

Lock-in or lock-out? How structural properties of knowledge networks affect regional resilience

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Abstract

This article develops an evolutionary framework of regional resilience with a primary focus on the structural properties of local knowledge networks. After presenting the network-based rationales of growth and structuring of clusters, we analyze under which structural conditions a regional cluster can achieve short-run competitiveness without compromising long-run resilience capabilities. We show that the properties of degree distribution (the level of hierarchy) and degree correlation (the level of structural homophily) of regional knowledge networks should be studied to understand how clusters succeed in combining technological lock-in with regional lock-out. We propose simple statistical measures of cluster structuring to highlight these properties and discuss the results in a policy-oriented analysis. We conclude showing that policies for regional resilience should focus on ex-ante regional diagnosis and targeted interventions on particular missing links, rather than ex-post myopic applications of policies based on an unconditional increase of network relational density.

Key words: Resilience, clusters, assortativity, regional policy

JEL classifications: B52, D85, O33, R11, R12

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1. Introduction

The literature largely acknowledges localized knowledge networks as a significant factor of regional performance in knowledge-based economies. In a context of complex knowledge and rapid change, research converges in signaling that regions' ability to host networks of complementary and interacting organizations is a key factor to explain regional performance differences (Owen-Smith and Powell, 2004; Rychen and Zimmermann, 2008). Largely evidenced, such a move toward a relational approach to regional performance (Boggs and Rantisi, 2003) has led, particularly in Europe, to a massive development of clusters policies based on incentives for collaboration and network development (Martin and Sunley, 2003).

Nevertheless, behind this large consensus, very little research has pursued the question of the long-run evolution of regional innovative structures. The articles by Tödtling and Trippel (2004), Hassink (2005), Suire and Vicente (2009), Simmie and Martin (2010), Menzel and Fornahl (2010), Crespo (2011), Boschma and Fornahl (2012) and Cooke (2011) constitute notable exceptions. They are the mark of a

burgeoning and promising research field for understanding how some performing regions can decline at a given moment in time, whereas others are able to renew and sustain their growth in a disturbed economic environment. Mainly dedicated to innovative regions and technological clusters, this research is part of a more general wave of research on regional resilience. This wave is structured around formal communities of scholars (Swanstrom, 2008)¹ and seminal special issues (Christopherson et al., 2010), and concerns a wide range of challenges, such as the resilience of urban places (Wrigley and Deloga, 2011), the renewal of old industrial systems (Hassink, 2010), or the ecological transition of local innovation systems (Cooke, 2011). These researches are nowadays of a growing interest, as the macroeconomic context is characterized by chronic instability. Financial and economic crisis, but also rapid technological cycles, environmental considerations, and new growing consumption paradigms challenge global and also regional policies.

Regional resilience and cluster life cycles are the key concepts that have recently emerged in the literature on regional development. These concepts reflect a common attempt: understanding the evolutionary process through which a regional ecosystem of organizations and institutions succeeds in maintaining its growth path by disconnecting its cycle from the cycle of technologies when these decline. Some regions have difficulties in coping with technological and market decline, even if they were performing during the maturity stage. Others reorganize resources and networks to enable them to enter into a new related stage. All this burgeoning research tries to go beyond a classical view of resilience as a mechanical return to the equilibrium after exogenous and external shocks. It attempts to capture the endogenous mechanisms of adaptability, viewed as the ability of the actors and their social agency (Pike et al., 2010) to anticipate, evolve, and so adapt to disturbed and cyclic economic environments.

To deal with this question, we suggest combining a multidisciplinary theoretical analysis that discusses the critical factors of regional resilience, with an evolutionary economic geography framework (Boschma and Frenken, 2006; Martin and Sunley, 2007) that focuses on an out-of-equilibrium approach of regional science. Our contribution is centered on the study of the structural properties of networks that can help having a better understanding of the tensions and conflicts in adaptive systems between connectedness and increasing order on the one side and the resilience properties on the other side. Although the first ones typify the prominence and stabilization of a particular economic structure, the second ones require a high level of flexibility and restructuring capabilities (Pendall et al., 2010; Simmie and Martin, 2010; Cooke, 2011).

Networks have been of a growing interest in the social sciences for a couple of years (Borgatti and Halgin, 2011). They are at the heart of well-known theoretical research in sociology (Uzzi, 1997; Borgatti and Everett, 1999), economics (Jackson and Wolinsky, 1996), geography (Glückler, 2007; Ter Wal and Boschma, 2009) and management sciences (Powell and Grodal, 2005), with a high level of absorption of results coming from physics and complex systems theories (Albert and Barabási, 2002; Newman, 2003). Considering that networks can be represented by two basic primitives (the nodes and the ties that connect the nodes), network theories give a simple but useful representation of social structures in a static sense and have more recently focused on a

1 See also the publications of the *Building Resilient Regions* Institute: <http://brr.berkeley.edu/economic-resilience/>.

dynamic purpose (Ahuja et al., 2012). Obviously, on the one hand, theorizing regional resilience only through the dynamics of knowledge networks can be viewed as a partial and *ceteris paribus* approach, and in a sense it is, because other dimensions matter such as the cognitive, political and institutional ones, as perfectly identified in a seminal research of Grabher (1993). But on the other hand, scholars have also pointed out the key role of network dynamics on the renewal of clusters. For instance, in the early 1990s, Saxenian (1990) reminded that ‘The resilience of the Silicon Valley (...) is the product of the region’s dense networks of social, professional, and commercial relationships, not simply of unfettered markets or national policy’ (91). For Tödtling and Trippl (2004), institutions and policies are not sufficient conditions for the renewal of clusters in mature regions and industries: ‘Direct intervention and the provision of subsidies and infrastructure are generally not enough. (...) The renewal of clusters implies also a renewal of networks. This includes new links with knowledge suppliers as well as innovation networks among companies’ (1178). And more recently, Cho and Hassink (2009), in the line of Grabher (1993) showed that the difficulties of mature regions renewal could be found in political, cognitive and functional lock-ins, the latter being associated to networks: ‘Their key feature concerns a particular constellation that negatively affects necessary economic renewal. Local networks of dominant industrial production become so narrowly focused on a particular type of retrogressive economic activities that is unable to shift into a new restructuring track. When being locked into rigid trajectories, the existing networks face increasing costs, due to reluctance and resistance, to replace old with new networks’ (1185).

