*. In such contexts, early decision makers generate externalities in two ways. Firstly, they produce additional information about the properties of their chosen technology (region), and so reduce the informational problem. As epidemic models show, information is more easily available for more popular technologies (regions) (Geroski, 2000). Secondly, in uncertain contexts actors tend to adopt mimetic behaviours by imitating the decisions made by similar actors in similar situations. They cause bandwagon effects (Bikhchandani et al. 1998). Although mimesis and bandwagon effects drive to convergent decisions, they do not generate any additional return for co-adopters or co-located firms (Vicente and Suire, 2007).

The most popular regional external effects, source of increasing (decreasing) returns, are agglomeration externalities. They are defined as "advantages (or disadvantages) that local firms draw from a concentration of economic actors and activities in their close vicinity" (Neffke, 2009). These effects, external to the firm but spatially constrained, are usually classified in three categories. Localisation externalities involve the formation of pools of skilled labour, specialized inputs and services and specialised knowledge spillovers (Marshall, 1920). Jacobian externalities, function of the agglomeration's diversity, refer to the benefits (or costs) of being located near to diverse industries that may be source of inter-industry spillovers (Jacobs, 1969). Urbanisation externalities, associated with the size of the city, not only involve market access, public utilities and common infrastructures, but also additional costs associated to congestion. Assuming that positive externalities are bigger than negative ones co-location becomes more attractive than isolation, attractiveness is a positive function of the number of co-located actors.

This account about agglomeration externalities has two shortcomings for cluster's lifecycles. Firstly, their rise as co-location goes it is not so straightforward. Hanson and Pratt (1992) argue that places are not just the containers where labour market processes take place, but it is through place-based interactions that local labour markets emerge. Similarly, the emergence of number of specialized suppliers and complementary service providers also requires interaction in order to identify the specialized needs and define the nature of linkages. The generation of knowledge spillovers has received large attention. It is argued that geographical proximity is neither a necessary nor a sufficient condition to observe them. Contrary, knowledge spillovers, as any knowledge flow, should be supported by other forms of proximity such as institutional, organizational, social and cognitive proximities (Boschma, 2005). Knowledge flows to be effective need a minimal cognitive proximity (Nooteboom, 2000). Consequently, diversity is not enough to boost innovation, what matters is related variety defined as diverse "industrial sectors that are related in terms of shared complementary competences" (Frenken et al., 2007). Secondly, the above account assumes passive firms in the defence of their choices. However, given the strategic character of locational decisions, previous entrants engage in explicit strategies to defend their choice rather than *wait for* later entrants to follow them. Both nuances claim for the relevance of interaction, i.e. the existence and structure of underlying networks, to explain regional and technological dynamics.

From the technological point of view, increasing returns externalities are known as network externalities: the user's utility obtained by adopting a technology is positively dependent on the number of adopters. The private decision of an actor adopting a technology creates direct physical effects on size, indirect effects on quantity, quality and variety of complementary goods, and induced effects on quantity, quality and variety of complementary services (Katz and Shapiro, 1985). However, network externalities may not arise automatically. The demand side induces them, but they require the adoption of certain behaviours from the supply side in order to be generated: construction of complementarity and compatibility. In technological competition, network externalities, and so co-operative behaviours to build up complementarity and compatibility, are fundamental to establish and maintain a technology on the long-term (Arthur, 1989). Since both strategies cannot be achieved in isolation, they depend on the existence and structure of networks. Consequently they are linked to regional dynamics.

The literature has identified several forms to organize this "battle". They range from market-mediated for a *de facto* standard to politically-mediated for *de jure* standards (David and Greenstein, 1990). They reflect the need to develop collective strategies of co-operation and interaction among supply actors, because proprietary control and risk of wrong choices create incentives for firms to act and defend their technology. Pricing strategies and the construction of compatibility are the basic competitive tools (Katz and Shapiro, 1994). Compatibility decisions are done to allow different technologies to be interchangeable either vertically (successive generations) or horizontally (alternative new technologies) (Katz and Shapiro, 1985). Complementarity means to wide the range of attachable goods and potential uses to a certain technology (Katz and Shapiro, 1994).

All the three externalities considered insist on the role of interactions for their generation. This underlines that externalities not only depend on quantitative accounts but also on qualitative features of actors. Actors are heterogeneous and differ with respect to many attributes that enhance or hamper the size of informational, agglomeration and network externalities. Moreover, externalities reveal the role of transversal different networks, which are present in the evolution of technological and regional dynamics interconnecting them. For cluster's lifecycle, not only the existence of networks but also its structure and overlapping areas become fundamental, because the evolution of regional and technological dynamics depends on the balance between local and non-local relations, the complementarity of their competences, their nature and the structure.

We can conclude that the technological and regional processes underlying the cluster's evolution results from the combined effect of chance, necessity and external effects (informational signals, agglomeration economies and network externalities) generated by interactive heterogeneous actors. In the following sections we focus on the particular form these factors take at each stage of the lifecycle and the interplay among them.

3. Regional and technological dynamics in the cluster emergence

Contrary to what is usually assumed, clusters are not established *per se*, Silicon Valley or Toulouse aeronautics/aerospace cluster have not always existed. Their current success has gone through a previous stage of emergence where the conditions were different. In this section we first analyse the conditions required for a new cluster to emerge, and later we turn to study the double competitive process in itself.

