Making Geographical Clusters More Successful: Complexity-Based Policies
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Making Geographical Clusters More Successful: Complexity-Based Policies

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In recent years there is increasing evidence of the adaptive failure of geographic clusters (GCs) ranging across the US, UK, and other parts of Europe. To explain success and failure in GCs, complexity science is used. It holds that successful GC evolution happens only if they behave as effective complex adaptive systems (CASs). A review of complexity science is offered and suggests seven essential properties of CASs, four from the European and American Schools, and three drawn from the Econophysics School. Furthermore, we suggest that when GCs lose one or more CAS properties they tend to fail. Finally, we suggest policy guidelines, aimed at fostering the GC success. They are based on the seven properties of CASs and are addressed to guarantee that GCs keep all these properties.

Introduction

Geographical clusters (GCs) are geographically defined production systems, characterized by a large number of small and medium sized firms that are involved at various phases in the production of a homogeneous product family. These firms are highly specialized in a few phases of the production process, and integrated through a complex network of inter-organizational relationships.

The literature on GCs involves different streams of research: social sciences, regional economics, economic geography, political economy, and industrial organization. These studies have developed key notions and models to explain the reasons of GC competitiveness, such as: the flexible specialization conceptualized by Piore and Sabel (1984); the localized external economies concept anticipated by Marshall (1920) and further formalized by Becattini (1990) and Krugman (1991); the industrial atmosphere notion conceived by Marshall (1919); and the innovative milieu notion developed by the GREMI (see, for instance, Maillat, *et al.*, 1995). All these studies have recognized that GCs are a successful production model.

Examples of successful clusters include the financial services clusters in New York and London, the electronics cluster in Silicon Valley (Saxenian, 1996), the film production cluster in Hollywood (Faulkner & Anderson, 1987) and Bollywood, the industrial districts in North-Central Italy (the Third Italy) (Brusco, 1982; Paniccia, 1998; Porter, 1998), in South-West Germany (Baden-Württemberg) (Braczyk *et al.*, 1995), and most recently the developing automobile industry in the Czech Republic and Slovenia, the off-shoring cluster in Bangalore (India) and textile clusters in China.

Despite the great number of successful GCs spread all over the world, there is evidence that some GCs are undergoing a decline phase. Examples of failing GCs come from: the Pittsburgh steel cluster (Hall, 1997), Detroit's automotive industry (Helper, 1990), minicomputer firms located in the Route 128 cluster (Saxenian, 1996), the Akron tire cluster (Sull, 2003), the aerospace cluster in Southern California (Scott, 1991), and several in the UK. A few studies have investigated the reasons of the GC's decline (Saxenian, 1996; Pyke & Tomaney, 1999; Bathelt, 2001; Sull, 2003). These studies, however, also present some limitations because they adopt a case study approach and provide explanations of the GC crisis that are specific to the analyzed GC and cannot be generalized.

In this paper we propose an explanation why some GCs are successful and others are failing. In doing so, we move beyond current economic, organization science, and economic/spatial geography approaches, by using complexity science, a discipline originating in physics and biology. It is increasingly popular in explaining managerial and organizational dynamics (Stacey, 1992; Goldstein, 1994; McKelvey, 1997, 1999, 2004), strategic change (Houchin & MacLean, 2005), policy (Allen, 1993), entrepreneurship (Peterson & Meckler, 2001), and organizational information systems (Allen & Varga, 2006). Recently, complexity science has also been applied to economic and spatial geography (Allen, 1982; Batty, *et al.*, 2004; Manson & Sullivan, 2006; Martin & Sunley, 2007; McKelvey, forthcoming).

Amongst the different streams of study in complexity science, we focus primarily on complex adaptive system (CAS) theory, identifying the main properties of CASs. A CAS is a set of heterogeneous and interacting agents that emerges as a new order, or new structure/process over time. CASs evolve and adapt to changing environmental conditions without any singular entity deliberately managing or controlling them (Holland, 1998). We identify seven properties to recognize that a system is a CAS. Four are single-level elements present in more conventional complexity theories: *heterogeneous agents*, *melting zone*, *coevolution*, *and self-organization and emergence*; three others are multilevel elements from the most recent econophysics development in complexity science: *non-additive (nonlinear) interaction amongst agents*, *butterfly effects* and *scalability*. We argue that successful GCs need to have all seven of these properties to operate effectively.