Our purpose is to identify simple but empirically testable signatures of structural properties of local knowledge networks that give interesting properties for understanding the conditions of regional resilience. Section 2 discusses cluster growth, structuring and properties, in the framework of the abounding literature on networks. Section 3 studies structural conditions for local knowledge networks to display performance and resilience properties. For that, we analyze how social agency and structural properties of clusters can simultaneously lead toward technological lock-in and regional lock-out. Section 4 proposes two statistical measures of cluster structuring that highlights how these properties can interact. Finally, Section 5 discusses the results and gives new insights for regional policies, confirming that network density is not the *panacea* for cluster policy (Martin and Sunley, 2003) and showing that more targeted and surgical interventions are more effective at improving regional resilience.

2. Cluster and network theories

2.1. A (too) short history of cluster analysis

Clusters, simply defined at this stage as localized knowledge networks in technological and market domains, are nowadays viewed as a primary concept for regional competitiveness and growth policies. In Europe, since the Lisbon Agenda of 2000, cluster policies are one of the main tools for leading Europe toward ‘the most competitive and dynamic knowledge-based economy in the world by 2010’². From guideline dissemination (European commission, 2008) to the creation of a public-

2 Presidency conclusions of the Lisbon European Council, March 2000. See http://www.europarl.europa.eu/summits/lis1_en.htm.

funded European Clusters Observatory (European Commission, 2009), the European Commission has convinced regional and national policy makers that competitiveness is highly correlated to the absorption of the ‘good practices’ of cluster policies. Nevertheless, cluster success stories or declines are not the direct consequences of policy implementation, but the result of various historical trajectories. These trajectories mix public interventions but also different contingencies related to entrepreneurship, learning and self-organized network formations, with a high level of unpredictability (Saxenian, 1990; Feldman, 2001; Wolfe and Gertler, 2004). Apart from a few notable critical articles (Martin and Sunley, 2003), the academic literature has viewed clusters as a source of regional performance in modern economies. This is particularly true since the publication and wide diffusion of the empirical study of the Silicon Valley by Saxenian (1994) and the cluster theory developed by Porter (1998). Since then, geographers, economists, sociologists and also specialists of network analysis and management scientists have converged toward the idea that agglomeration economies arise not only from market forces nor from ‘cookie cutter’ policy guidelines (Wolfe and Gertler, 2004) but also from non-market interactions and network formations that can give rise to an unpredictable local web of knowledge flows that improves or scleroses regional competitiveness. Clusters have increasingly been studied from a multidisciplinary angle. Economists have exchanged with geographers of innovation to understand how knowledge spillovers arise more from strategies of knowledge exchange than from ‘in the air’ knowledge flows (Breschi and Lissoni, 2001). Economic geographers have exchanged with network sociologists by introducing social network analysis into regional systems of innovation (Ter Wal and Boschma, 2009). And management scientists have done the same by analyzing local organizational networks as a source of structural embeddedness that favors the production and diffusion of knowledge (Owen-Smith and Powell, 2004).

2.2. Clusters as knowledge structures

A cluster can now be defined as a local relational structure that results from the identification of a set of nodes of various institutional forms (the organizational demography) and the ties between them (the relational structure). Interorganizational ties in a cluster can be of different nature (productive, commercial, cognitive or social) and of different geographical length. Our discussion focuses on organizational relations locally constructed to exchange knowledge in high-tech technological domains. This relational structure can be represented in the form of a network, featured by structural properties that highlight the channels through which knowledge flows and the level organizations’ embeddedness.³

3 Cluster literature acknowledges that local interactions constitute only a part of the networks in which organizations are embedded. According to Bathelt et al. (2004), Wolfe and Gertler (2004) and Coe et al. (2008), successful clusters are those that succeed in building and mixing local and global channels to manage knowledge access at different geographical scales. In this vein, Owen-Smith and Powell (2004) introduce clusters as networks that are part of a nested system of networks mainly devoted to knowledge exploration, whereas global networks are more dedicated to relationships for technological integration and exploitation. And for Sturgeon (2003), Cowan et al. (2004) and Balland et al. (2013), successful clusters are those that succeed, through their internal organization of knowledge flows, in turning new ideas into dominant design and technological standards, relying on strategic global partnerships for that purpose.

These structural properties can have a high degree of variability from one cluster to another. Clusters can have a very weak level of relational density if organizations value isolated strategies over knowledge partnerships, or if non-local partnerships are preferred over local ones. In that case, the clusters are no more than the simple result of a co-location process. On the contrary, clusters can display a high level of density when knowledge complementarities, trust and social proximity (Boschma, 2005) lead to high levels of local cohesiveness. Even with a fixed level of density, a strong variability of structural properties remains. The distribution of degree centrality can vary from flat to sloped. To put it differently, the shape of the degree distribution refers to the hierarchy of positions in the web of relations. Some organizations can have many relations due to a high relational capacity (König et al., 2010). This is generally linked to the size of the organizations, their absorptive capacities or the openness of their model of knowledge valuation.⁴ On the contrary, some others remain poorly connected due to their newness, small size or closed model of knowledge valuation. Last but not least, beyond the level of cognitive homophily of the organizational demography, clusters can display various levels of structural homophily, which is generally captured by a network index of assortativity (Newman, 2003; Watts, 2004; Rivera et al., 2010). The structure of relations will be assortative when highly (poorly) connected nodes tend to be connected disproportionately to other high (weak)-degree nodes, and disassortative when highly (poorly) connected nodes tend to be connected disproportionately to other weak (high)-degree nodes. Therefore, the level of network assortativity gives a formal representation of the way knowledge flows between central and more peripheral nodes.

2.3. Cluster growth

Where do the nodes and the ties come from? Network theory is very useful for analyzing cluster properties. But the emergence of the aggregate properties commonly studied in physical systems has to be founded on microeconomic behaviors, including rationality, strategy and decision externalities, rather than on simple and myopic behaviors (Watts, 2007). In particular, these microfoundations are necessary to understand how new entrants join a cluster and (re)shape and/or reinforce its relational structure. Network theory has identified several drivers of network formation. Two of them are extreme and simple cases of node entry and tie formation.