3.1. Conditions for the emergence of clusters

A cluster's emergence implies a break with the existing spatial pattern. These breaks can be triggered by an increase in demand or a technological shift. Increases in demand are acknowledged to have the potential to create new clusters of productive nature through dispersal dynamics. They increase the production capacity of existing clusters (Storper and Walker, 1989). However, the emergence of clusters of technological nature is basically the result of a technological shift or the need of a technological evolution (Brenner, 2004). The advent of a breakthrough innovation generates a double indeterminacy, technological on one hand and regional on the other hand. Consequently, a double competitive process is launched.

P1: *Clusters emerge in those regions that manage to be successful in the regional and technological competition process created after a technological shift.*

The technological indeterminacy originates because the technological shift does not generate a unique technological form. So a process driven by variation, selection and retention is launched. Different technological alternatives compete to become the dominant or standardised one (Anderson and Tushman, 1990). The initial form of the new technology is progressively shaped through this competition. As the battle between VHS and Beta in the late 70s, or the Minitel vs. Internet during the early 90s proved, this competitive context is characterised by high uncertainty, incomplete information and heterogeneous actors voluntary and/or involuntary interacting.

The spatial indeterminacy appears because a gap is formed between the new locational specifications[1] of the emergent technology and the regional conditions accumulated along the past trajectories (Boschma, 1997). Regions may be locked-in in a production environment defined by the productive conditions accumulated in the past but which are unfitted to answer the needs associated with the new technology. Although Scott and Storper (1987) established the concept "Window of Locational Opportunity" (WLO) to refer to the "moments of enhanced locational freedom" enjoyed by an industry, it equally applies for contexts in which the location of actors entering a new technological field does not depend on past conditions. This indeterminacy launches a competition among regions to become the location norm.

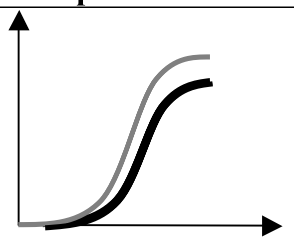
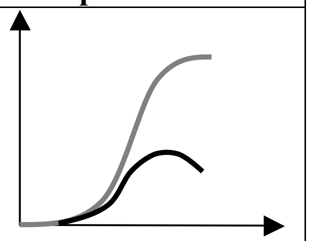
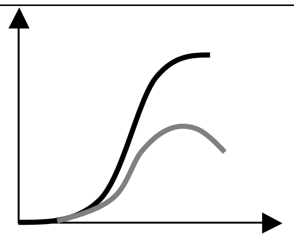
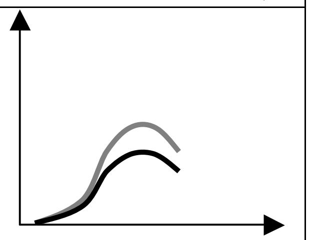
From that perspective local environment is not a static selection mechanism. Grounded on location capabilities (Storper and Walker, 1989) or creativity (Boschma, 1997) of actors the environment is dynamically shaped to close the mentioned gap. However, space does not become irrelevant. Firstly, technological change is not exogenous to space; innovations are triggered by spatial structures and

[1] Locational specifications refers not only to the labour, natural resources and consumers, but also to the more complex vertical and horizontal linkages that are fundamental to define the technology input-output conditions (Storper and Walker, 1989)

practices revealing problems and opportunities (Storper and Walker, 1989). Secondly, spatial conditions differ among regions due to their different histories and mixtures of advantages, constrains and capabilities (Boschma, 1997). This introduces a nuance on the vision of Storper and Wlaker (1989) who consider only the role of chance in the formation of the industrial spatial pattern. Differently, Boschma (1997) defends that chance is not enough to explain emergence of new clusters since new spaces are built on the base of existing spatial conditions. So, chance is relevant when the particular conditions to stimulate the attraction and creation of localisation specifications are widely available on space. In this sense, Feldman and Francis (2004) underlined the role of entrepreneurs. The pursuit of their own interest contributes to shape the environment, spark regional transformation and overcome the constraints of initial conditions to close the WLO. Dalla Pria (2008) insisted on the relevance of policy decisions to foster cluster emergence by altering the initial conditions. Bresnahan et al. (2001) talked about the role of large firms to nurture technical and managerial competences.

With these indeterminacies a double competition begins (Table 1). According to proposition 1 with a failure in the technological competition the demand for the technology is too weak to sustain the existence of a cluster. Similarly, a failure in the regional competitions implies that the region was not able to generate the conditions to attract new entrants and agglomerate, the cluster will neither exist. Since both indeterminacies have the same origin, and most of the actors are involved in both competitive processes, the regional and technological competitions are interdependent. The resulting techno-spatial pattern is a dynamic process that depends on the individual evolution of each process and the interplay among them.