First, networks can evolve through the entry of new nodes that do not connect to any other node (isolates) or through the entry of new nodes that connect to others either by purely random attachment mechanism or by preferential attachment mechanism (Albert and Barabási, 2002). Random attachment means that entering nodes randomly connect to others with no particular preference for their position in the structure.

Considering the important role of this literature for cluster studies, our present purpose is limited to local networks and their structural properties. As a matter of fact, the following theoretical research stresses on the endogenous abilities of clusters to exhibit resilient properties. It means that the influence of the position of a particular cluster in the international and global hierarchy is considered as an exogenous parameter.

4 The hierarchy of positions and degree centralities of organizations are only considered here at the level of local interactions. Following the previous note, this hierarchy can be stronger if we take into account global interactions and pipelines, for which big and hub companies are generally more concerned (Vicente et al., 2011).

Isolate entrants and random attachment mechanism will give rise to a rather flat hierarchy of node degrees (Erdős and Renyi, 1959). In terms of location decision externalities and individual strategies, both kinds of processes can be associated with a locational cascade (Suire and Vicente, 2009). In locational cascades, new entrants draw payoffs from belonging to the structure as a whole, not from targeted connections to particular nodes in the structure. Locational cascades have been largely evidenced for clusters that attract new organizations because of an external audience and a geographical charisma (Romanelli and Khessina, 2005; Appold, 2005). Organizations converge to a ‘locational norm’ because the charisma displayed by one place in terms of R&D productivity provides a signal of quality and a strong incentive for being located there, whatever the position in the relational structure.

Second, entries can occur through a process of preferential attachment. In this opposite case, nodes with many ties at a given moment of time have a higher probability to receive new ties from new entering nodes. The higher the degree of a node, the more the node is attractive for receiving new ties, so that the network grows through an increasing hierarchy (Albert and Barabási, 2002). This behavioral pattern of nodes can be associated to a network effect in location decision externalities. This means that the more new entrants are connected to highly connected nodes, the more their payoffs increase, due to the benefits of reciprocal knowledge accessibility and technological connections to an emerging and growing standard. This branching process is now linked to targeted connections in the structure rather than random ones and is consistent with the relational constraints that typify the production and diffusion of technological standards in high-tech industries and markets (Farell and Saloner, 1985; Arthur, 1989). It is also consistent with the relational behavior of spinoffs that tend to connect to their often highly connected parent’s company (Klepper, 2010).

2.4. Cluster structuring

Beyond node entry, clusters structure themselves through the construction and dissolution of ties. The literature acknowledges two categories of individual incentives that shape social structures and dissociate *closure* from *bridging* network strategies (Baum et al., 2012). Triadic closure implies that a node with links to two other nodes increases the probability for these two nodes to have a tie between them. Such an argument is grounded on the process of trust construction that grows between two related nodes, because it fosters cooperation and knowledge integration within groups of nodes. Closure in knowledge networks strengthens the mutual monitoring capability of organizations. Indeed, on the one hand, it decreases the possibilities of opportunistic behaviors (Coleman, 1988). On the other hand, it increases the effects of conformity required by technological standardization processes: without such closure, organizations can be tempted to play the battle of standards and accept the risk of a payoff decrease. As this process develops, the clustering coefficient of the network increases, and triadic closure tends to shape a core component in the network (Borgatti and Everett, 1999), in particular when closure prevails for highly connected nodes.

The second category of individual incentives relates to bridging strategies and introduces the idea of a more disruptive relational behavior. For a given network, bridging ties will be shaped when one node finds an opportunity to connect

disconnected nodes or groups of nodes. Such an agency behavior (Burt, 2005) is more entrepreneurial than the former, because bridging provides access to new and non-redundant knowledge and new opportunities for improving innovation capabilities (Ahuja, 2000; Ahuja et al., 2009). In the case of clusters, these bridging strategies have implications on the overall structure because they can enable better circulation of knowledge between the core and the periphery of a network (Cattani and Ferriani, 2008).

3. Are performing clusters also resilient?

The mechanisms of node entry and tie formation in clusters, as well as the resulting structural properties, are critical parameters in the economic analysis of the functioning and performance of clusters. But is performance incompatible with resilience, or are there particular structural properties that enable certain clusters to combine the two features? This question is crucial for the cluster research agenda, as well as for regional policies that face faster technological cycles and increasing turbulence in the economic environment.

3.1. Lock-in and lock-out in cluster growth trajectories

Regional resilience is considered here in an ‘out of equilibrium’ approach (Simmie and Martin, 2010) that opens the debate on performance versus resilience of clusters. Such a debate requires an understanding of the complex dynamic process through which a system of local interactions succeeds in emerging as a competing and leading location in a particular technological domain, while maintaining the conditions of its renewal by adapting to patterns of technological life cycles, market dynamics and consumer’s evolving paradigms. The direct transposition from physical network theory clearly shows that there is an opposition, or at least a trade-off, between efficiency and resilience (Brede and Vries, 2009). The more efficient the network is, minimizing ties and maximizing reachability, the more sensitive it is to external shocks and the more it exhibits fragility properties. Introducing strategic behavior, cognitive features and agency in network theory let us overcome the myopic behavior of nodes. The integration of the strategy in the relational behavior lets us challenge this trade-off. There is empirical evidence that some regional networks are able to re-direct their development paths through a complex overlapping process between a mature market domain and a new emerging related one and so maintain their growth trajectories. Hassink (2007) for instance highlights the relational and institutional dynamics in West Münsterlad that explained the fruitful transition from the textile industry toward medical applications and devices. Such resilient processes are also observed by Cooke (2011) in the Silicon Valley, where the mature sector of semiconductors that had led the Valley to be a successful place in the computer industry in the 90s has also been introduced and recombined with new applications in promising and efficient solar technologies.