Table 1: The double competitive process at emergence[2]

		REGIONAL COMPETITION	
		Competitive Success	**Competitive Failure**
TECHNOLOGICAL COMPETITION	**Competitive Success**		
	Competitive Failure		

Grey: technology. Black: region

In the upper-left case a cluster emerges. The region is able to take advantage of the WLO by meeting the new locational specifications required before alternative locations. Moreover, the regional

[2] X-axis : time ; Y-axis : cumulated employment in a technological field in the same region (black). Technological adoption (grey).

dynamics is able to strengthen the competitive performance of the technology to become the standard. This is the case of biotech in San Diego, where entrepreneurs have profited of region's scientific capabilities to, firstly, set biomedical research centres, then lobbying for the establishment of university in their proximity and finally, since late 70s, creating and attracting biotech firms leaded by Hybridtech (Casper, 2007). Contrary, the upper-right case represents a failed emergent process. Early co-located actors were engaged in good technological dynamics, however the regional process stopped in the creation of proper environment for the industry, new entrants decide to locate elsewhere and the cluster does not emerge. This illustrates the failed emergence process of a biotechnology cluster in Lombardy due to the "structural weakness in the [regional] industrial base, in the research system and at the institutional level" (Orsenigo, 2001). The lower-left case represents the figure in which the cluster may emerge because of the strength of its regional dynamics. However, its effective development is compromised by its weak capacity to impose in the technological competition. Two outcomes are possible here. Firstly, a small cluster focused on a local standard may appear. Secondly, based on the strength of its regional dynamics the cluster manages to shift and integer a more performing technology to emerge. Finally, the lower-right case illustrates the case in which no cluster emerges because of the fragility of the regional and technological dynamics on it.

3.2. Emergence: a double competition process

This section explains how the factors identified in section 2 drive the regional and technological dynamics for cluster's emergence. According to the literature the double competitive process goes by two phases with different logics. The first refers to the initial stage where no externalities exist; each actor decides individually. In the second phase external effects become important and decisions made by previous entrants influence latecomers. We show that different mechanisms at play in each phase and each dynamic explain the location and structure of the cluster.

The emergence of a cluster is necessarily nurtured by the arrival of firms into the region. Following Klepper (2002), these new entrants can be classified in three categories depending on their founder's background: diversifiers, entrepreneurial or parent spinoffs and inexperienced firms. The particular mechanisms at play guiding the decisions of co-location of new entrants drive the *potential* cluster through the different emergent phases, and produce different cluster structures.

P2: *Regional competition success depends on the existing geographical endowment, chance and the interactive behaviour of co-located actors*.

Regionally the first phase, the pioneering phase (Bresnahan et al. 2001), is characterised by the existence of particular specifications and the transformation of local private/public actors from latent to active in response to an exogenous shock opening the WLO. The actions of these first entrants shaping the environment to meet the new locational specifications are fundamental to the cluster development (Feldman and Francis, 2004). The second phase, the agglomeration phase (Dalla Pria, 2008), refers to the emergence of a location norm. The eventual generation of agglomeration externalities by early entrants influence the location decisions of new entrants.

From a deterministic approach the cluster emerges by a resource effect. Each new entrant chooses individually the region because of its existing geographical endowment. In a strict sense, no spatial indeterminacy is created. The success of oil-extraction clusters or sun-and-beach tourist areas in the regional competition is grounded on the geographical endowment that characterises the region. However, deterministic views are too narrow to entirely explain emergence, especially for technological clusters, in a world where externalities exist and the environment can be shaped.

In non-ergodic contexts what matter is to close the gap between the existing and required locational specifications sooner and better than alternatives regions. The pioneering phase depends on chance. Firstly, triggers are uncertain and unpredictable. Secondly, the place where pioneering new entrants become active and/or chose to locate in a region depends on chance (personal stories or political decisions). Moreover, although some environments may be better fit than others, the static and dynamic capabilities or creativity of actors manage to progressively shape the environment by transforming generic resources widely available in space into specific ones. At this stage, individual features such as creativity or learning capacity of diversifiers, strart-ups, spinoff and even policy actors are important.

As the demand for technology progresses, actors continue to enter and make location decision. The independent actions and eventual collaborations that progressively develop among co-located actors may transform regional dynamics in self-sustaining. Externalities guiding the agglomeration phase appear. The location decisions of previous entrants influence new ones. Eventually, the region becomes the location norm.

When externalities are caused by informational signals, an informational cascade is launched and the cluster emerges by a mimetic effect. Each new entrant infers which the best location is by looking at what previous actors in similar circumstances have done. The reputational capital of first movers influences positively the speed of the agglomeration phase. Since mimesis is founded over similarity, the co-located actors have very similar knowledge bases. Although focussing favours the agglomeration phase (Menzel and Fornahl, 2010), it reduces local exchanges in order to avoid involuntary flows of knowledge towards direct competitors. With weak localisation externalities due to homogeneity and lack of interactions, the size of agglomeration externalities depends on the previous existence of related variety in the region and the particular balance between city-amenities and congestion effects. Such was the story of Silicon Sentier in the late 90s. The arrival of Yahoo and other leaders in the emerging e-business caused a locational cascade. The early entrants were followed in order to reduce uncertainty and gain legitimacy. In spite of the endogenous creation of collective identity, no relevant network was formed due to their homogeneity and competition (Dalla Pria, 2008).

Alternatively, the agglomeration phase can be guided by interactive motivations source of increasing returns. As co-location goes two related phenomenon develop. Firstly, the environment is permanently re-shaped because collective action boosts locational capabilities. Secondly, agglomeration externalities increase with the number of co-located actors. While the localisation economies will appear as the co-location goes by a focussing process, jacobian externalities depend on the existence of a diversified industrial base. Both combined effects increase regional attractiveness face to potential alternatives. It locks-in the process and effaces the initial heterogeneous locational preferences.