The mechanisms through which these resilient processes occur have to be understood in terms of path dependency and adaptability (Pike et al., 2010; Simmie and Martin, 2010). Such an approach is better suited for understanding both the way in which a region draws its success from its ability to organize knowledge networks toward domination in a particular technological field (the performance property) and the

ability of these networks to move from this field to another when the former declines (the resilience property). Do ‘winner takes all’-type clusters necessarily imply loser regions when market declines? To understand this causality, one has to distinguish the mechanisms that can lead simultaneously toward technological lock-in and regional lock-out and then understand how the structural properties of knowledge networks contribute to both.

3.2. Regional resilience and the structural properties of knowledge networks

Successful clusters at a moment in time and in a particular technological field are the ones that have succeeded in going from the exploration of new ideas to the exploitation of a technological standard or dominant design on a mass market, with in between, a collective process of knowledge integration between complementary organizations along the knowledge value chain (Cooke, 2005). Beyond the traditional scheme of exploration/exploitation that typifies the innovation process of a single organization, the knowledge integration phase is at the heart of the cluster’s purpose. Indeed, the success of many products results from their degree of compositeness, the variety of uses and applications supported by the products, scientific as well as symbolic knowledge and the compatibility and easy interoperability between elements that are the rule of a dominant design diffusion. The chasm that sometimes prevents some products from reaching the mass market (Moore, 1991) is more often the consequence of a failed integration process, that is, a problem of industrial organization, rather than a problem of the product quality in itself.⁵ Therefore, successful clusters are the ones that achieve the imposition of well-integrated and performing complete technological systems on mass markets. As the literature shows (Klepper and Simmons, 1997; Audretsch *et al.*, 2008), these clusters evolve from an initial scattered structure of burgeoning organizations in the early market stages to a structure with a limited number of hub and oligopolistic organizations in mature markets. Along the life cycle of products, and especially composite ones, such a network dynamic produces path dependence and technological lock-in. The more the technologies generate increasing returns to adoption, the more markets for these technologies become locked-in and resist to other competing technologies (Arthur, 1989).

But are clusters producing these technologies necessarily locked-in too? The answer depends on the way in which their relational structure evolves along the life cycle of products. First, recall that networks can grow through preferential attachment. This means that the more nodes display a high degree, the more newcomers connect to these nodes, engendering a high level of hierarchy in the distribution of nodes. But second, recall that beyond network growth through node entry, networks can also evolve by the addition and rewiring of ties between existing nodes through closure or bridging (Baum *et al.*, 2012). When closure prevails, the cluster evolves toward a high level of transitivity between nodes which is the mark of isomorphic and conformist relational behaviors. In that case, the structure of the cluster exhibits tight couplings into a core component and a loosely connected periphery of nodes. The ossification of the cluster goes with the formation of an assortative network, in which highly connected nodes are tied

5 Organizations can have a voluntary strategy of niche products and thus a narrow market objective. This issue does not concern our aim, which is more focused on technological standards and mass-market products.

predominantly with other highly connected nodes in the core, and peripheral nodes remains connected between themselves. On the contrary, a core/periphery structure with a disassortative web of knowledge relations can emerge as the entry of newcomers and rewiring process goes on. For that, the node bridging strategy has to prevail over the closure strategy. Consequently, highly connected nodes spend a share of their relational capacity on peripheral nodes, and the network as a whole displays more paths between the core and the periphery than for the assortative network.

The patterns governing the entries dynamics into networks and the structuring process that follows are at the heart of the lock-in/lock-out debate. Academics acknowledge that preferential attachment is a natural pattern of social and human networks that contributes to fostering the legitimacy of social norms and conformist effects in sociology (Watts, 2004) or technological standards and dominant designs in business studies (Frenken, 2006). But the debate between closure and bridging is more controversial, and it is controversial for cluster studies too (Eisingerich et al., 2010). Indeed, closure favors technological lock-in and thus the ability of the relational structure to perform in markets. The tight coupling between high-degree organizations favors conformism and trust in a stable and cohesive structure that prevents opportunism and promotes an efficient integration of knowledge in a context of weak environmental uncertainty. But closure favors network assortativity and then prevents regional lock-out, because the low connectivity between the core nodes and the peripheral ones limits the re-organization of knowledge flows when uncertainty grows or when the market starts to decline. So when preferential attachment and closure interact, the ability of clusters to deal with a positive technological lock-in goes against their ability to produce the conditions for technological lock-out, and then resilience (Simmie and Martin, 2010). To foster adaptability and resilience, clusters also have to develop bridging strategies to open more disruptive relations between the core and the periphery of nodes, preserving minimal cohesiveness in the core, while multiplying the channels for potential or latent flows of fresh and new ideas coming from peripherals nodes (Grabher and Stark, 1997; Cattani and Ferriani, 2008). Such a mix of patterns does not undermine the hierarchy of degrees that emerges when the technology goes toward exploitation. But to be disassortative, the oligopoly structure of hub organizations, which appears as the technology reaches maturity, has to maintain a not too low amount of entrepreneurial connections with the periphery, to overlap exploitation in a particular knowledge domain and exploration in another related one. Such a structural property of clusters is consistent with the behavior of firms according to their maturity and age. Indeed, Baum et al. (2012) develop evidence on the predisposition of organizations to deal with closure or bridging strategies according to their age. Supposing that the age of organizations is positively related to their hub position and high degree, then the resilience capabilities of local knowledge structures can be weakened by an insufficient level of connectivity with newcomers. If it is supposed that the capacity constraints in the amount of ties an organization can maintain is related to its size and age, as König et al. (2010) do, then the high capacities of hub and central organizations can be a strong source of resilience if they go against the natural tendency to reproduce existing and conformist ties. Ahuja et al. (2009) find empirical evidence on that by capturing the micromotives for more disassortative behaviors. They highlight a threshold and non-monotonic effect in the strategy of embeddedness and closure between central nodes. According to them, the growing benefits in terms of trust and knowledge acquisition can go with an increasing rigidity

and conformity that produces disincentives for collaboration. Likewise, in spite of risks of knowledge holdup and contract incompleteness, they find that peripheral organizations succeed in connecting to central nodes, through a ‘creeping’ strategy facilitated by the ability of mature organizations to find sometimes new and disruptive opportunities to connect to peripheral newcomers.

4. Two simple statistical signatures of local network resilience

Therefore, the level of hierarchy of node degree and the level of assortativity appear as two simple statistical signatures of the ability of clusters to perform but also to avoid negative lock-in through their endogenous resilient capabilities. Other individual parameters matter, such as age or size, cognitive variety and the model of knowledge promotion and valuation of the organization. But each of them can be associated to the two former parameters because they influence the relational behavior of clustered organizations. Regional resilience studies should rely on the structural and topological properties of knowledge networks as key factors. The correlation between relational behavior and individual features has to be captured in parallel.

4.1. Degree distribution and degree correlation: statistical measures

Hierarchy and assortativity can be measured through two simple statistical signatures. The first corresponds to the degree distribution of the network. The more sloped the distribution is, the more the network displays hierarchy in the degree of nodes. From weakly connected nodes to highly connected nodes, the degree distribution exemplifies the level of heterogeneity in the network in terms of actual relational capacity. The second property corresponds to the degree correlation. Networks can be characterized as assortative or disassortative to the extent that they display a positive or negative degree correlation. A network is assortative when high-degree nodes are connected to other high-degree nodes, and low-degree nodes are preferentially connected to low-degree nodes, so that the degree correlation is positive. And a network is disassortative when high-degree nodes tend to connect to low-degree nodes, and vice versa, so that the degree correlation is negative. For a given amount of nodes and ties in a particular network, one can easily capture these two salient properties.

Consider a fixed number of nodes and ties in a network N .⁶ If we note k the degree of a particular node h , we can then write two simple equations to characterize the network topology. By referring to a rank-size rule, we can classify node degrees from the largest to the smallest⁷ and then draw the distribution on a *log-log* scale. Such that:

$$k_h = C(k_h^*)^a,$$

⁶ Then, we only focus on the structuring of the network. Entries are considered as exogenous, or occurring in previous periods. Such a supposition is consistent with the following policy focus, which only deals with the relevance of public-funded incentives for collaboration in an existing structure.

⁷ If two nodes have the same degree, we arbitrarily rank them as long as it has no incidence on the slope on the power law.

with k_h^* being the rank of the node h in the degree distribution, C a constant and $a < 0$ the slope of the distribution or equivalently,

$$\log(k_h) = \log(C) + a \log(k_h^*).$$

Second, we can calculate for each node h , the mean degree of the relevant neighborhood (V_h), that is,

$$\bar{k}_h = \frac{1}{k_h} \sum_{i \in V_h} k_i,$$

where k_i is the degree of node i belonging to the interaction neighborhood of node h .

Then we estimate a linear relationship between $\bar{k}_h$ and k_h , such that

$$\bar{k}_h = D + bk_h,$$

with D a constant and b a coefficient capturing the degree correlation.

If $b > 0$, the network N exhibits assortativity with a positive degree correlation, whereas if $b < 0$, the network N is disassortative with a negative degree correlation.

Finally, thanks to the ordinary least squares method, the joint estimation of parameters a and b enables us to characterize useful structural network properties.

$$\begin{cases} \text{degree distribution} : \log(k_h) = \log(C) + a \log(k_h^*) & (4.1) \\ \text{degree correlation} : \bar{k}_h = D + bk_h. & (4.2) \end{cases}$$

4.2. Discussion

Using Equations (4.1) and (4.2), and considering a network N with a fixed number of nodes ($n=33$) and ties ($t=64$),⁸ Figure 1 summarizes this proposition, giving more details on three typical topologies and their statistical signatures.

1. The so-called random network presents a relatively flat degree distribution $|a|=0.37$ with a degree correlation $b \sim 0$. From the point of view of a physical or engineering approach of networks, and whatever node is removed, such a network displays a high resistance to external shock. Due to a rather flat hierarchy within the whole network, regardless the node removed, the fluid will still find paths to irrigate the whole of the network. From the point of view of a more socioeconomic oriented approach, such a network also displays a strong potential for knowledge flows re-organization and diffusion because the nodes are linked by many paths. But such a random network does not succeed in generating conformity effects and the emergence of technological standards. Indeed, the lack of cohesiveness and the absence of a core group weaken the control of collective behaviors that would exploit products on the market by efficiently gathering pieces of knowledge.
2. On the contrary, the ‘core/periphery and assortative network’ presents a strong slope in the degree distribution $|a|=0.89$ so that the cohesiveness of the core promotes a conformity effect, and, from a technological perspective, a high

⁸ In such a way that the density remains the same for the three networks $=2t/n(n-1)=0.1212$, where t is the number of actual links and n the number of nodes.