However, interactive mechanisms are not unique, because clusters are composed of different overlapping networks, and the individual motives for interaction may be quite different. If laggards enter to interact with a main actor due to its market position or reputation, the agglomeration goes through a directed network effect. Contrary, non-directed network effect exists when new entrants locate in the emergent cluster by the attractiveness of the local network in itself rather than by individual attractiveness. The directed network effect explains the Toulouse aeronautics/aerospace cluster's consolidation. The establishment of Airbus and the main French research institutions in aeronautics and space become the focal point for latecomers. However, the agglomeration force of Silicon Valley is not based on the presence of a particular actor, but on the networking and collaborative practices that have created a "complex mix of social solidarity and individualistic competition" (Saxenian, 1994) crucial for individual and aggregated success.

The technological shift at the origin of the double competition process should be followed of an increase of demand in order to nurture not only the agglomeration process but also the technological cycle. It is through this increase in demand that technological competition develops.

P3: *Technological competition success depends on the nature of the technology, chance and the strategic behaviour of actors in the technological field*.

Technologically, the first phase, or ferment era (Anderson and Tushman, 1990) without dominant design or standard, is characterised by the uncertainty in technology and market. No certainty about the potential applications of the technology exists, so the opportunities for successful innovations are abundant (Utterback and Abernathy, 1975; Anderson and Tushman, 1990). The innovation intensity and experimentation is high (Klepper, 1997). The second phase, or era of incremental change, refers to the cumulative effects succeeding the appearance of a dominant design or standard (Anderson and Tushman, 1990). Uncertainties about the technology are reduced, product innovations decline and the generation of network externalities in the demand side modifies the supply side organization.

Deterministic views on technology explain competitive success by the exogenous users' preferences and intrinsic performance. Each new adopter makes its choice regardless of what previous adopters have done. In such ergodic contexts the demand side does not influence the supply side organization. However, since network externalities exist the individual behaviour and organizational results radically change. What matter is to gain quick diffusion in order to rapidly go trough the early markets, cross the chasm and enter the mass market (Suire and Vicente, 2009b). In these circumstances the technological competition success depends on chance and the rise of network externalities.

In ferment era chance is important at two levels. First, it may represent a particular sequence of independent adopters in favour of the technology. Second, chance can take the form of a favourable political decision that establishes a technology as the new *de jure* standard. As the number of adopters increases, the technology shifts into the incremental change era and externalities become important in different (and eventually complementary) ways. Informational signals may be source of externalities generating an informational cascade of technological adoptions through an indirect interaction process. This can be accelerated by the reputation and market power of early entrants. Moreover, the rise of number of users can create network externalities and push to supply side re-organization.

In fact, the size of network externalities depends on the strategies adopted by supply actors. Constructing vertical compatibility reduces sunk costs and so enhances the transition from old technologies to new ones. Enhancing horizontal compatibility let adopters (and producers) avoid lock-in into loser technologies. However, sponsors of technological varieties may not look for full compatibility to control network ownership and appropriate additional rents (Katz and Shapiro, 1994). Finally, complementarity raises the impact of indirect effects and enlarges the set of potential users. Consequently, the higher the compatibility and complementarity are, the higher the possibilities of a technology to become a standard.

P4: *The success on the regional and technological competition processes are interlinked*.

Firms and institutions are characterised with respect a technology and a location, so their decisions in each dimension are necessarily interdependent. This relation can be scaled up to the aggregate level and reinforced by the existence of transversal networks. Consequently, regional and technological evolutions are not independent.

Agglomerations influence the capacity of local actors to generate and defend a potential dominant design. Complementarity and compatibility require the combination of different pieces of knowledge, so they depend on the quantity, diversity and nature of resources and interactions regionally available. Inversely the generation of a dominant design in a region influences the agglomeration process in it at different levels. Firstly, it reinforces the need of collaboration. Secondly, the regional structure of the cluster will be influenced by the organization of the technological field, and finally it reinforces the region's external identity (Romanelli and Khessina, 2005).

Although a cluster can emerge with different technological and regional dynamics and their reciprocal interplay, the resulting structure is not unique. The different mechanisms at play in the first and second phase of the emergence result in clusters with different structures.

If the success on the regional competition is based on a pure resource effect, the emergent structure will be characterised by a set of independent co-located actors. The variety on knowledge bases and competences will depend on the specificity or generality of the resource launching the process. In these circumstances the size of agglomeration externalities will be limited due to the lack of interactions. Moreover, if the success on technological competition is based on the individual preferences and intrinsic performance of the technology, such a structure will be reinforced, because the demand side does not generate feedbacks pushing to re-organization of the supply side. However, if in the technological context network externalities are generated, actors are pushed to tie strategic interactions. The geographical length of these interactions will depend on the diversity and complementarity of regional knowledge bases.

If the regional success is based on mimesis, the emergent local structure is characterised by a set of independent co-located actors too. Although this gives them a collective identity, no relevant relations are generated. Moreover, mimesis only attracts actors with similar knowledge bases. The existence of regional diversity will depend on the previous industrial base in the region. Both effects have two consequences: the agglomeration externalities are low, their capacity to defend the technology is lower.

Finally, when the success of the regional competition is grounded on interactive motivation of co-located actors two main structures may emerge. If the process is driven by a directed network effect the cluster will look like a hub-and-spoke (Markusen, 1996). Contrary, if the non-directed network effect predominates, a structure of marshallian type will result (Markusen, 1996). The existence of interactions grounds the generation of agglomeration externalities, and implies a minimal knowledge diversity that can be reinforced by the previous regional industrial base. From the technological point of view agglomerations driven by network effects enhance the construction of complementarity and compatibility and so increase the possibilities to impose on the technological competition.