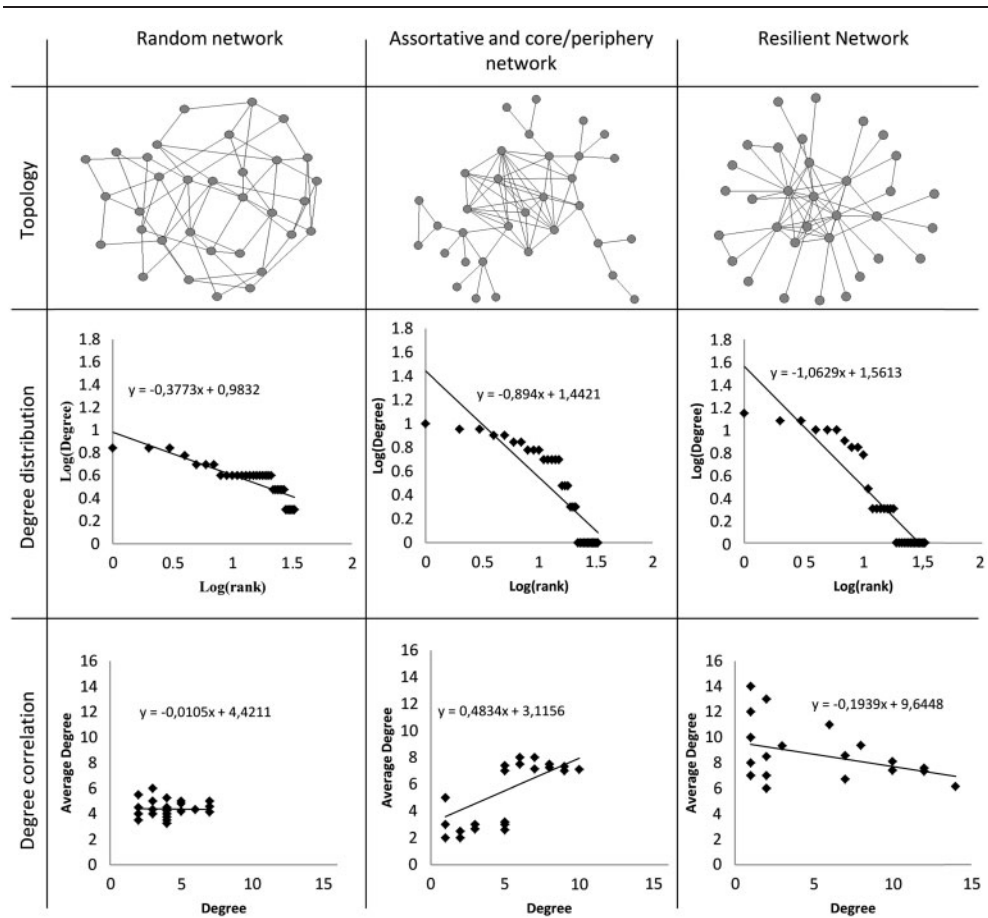


Figure 1. Network topology, degree distribution and degree correlation.

- probability of the emergence of a standard. Nevertheless, its strong assortative structure ($b > 0$) weakens its resilience properties because the periphery is loosely connected to the core. From a physical or engineering approach of networks, an excess of cohesiveness and triadic closure into the core would engender a lack of modularity in the case of a targeted external shock. From a more socioeconomic approach, this excess of assortativity will reduce the ability of the existing structure to activate new explorative ties when markets for the exploited technology decline, due to a weak level of bridging between the oligopoly structure and the peripheral ones. Therefore, the assortative knowledge network favors technological lock-in without maintaining regional lock-out conditions because of its relative inability to overlap exploitation links on mature markets and explorative ones on emerging related ones.
3. Finally, the ‘core/periphery and resilient network’ exhibits here again a high sloped degree distribution with $|a| = 1.06$, but the degree correlation is now negative ($b < 0$), so that the network presents a certain level of disassortativity. In other words, this negative correlation indicates a high level of connections between the core and the periphery, so that information and knowledge can circulate through

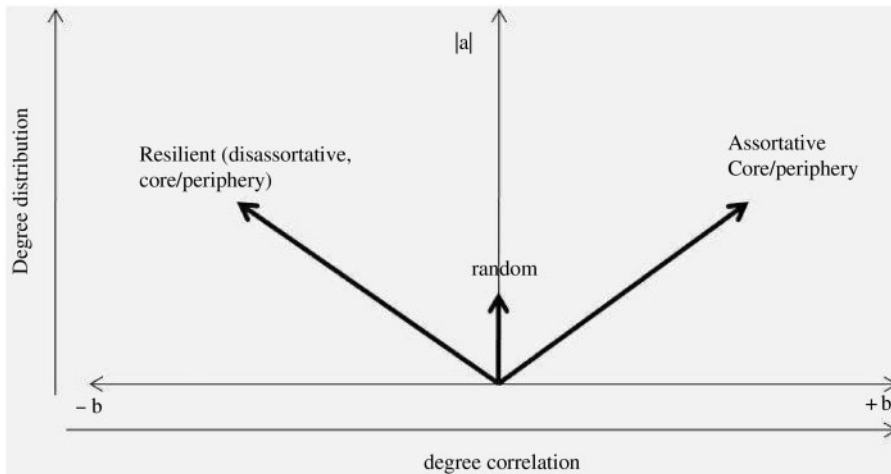


Figure 2. Statistical signature of cluster structural properties.

many structural bridges between the core and the periphery. Thus, targeted shocks on core members do not weaken the whole structure to the same extent as in the previous structure. Similarly, innovative or explorative behavior can diffuse more easily from periphery to core members, due to the ability of the oligopolistic organizations to combine closure and bridging ties in the overlapping explorative and exploitive phases in their relational patterns.

Figure 2 provides a more abstracted representation of these critical structural properties of local knowledge networks.

By representing degree distribution and degree correlation in the same layout, one can have a better understanding of how the structure and properties of local clusters can together improve aggregate performance and structural conditions for resilience. The further up in the layout a cluster is, the more its structural hierarchy enables it to impose standards and dominant designs on markets. And the further left in the layout it is, the more the disassortative patterns of relations increase regional resilience capabilities. For physical networks, efficiency and resilience are incompatible (Brede and Vries, 2009). But for socioeconomic networks, because of social agency and the ability of nodes to build and maintain ties for overlapping explorative and exploitative ties, performing networks are not necessarily incompatible with regional resilience. For the two to coexist, the emerging oligopolistic structure that arises when the technology reaches maturity has to remain sufficiently linked to fresh and new ideas coming from peripheral but promising nodes for future collaborations. On the other hand, when closure strategies in the mature oligopolistic structure exceed a certain threshold, then redundancy of knowledge flows and conformity effects prevail and the possibilities for regional resilience fall unavoidably.

4.3. Illustrations

Capturing the resilience of clusters through network distribution and correlation can find first evidences in the literature on case studies and fieldwork analysis, even if their

theoretical backgrounds rely on more general considerations on clusters or different targeted conceptual entries.