To sum up, clusters' emergence result of a double interlinked competition process. However, the mechanisms at play along the phases of emergence are not structurally neutral. Resource effect and mimetic behaviours result on clusters with low interactions but based on the particular factor endowment or fashion. Contrary, network effects result on clusters anchored on the richness of local interactions, but their structure will depend on the nature of the technological field and the interactive motivations.

4. Regional and technological dynamics for viability

The literature usually implicitly assumes that clusters once established become permanent successful structures. However, face to threats of different nature, they are also exposed to decline. This section focuses on viability conditions of clusters. Firstly, we define what viability is. Secondly we analyse the interplay of different factors to reinforce or weaken the cluster's viability.

4.1. Viability conditions for the long-term dynamics of clusters

Clusters are complex structures embedded in a larger landscape. So, the continuous transformations of the later will influence the evolution of the former by the generation of threats and opportunities of different nature. We classify the transformation affecting the long-term evolution of a cluster in two categories depending on their origin: technological and regional. Technologically different factors may compromise the cluster's evolution. Firstly, the arrival of a new substitutable technology that overcomes the existing technological lock-in. Two different scenarios exist. If the technological shift is produced in the cluster it will be in good position to take advantage of the new opportunity to launch a new growth wave because it is driving the change. Contrary, if the discontinuity is created elsewhere, inertia dynamics may hamper the possibilities of the cluster to take advantage of the WLO. Secondly, organizational changes on the technological domain may also launch the decline of a cluster. When the technological cycle advances, competition shifts from innovation to prices. Cluster's survival requires adapting to new competitive rules. However, a too tight relation of the cluster with the technological evolutions might also compromise the cluster evolution because of the impossibility to dissociate both cycles. Finally, the technological dynamics may be altered by random exogenous changes of very different nature originated on political, social or economical spheres.

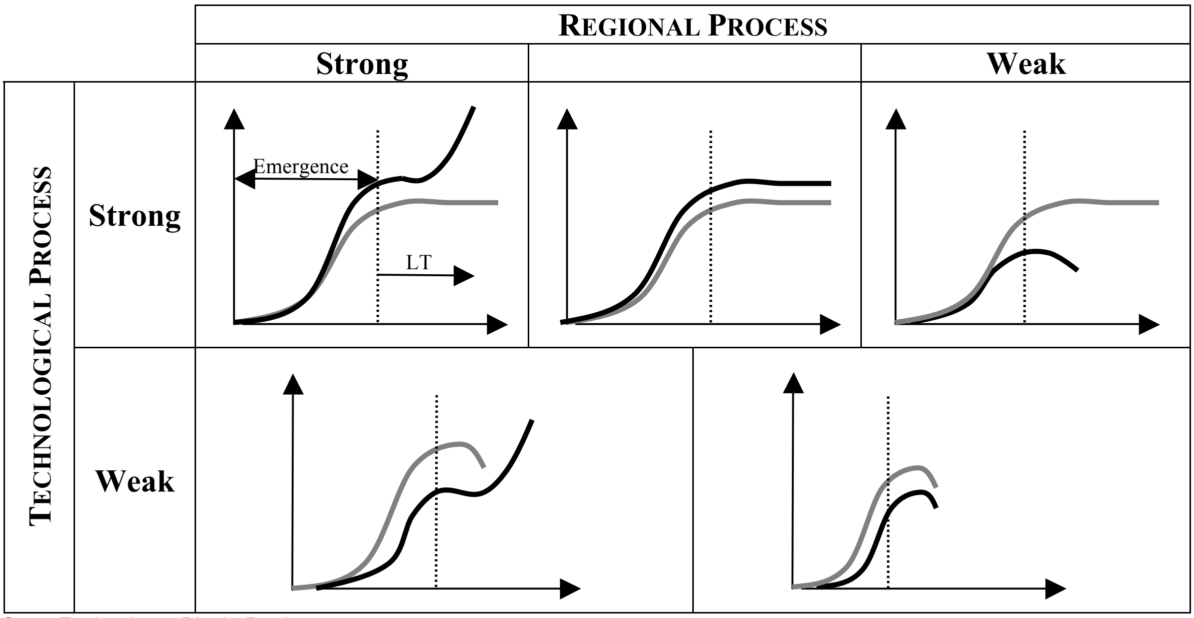
From the regional point of view, the origin of transformations may be also diverse. The spatial consequences of a technological shift opening the WLO constitute a first threat (or opportunity). Moreover, a cluster's evolution may be threatened by degradation of the regional conditions that have supported the emergence and lock-in. Grounded on the own evolution of the cluster or on the advent of some exogenous random changes, the degradation can be caused by the *ubiquitation* of non-contestable resources or by the rise of diseconomies of agglomeration. As a consequence the strength of the regional lock-in and viability conditions of the cluster are reduced.

Consequently, face to a changing environment the long-term evolution of the cluster depends on its viability capacity (Suire and Vicente, 2009a). Viability of clusters has two dimensions. Firstly, the capacity to lock-in the technological and regional dimensions; a process is locked-in when any new adopter (entrant) prefers to choose the same technology (region) than the previous decision-makers, because the utility and profitability it obtains is bigger than with eventual alternatives. Secondly, the capacity to adapt to threats and opportunities of divers origin on the other hand; when the lock-in is overcome the viability depends on the capacity of the cluster to move into a new technology and re-build regional conditions.