For instance, [Saxenian \(1990\)](#) has led an empirical investigation on the resilience of the Silicon Valley during the 1980s, when the semiconductor industry had reached a high level of maturity and had started to decline in terms of high-tech employment. She put ahead the high level of disconnection between the mature core of established big companies and the burgeoning network of start-ups. While the core of big companies presented the characteristics of a closed oligopolistic structure during that period (mainly AMD, National Semiconductor, Intel), with a general purpose technology and mass production strategy, the network of start-ups was more focused on high performance and value-added components and presented on the contrary a highly open structure of knowledge sharing, developed as ‘a revolt against the established semiconductor firms’ (91). History repeats itself, since she quite rightly notes that ‘Ironically, the region’s established producers helped create this infrastructure during the 1950s and 1960s, but abandoned it in the 1970s as they shifted to high volume production. They came to view regional tradition of information sharing and networking as signs of immaturity rather than sources of dynamism, and they distanced themselves from customers and suppliers as they standardized products and processes’ (95). Besides the well-known roles of serial entrepreneurship spirit and venture capital availability,⁹ Saxenian explains the resurgence and resilience of the Silicon Valley at the end of the 1980s by the building of new connections between the declining established core companies and these growing peripheral start-ups. ‘While some like H-P and Apple began by pursuing the cost reductions and quality improvements of just-in-time production, they are now building long-term and trust-based relationships—particularly with suppliers of technically complex and fast-changing components’ (103). Such a resilient process rests on two features of the cluster. On the one hand, the historical formation of a core of hub and highly connected companies, which can be captured by a strong hierarchy of firm sizes and relational capabilities—and then a highly sloped distribution of degrees—has led the Valley to become one of the leading places of technological integration and standards setting. But on the other hand, the connections of these core companies to burgeoning and peripheral organizations—and then a more disassortative relational behavior—have led all the organizations to avoid conformist behaviors. As a matter of fact, as perfectly theoretically developed in the abovementioned research of [Ahuja et al. \(2009\)](#), established companies have found new sources of innovation and product differentiation in markets, while emerging companies have found growth perspectives through a better integration of their new products in well-diffused technological systems. Once again, Saxenian provides a good interpretation of such a network-based resilient process: ‘Both customers and suppliers describe mutual commitments not to abandon each other during downturns or to exploit advantages during upturns’ (103).

More recently, [Cho and Hassink \(2009\)](#), on the contrary, show that such a resilient process can fail in other contexts and technological domains. Following the theoretical framework of lock-in in regional development ([Grabher, 1993](#)), they study the renewal difficulties of the textile industry in Daegu (South Korea). Launched in the 1950s, this industry entered a strong crisis phase in the 1990s, and one of the local authorities’ responses to that crisis was to develop and fund an ambitious project based on the

9 See also on this point [Kenney and von Burg \(1999\)](#).

modernization of industry (The *Milano Project*). This project relied on public funds and incentives for the building of new networks based on a more research and design-oriented value chain. The purpose of such a project was to create the conditions of a lock-out and a renewal of an industry that had entered in a progressive phase of decline and lock-in. According to the authors, the relative failure of this attempt of institution-driven resilient process relies on two main failures in the expected network evolution and adaptability. First, the traditional local network of producers is featured by a ‘rigid or sticky structure (...) of horizontally interrelated producers around a handful of large supplier firms of “raw fibers” and a number of large textile companies with markets outlets’ (1193). Then, in spite of a hierarchy of positions and relational capabilities in the structure that helps the structure to exploit products on markets, they stress on the rigidity of the network and then the inability of its organization to open itself to new ideas or processes. This observation is reinforced by another one related to the strong weight of clientelism into the traditional network, ‘that weakens local entrepreneurs’ vitality and creativity for the endogenous restructuring of the textile industry’ (1193). Such a clientelism is a mark of an excess of cohesiveness into the core of historical organizations, because it gives rise to an excess of conformity and passive behaviors, and a reluctance to new entries or more entrepreneurial connections, and then more disassortative behaviors. Second, they point out an important reason for the failure of the renewal of the local textile industry: the *Milano Project* ‘was headed by representatives of major research institutes’ (1194). Thus, the major stakeholders of this ‘lock-out program’ do not come from the traditional network, which naturally engenders conflicts and resistance to renewal for established organizations, and then dramatically reduces the emergence and development of more open relational behaviors from established companies toward newcomers. This kind of discontinuity in the whole of the network and the absence of bridging organizations that connect the established and the emerging networks weaken the resilience of the local industry, while such gatekeepers have been identified as the critical organizations of local industrial renewal in other empirical cases (Cattani and Ferriani, 2008; Lazzeretti et al., 2011).

5. Policy implications

Abstracting the analysis of regional resilience around only two statistical signatures of local knowledge networks could be seen at a first glance as a narrow entry for investigating such a complex process. Nevertheless, these signatures provide a large array of policy implications which go beyond, and should go beyond, policies based on network density and incentives for increasing collaborations. On the contrary, these statistical signatures of clusters allow us to avoid the strong tendency of ‘cookie cutter’ clusters policy guidelines (Wolfe and Gertler, 2004), by defining various and more surgical interventions. If knowledge collaborations and networks matter, regional policies can be underproductive if an unconditional index of network density is defined as a goal for supporting clusters. Between *laissez-faire* and a standard and costly increase of relational density, our statistical signatures provide stylized nine categories of targeted policies.¹⁰ Basically, policy makers can concentrate their

10 We should take them as stylized categories because they are based on our abstract discussion that has not specified cognitive features of nodes and the nature of cognitive ties.

Table 1. Policies supporting regional resilience

Degree distribution correlation	$\Delta a = 0$ (1)	$\Delta a > 0$ (2)	$\Delta a < 0$ (3)
$\Delta b = 0$ (A)	Laissez faire	Reinforce the upper part of the hierarchy of knowledge networks	Reinforce the lower part of the hierarchy of knowledge networks
$\Delta b < 0$ (B)	Promote structural heterophily and disassortativity	Reinforce the upper part of the hierarchy of knowledge networks Promote structural heterophily and disassortativity	Reinforce the lower part of the hierarchy of knowledge networks Promote structural heterophily and disassortativity
$\Delta b > 0$ (C)	Reinforce the structural homophily and assortativity	Reinforce the upper part of the hierarchy of knowledge networks Reinforce the structural homophily and assortativity	Reinforce the lower part of the hierarchy of knowledge networks Reinforce the structural homophily and assortativity

attention on only one instrument, the other one remaining fixed ($\Delta|a| \neq 0$, $\Delta|b| = 0$ or $\Delta|b| \neq 0$, $\Delta|a| = 0$) or can play a mixed strategy with both variables at the same time ($\Delta|a| \neq 0$, $\Delta|b| \neq 0$). Table 1 gives an overview of the policies.

Considering cases when one of the two critical parameters is fixed, meaning that policy makers have to target their incentives on one of the two network properties to enhance performance and resilience properties, two categories of ‘surgical’ policies can be implemented.

First, for clusters that host highly connected companies and that can be considered by policy makers as having reached a mature oligopolistic structure, cluster diagnostics should lead policy makers to act on the assortativity dimension of knowledge networks. In this case, $\Delta|a| = 0$, and policies are *type-1* and *ties-oriented*. Besides a *laissez-faire* policy (*1.A-policy*), two instruments are available for policy makers. On the one hand, they can interpose to resolve the insufficient level of connectivity between recent newcomers or burgeoning Small and medium enterprises (SMEs) and the core of mature organizations. In this case, a re-allocation of public funded ties from an excessive cohesiveness of the core to a better connection between the core and the periphery (*1.B policy*) increases the long-run dynamics of clusters and the capacity of the overall structure to overlap mature technologies and emerging ones, without compromising the oligopolistic core structure. Thus, this *1.B-policy* fits with clusters that displayed an excess of assortivity between core members and between peripheral members, so that fresh and new ideas produced in the periphery have difficulties irrigating the core component of the cluster. On the other hand, even if some organizations are high-degree ones, the knowledge network can exhibit an insufficient level of cohesiveness into the core. In that case, leading organizations do not succeed in maintaining a high level of knowledge integration. Such a *1.C-policy* focuses on few but important

missing links to improve the closure of high-degree organizations, a necessary condition for clusters to impose technological standards on mass markets.

Second, cluster policies can focus only on the organizations' degree. In this case, policies are *actor oriented* and target their action on the hierarchy of the network structure. Besides *laissez-faire*, clusters which face problems for reaching maturity in mass markets should benefit from an *A.2-policy*. It concerns clusters that do not succeed in building an oligopolistic structure of organizations and display in their overall structure a lack of relational capacity of organizations. But these policies are inappropriate for clusters that have reached a leading place in the field. In this case, windfall payoffs for central organizations will decrease the policy efficiency. On the contrary, cluster diagnosis can highlight an excess of isolation of organizations, and therefore, policies aim to reinforce the lower part of the degree distribution. Decreasing the slope of the degree distribution does not mean reducing the degree of leading organizations of clusters, but on the contrary, increasing the degree of newcomers or isolated organizations. Such an *A.3-policy*, which should consider specific programs for a better integration of SMEs and start-ups in local knowledge networks, is particularly suited to enhance the regional lock-out capacities of clusters.

Furthermore, combining *ties* and *actor-oriented policies*, mixed strategies for policy makers appear as more efficient for regional performance and resilience than an unconditional and costly watering for collaboration. *Ex ante* diagnosis should help policy makers to orient public funds toward increasing the capacity of clusters to overlap mature and emerging knowledge domains and thus develop more open structures of knowledge interaction (all *type-B* policies). On the contrary, when a lack of cohesiveness weakens the knowledge integration process, all *type-C* policies are suited and prevail on the others. Likewise, all *type-2* policies are suited to reinforce leading companies to compete in mass markets, while *type-3* ones are dedicated to an increasing capacity of SMEs and burgeoning companies to connect to more central organizations to provide fresh and new ideas.

Degree distribution and degree correlation appear as interesting catalysts for policies toward regional resilience. They provide simple but targeted tools for applying distinctive surgical policies. Policies for regional resilience have to be replaced and contextualized (Bristow, 2010). Indeed, according to the particular situation of the cluster in terms of structural properties and market position, the simple increase in relational density can lead to unproductive outcomes and reduction of resilience capabilities. These two structural properties do not challenge cluster policies as a whole nor conclude on the relevance of *laissez-faire* (Martin et al., 2011). On the contrary, they invite us to consider particular targeted incentives for bridging potential missing links in cluster long-run dynamics.

6. Conclusion

In spite of its high level of abstraction and complexity, the science of networks applied to regional science provides promising perspectives for static as well as dynamic analysis of clusters. Here, we have tried to show that it was possible to reduce this complexity to two simple statistical signatures of knowledge networks. Degree distribution and degree correlation highlight the critical structural properties that increase the performance of

clusters in a particular technological field, without decreasing their resilient properties. If the hierarchy of degrees is a more or less common pattern of social and organizational networks, disassortativity is less manifest. Indeed, human and social behaviors are generally characterized by structural homophily, so that the more an agent increases its relational capacity, the larger is his tendency to interact with other highly connected agents. However, this property of assortativity of local knowledge networks weakens the ability of clusters to combine market exploitation and absorption of fresh and new ideas and, then, can be a source of negative regional lock-ins.

The combined measures of degree distribution and degree correlation confirm that a window of parameters exists, for which clusters can display performance in the short run, and resilience in the long run. Capturing this window more precisely requires an additional effort of modeling. Moreover, as we have pointed out earlier, clusters are relational structures that are more or less embedded in larger networks of global relationships. The form and the degree of this embeddedness can also play a role on the local properties of resilience, in particular through the study of how big companies connect themselves to transnational networks.¹¹ Combining local and global interactions in a search for more complex statistical signatures could be a promising challenge in the future. But at this stage, such a framework furnishes new perspectives to highlight empirical evidence on the ability of regional systems of innovation to resist and adapt to turbulent macroeconomic environments, new growing consumer paradigms and the shortening of market cycles. It also constitutes a first step for a policy platform for resilient regions. In particular, policies based on the support of disassortative links will help clusters to overlap technological domains and then follow a stable rather than a declining growth trend.

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11 Introducing global relationships as an endogenous parameter of cluster resilience could be an additional and relevant step for further researches. At this stage, the structural properties of local knowledge networks give interesting first results on the ability or not of clusters to reach maturity and performance in a particular knowledge domain, while maintaining renewal abilities toward a related new one. Obviously, in a more extended approach, these results will be conditional to the level of structural embeddedness of the cluster in global innovation networks (Sturgeon, 2003), since technological exploitation on global markets still remains important once the resilient process is engaged.

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