P5: *Viability of clusters depends on the strength of regional and technological processes. The stronger they are the more viable the cluster is*.

Clusters based on strong regional and technological processes have the capacity to lock-in these dynamics and so reduce the risk of potential threats to arrive. Contrary, with weak processes the barriers for new technologies to diffuse and new regions to emerge are lower, capacities for long-term evolution are minored. Moreover, clusters based on strong processes have larger adaptive capacity than those based on weak ones. Structures characterised by different combinations of strong and weak technological and regional processes result in clusters with divers viability conditions (Table 2[3]).

Table 2: Typology of viable clusters[4]



Grey: Technology. Black: Region

The upper-left case, supported by strong regional and technological processes, represents long-viable adaptive structures. The cluster manages not only to lock-in the technological dynamics, but also its regional process is strong enough to generate and shift into new related and growing technological domains to avoid stagnation. Such is the above-mentioned case of Silicon Valley, also called *Silicon Valley 5.0,* due to its capacity to create positive synergies to lock-in the technological and regional dynamics and create successive waves of development. Moving right on the table, the viability of the cluster is minored due to a weaker regional process. In the second case the cluster manages to lock-in the regional and technological processes, but it fails in dissociating its evolution from the technological one. The Jura cluster (Swiss) suffered this problem. Although the cluster was able to lock-in the watch

[3] Since the definition of regional and technological process depends on several features, these categories should not be interpreted as closed cases but as stylized representations in a continuum.

[4] X-axis : time ; Y-axis : cumulated employment in a technological field in the same region (black). Technological adoption (grey).

industry into a mechanic technology paradigm during more than fifty years, when in the 70s electronic and digital watches developed the cluster, trapped by inertia, fails to quickly shit into the new paradigm and decline in parallel with mechanic watches (Glasmeier, 1991). In the upper-right case the regional process is so fragile that, confronted to exogenous threats, even if the technology is solid, the cluster declines. This was the case of the Silicon Sentier when the Internet bubble crashes in the early 2000s. In spite of the continuous growth of the e-commerce a relocalisation cascade produced the Sentier's decline (Vicente and Suire, 2007).

The lower-left case represents the paradoxical situation of a cluster with a strong regional process but with weaker technological dynamics. Even if the cluster does not manages to lock-in the technological process the regional process is strong enough to shift into a successful one. The NorCom cluster (Aalborg) manages to survive going through such a re-organization process. The *de jure* establishment of GSM as the new standard for mobile communications forced to NorCom firms to give up NMT systems in order to survive (Dahl et al. 2003). Finally the lower-right case represents a non-viable cluster, although it has emerged it has weak regional and technological process so weak capacity to lock-in or adapt.

4.2. Interplay of factors for viability

After defining viability and show that viable clusters require strong regional and technological processes, we focus on the identification of the main factors influencing the strength of these processes.

P6: *The strength of the technological process depends on the intrinsic performance of the technology, the size of switching costs and the size of network externalities. These factors are partially exogenously given and partially endogenously dependent on the strategies and actions of concerned actors.*

Higher intrinsic performance over the existing technologies is a necessary but not a sufficient condition for a new substitute technology to emerge. Its relative advantage should be balanced by the size of switching costs. So the smaller the performance gap between both alternatives and the higher the switching costs are, the stronger the lock-in. The generation of network externalities reinforces the lock-in by increasing the performance of the existing technology and the size of switching costs. This explains QWERTY keyboard survival, although more performing alternatives as DSK have appeared the size of the network externalities, the size of the switching costs and the relative small advantage explain why the inefficient QWERTY is still dominant (David, 1985).

The strength of the technological process is also affected by explicit actions of actors trying to defend their technology. Seeking for complementarity strengthens both dimensions of viability: lock-in and adaptability. Complementarity reinforces the lock-in by increasing the performance of a technology "by doing better", and also network externalities and switching costs "by doing more". Complementarity reinforces adaptability. Solving existing technical problems and finding new uses for a technology, independent industries are transformed in technically related ones. This regional branching process can potentially originate a new growing domain (Frenken and Boschma, 2007). So complementarity enhances the dissociation of cluster's cycle and technological cycle by linking successive waves of growth and escaping from declining technologies. Similarly, compatibility strengthens the technological process. Horizontal compatibility reinforces the lock-in, by avoiding alternative technologies to differentiate. Vertical compatibility positively affects the adaptive capacity by overcoming the advantages of new substitute technologies.

However, compatibility and complementarity do not arise automatically. They are constrained by possible technical limitations and they depend on the will of concerned actors. Each firm decides to make compatible bridges depending on their initial conditions, their private incentives and the possibility to establish side payments (Katz and Shapiro, 1985). Finally, their achievement requires the combination of different pieces of knowledge. So they are collective processes whose effectiveness depends on the existence, nature and structure of relations.

P7: *The strength of the regional process depends on the degree of non-contestability of resources, the costs of re-location and the size of agglomeration externalities. These factors are partially exogenously given and partially endogenously dependent on the strategies and actions of concerned actors.*

In the regional sphere, the more non-contestable the resource and the higher the re-location costs are, the stronger the regional lock-in is. In deterministic cases non-contestability is exogenously given by the existing factor endowment. However, with endogenously constructed resources, non-contestability only appears with collective processes of construction, because the replication of individual actions is easier than collective ones. Agglomeration economies reinforce the strength of the lock-in, because they increase the location costs savings and reinforce the non-contestability of the resources. In non-deterministic contexts, non-contestability and externalities do not rise automatically. They depend on the existence of local relations. The strength of the regional process depends on the strategic ability of actors to collaborate.

The strength of the regional process also depends on the ability to adapt to continuous changes in the external environment or the internal conditions. To anchor the firms to the region and avoid the re-localisation dynamics that may follow the *ubiquitation* or the rise of agglomeration diseconomies, a strong regional process should be able to permanently re-build new non-contestable resources and regional specifications, and ensure the positive effects of agglomeration economies. As in the emergence, this needs of creativity and attraction power. Although this can be done individually, collective answers are more effective.

The existence of social, industrial or R&D networks and the participation in regional and technological spheres of many actors make them interdependent. In fact, achieving technological complementarity and compatibility require an actor's behaviour that contributes to strengthen regional process in two ways. Firstly, it creates low contestable regional knowledge bases. Secondly, it increases the regional possibilities to launch a new growth wave through a branching process. Inversely, the necessary strategies to reinforce the regional process impact the technological one. The rise of agglomeration economies enhances the local circulation of knowledge and exchanges between actors in different stages of the value chain. This enhances the construction of complementarity and compatibility that requires the integration of different pieces of knowledge.

As previously shown regional and technological strengths depend on interactive behaviours conforming networks. However, viability is not only a matter of existence of relations but also of their several structural features. Firstly, the opposition between centrality vs. dispersion is relevant. While centralised networks in a single (few) actor(s) may be more coherent in their organization, they are more fragile and rigid because of its dependence on the central node evolution and decisions. A second structural feature is the balance between local and non-local ties, the buzz and the pipelines (Bathelt et al. 2004). The right balance enhances the local circulation of knowledge and reduces the risk of redundancy by incorporating new external pieces of knowledge. Too much internal or too much external focus are equally dangerous. Thirdly, strong processes in the regional and technological spheres need a balance of actors with different knowledge bases. This applies either for R&D networks where actors in different knowledge phases interact (Vicente et al. 2008), or for industrial networks where actors in different stages of the value chain are in contact.

In summary, the long-term evolution depends on their capacity to avoid and adapt to the technological and regional threats or opportunities. This is defined by the different strengths on the regional and technological processes. The strength of these processes depends on factors partially exogenous and partially endogenous. Since the effective endogenous creations require interaction, networks play an important role for viability. Since firms and institutions are heterogeneous the strength of the factors influencing viability conditions will also depend on the network structure.

5. Emergence and viability: two interdependent dynamics

In sections 3 and 4 we have shown that clusters are neither pre-established units nor never-ending stories. According to the hypothesis 1 they emerge and evolve as a result of the evolution of a regional and technological dynamics. In this section, according to the hypothesis 2, we argue that emergence processes and viability conditions are not independent from each other. Given the fact that the cluster's development is done through time, inertia and path dependency are involved. The structure emerged after a technological shift is the same facing threats and opportunities in the long-term. We show that emergence conditions influence the long-term dynamics of the cluster, because depending on the emergence mechanisms different structures are created.

As proposition 5 shows cluster's viability depends on the strength of the regional process. Following proposition 7 this depends on exogenous factors and endogenous behaviour of actors. With resource effect as mechanism of emergence, the cluster exists due to the availability of particular non-contestable resources. By definition this means a strong regional lock-in. As long as the underlying necessary resources continue to be non-contestable the regional dynamics will be locked-in. The region is the location norm of the industry because of the homogeneity of location preferences rather than by the generation of agglomeration economies, which may be weak due to the lack of interactions. However, their viability is minored due to their weak adaptive capacity. A transformation of the environment may reduce the non-contestability of the resource anchoring the firms to the region, without adaptive capacity the disappearance of the regional lock-in may cause the cluster decline. Furthermore, if no new alternative applications for the regional resources are found, increasing their alternative usability, the regional dynamics will fail to dissociate from the technological one. The decline of the later will lead to the decline of the cluster. Without interaction, the adaptive capacity to regional or technological transformations is defined by the sum of individual capacities with only weak synergies among them. No collective answer to adapt the region is developed.

A location norm emerged by mimesis is characterised by co-located similar firms that do not relate with each other and internally develop the required locational specifications. From the viability perspective these agglomerations have weak lock-in capacities. If they are based on informational signals no factors to anchor the cluster to the region are developed. The locational specifications are internally developed, so they are reproducible and contestable. Moreover, without interactions among local actors no major agglomeration externalities raise. Consequently, neither the existing resources, nor the increasing returns produced by co-locations reinforce regional dynamics. Co-location only depends on the ephemeral strength of reputation and fashion. The adaptive capacity of these clusters is also weak. As in the resource effect, the adaptation to regional or technological changes is done individually rather than collectively. It depends on their individual creativity, absorptive capacity and flexibility. The Silicon Sentier, emerged by a location cascade, was just endowed with a collective image behind the Silicon label, but there were neither non-contestable resources nor a collective organizational structure. With the crash of the dotcom bubble in 2001 the value of the Silicon label was eroded and an inverse process of relocalisation produced the decline of the cluster (Dalla Pria, 2008).

Finally, when regional dynamics emerged by network effect, the resulting agglomeration is characterised by a set of co-located firms and institutions interacting among them in R&D collaborative projects and/or as a part of a production chain. The system will appear as a cluster of marshallian style or a hub-and-spoke cluster depending on the relative importance of non-directed and directed network effects respectively. Both these structures lead to a strong lock-in due to the development of non-contestable resources and increasing returns. Firstly, collectively constructed location specifications are less contestable. Moreover, the emergence and constitution of a network is a non-contestable resource in itself. Finally, with interactions, agglomeration economies can become important. Silicon Valley is the best-known example of these regional and technological lock-in capacities. The quantity, quality and variety of actors and relations in the region contribute to create a unique collective resource that homogenizes the heterogeneous location preferences of new actors. Either parent spinoffs located elsewhere, as Microsoft, or new start-ups continue to choose the Valley for their location (Suire and Vicente, 2009b).

From the adaptability perspective, the existence of local networks with similar and dissimilar interactive actors endow the cluster with better capacities to adapt to transformations, and even drive the change. Voluntary or involuntary collective action enhances the re-specification of locational conditions and the construction of related variety, complementarity and compatibility to overcome threats and find opportunities. However, viability is not independent of the network structure defined by directed or non-directed network effects. Hub-and-spoke clusters are more rigid and fragile than marshallian clusters. On the one hand, the failure of Airbus, Thales Alenia Space or Astrium in Toulouse may imply the entire decline of the cluster due to their central role to articulate the whole cluster. On the other hand, face to a threat the adaptive capacity of the agglomeration is also strongly dependent on the individual adaptive capacities of the hub. Contrary, Silicon Valley evolution is not exposed to such central dependence what endows it with a higher capacity to take advantage of opportunities.

Proposition 5 states that cluster's viability also depends on the strength of the technological process. However, as proposition 6 shows this is partially dependent on the explicit strategies of firms and institutions involved on the technological field, because their actions contribute to improve the intrinsic performance, the size of switching costs and the size of network externalities. The nature of these strategies is linked to the regional dynamics and its mechanisms of emergence. A sustainable technological lock-in can be achieved without explicit strategies on the supply side. The adoption decisions made by users are enough to generate network externalities. In these cases even non-interactive emergence mechanisms may be supported by a long-term sustainable technological dynamics. However, location norms emerged by network effects produce stronger technological dynamics. By enhancing cooperation between actors with dissimilar but complementary competences, complementarity and compatibility are achieved. Consequently, they strengthen the technological lock-in, and enhance the adaptability to changes (or even trigger it). Contrary, mimesis or resource effect, getting together similar actors, reduces the possibilities to adapt and/or drive technological transformations by reducing the variety of resources blinding the opportunities to find new applications.

So, different mechanisms of emergence create different cluster structures with different viability conditions defined by the capacity to lock-in the process and the adaptive capacity to regional and technological threats and opportunities. Although emergence mechanisms based on interaction have *a priori* better viability conditions because they enhance the generation of agglomeration economies, collective locational specifications, and the construction of related variety, complementarity and compatibility. The existence of networks is neither necessary nor sufficient to explain viability, because it is also influenced by the resource contestability and the structural features of the network. So non-interactive mechanisms of emergence may result on viable clusters by the non-contestability of its factor endowment, and a cluster resulting from a network effect may show low viability because of the fragility of its structure.

6. Conclusion and discussion

This paper has studied the lifecycle of technological clusters. We adopt a dynamic approach in order to avoid the traditional assumptions looking at them as isolated, pre-established and never-ending successful stories. While studies focusing on the emergence conditions to solve former limitations are the more and more common (Bresnahan et al. 2001; Brenner, 2004), the later questions, trying to study the life cycle of clusters, has attracted much less attention (Menzel and Fornahl, 2010; Suire and Vicente, 2009b).

Clusters are defined over interdependent regional and technological dimensions, which are traversed by social, industrial and R&D networks. The evolution of the cluster is guided by changes of these two dimensions. Clusters emerge where the regional and technological dynamics are able to succeed on the double competitive process created after a technological shift. Although a parallelism between the technological and cluster cycle can be drawn at the emergence stage, in the long-term this is not a symmetric process. The long-term survival of clusters depends on the two dimensions of viability, which are defined with respect technological and regional dynamics. Different lifecycles of clusters are explained by different capacities to lock-in, adapt and take advantage of transformation in the regional and technological contexts.

We show that dissimilar viability capacities defining the long-term evolution of a cluster depends on the nature of the emergence process. The mechanisms explaining the success in the double competitive process at the emergence stages produce different structures of co-located actors. They will have different viability conditions and so produce cycles of different length. Non-interactive forms of emergence show low adaptive capacity only internally defined, but their lock-in capacities are dissimilar. While clusters emerged by mimesis are fragile because they are grounded on reputation and informational signals that may blow up, those emerged on the base of a resource effect may keep in the lead as long as the resource remains non-contestable. Interactive forms of emergence show *a priori* stronger viability conditions. Locational specifications collectively constructed and the generation of agglomeration economies through interaction reinforces the lock-in. Moreover, interactions, subject to proper structural features, enhance adaptability by the development of related variety, complementarity, compatibility and the collective reconstruction of new locational specifications. So cluster neither exist per se nor live forever. Their birth and their different cycle-length depend on the strength of regional and technological synergies to face the multiple transformations suffered by its surrounding landscape.

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