We then use complexity theory and the seven key elements to explain the rise and fall GCs. In particular, we show that successful GCs possess all the CAS properties and motivate the crisis of GCs as due to the loss of one or more CAS properties. We suggest policy guidelines aimed at fostering GC success; these could be phrased as researchable propositions. These are based on the seven key properties of CASs and are addressed to guarantee that GCs keep all these properties.

We begin by first briefly reviewing the key studies on GC competitive success and the three phases in the development of complexity science. Then we present CAS theory and describe the main CAS properties. In doing so, we distinguish between the more conventional treatment of complexity theory in organizational applications and the more recent multilevel perspective of econophysics. Next we frame GCs as CASs and we show that successful GCs exhibit in some measure all of our seven CAS properties. Finally we present policy guidelines for GC success.

Geographical Clusters

Traditional studies of GCs have analyzed the main features of GCs that assure them the competitive success. In particular, studies of economic geography point out the benefits associated with 'agglomeration external economies', mainly due to the lower input costs, the development of common suppliers, specialist labour pools, spillover of technical know-how, and the development of a greater comprehension of the workings of the particular industry by individuals and firms (Becattini, 1990; Marshall, 1920). Studies of industrial economics highlight the reduction of the transactional costs due to geographical proximity of firms and informal and face-to-face contacts among them as one of the most important benefits of GCs (Mariotti, 1989; Powell, 1987).

Studies of innovation management point out that GCs find competitive success from their innovative capacity, which is due to the presence of highly specialized technical competencies, the existence of networks of formal and informal relationships, and the geographical proximity that creates an environment wherein information, codes, languages, routines, strategies, and knowledge are easily transferred and shared (Cooke, 1999; Cooke & Morgan, 1998; Henry & Pinch, 2002; Storper, 1997; Lundvall & Johnson, 1994).

Synthesizing the results of these studies, the main features that allow the success of the GCs are: specialization of firms, presence of a specialized workforce, division of labour among firms, accumulation of specific knowledge in the local area, networking processes among both the economic and social system, development of a widespread innovative capacity, and presence into the GC area of a common system of social-cultural values.

However, these factors seem insufficient to guarantee GC success in the current competitive scenario that is much more dynamic, unpredictable, and instable. In such a context, in fact, many GCs are undergoing a decline phase. Thus, in this new situation, both new theoretical approaches to study the GC competitive advantage and new properties that they should exhibit are needed.

Complexity Science

We recognize three basic phases in the development of complexity science: the European, American, and Econophysics Schools.

The European Phase

The *European School* consists of Prigogine (1955), Haken (1977), and Mainzer (2004), amongst many others. It is math intensive, and originates with the natural science experiments on *'*Bénard processes'. In a Bénard process (1901), an energy differential is set up between warmer and cooler surfaces of a container (measured as temperature, ΔT); as the energy differential increases beyond specific *'critical values'* (R_{c1}, R_{c2}), the system undergoes a dramatic shift in the nature of the fluid flow. For example, increasing the heat under water molecules in a vessel exposed to colder air above leads to geometric patterns of hotter and colder water—order and organization appear. Prigogine (1955) termed these *'dissipative structures'* because they speed up the dissipation of the imposed energy (Swenson, 1989). The European school emphasizes the *tensions* that result from environmentally imposed energy differentials (McKelvey, 2004). These tensions give rise to a series of phase transitions whose initiation occurs at the lower bound, R_{c1}, of the region of emergent complexity.

The American Phase

The *American School* consists largely of scholars associated with the Santa Fe Institute (Anderson, *et al.*, 1988; Pines, 1988; Cowan, *et al.*, 1994; Arthur, *et al.*, 1997). Drawing from the life sciences and making extensive use of agent-based computational approaches, the American school complexity literature defines what emerges as CASs, namely a system of agents that emerges over time into a coherent form, and adapts and emerges itself without any singular entity deliberately managing or controlling it (Holland, 1995). Whilst the Europeans focus mostly on dramatic phase transitions at R_{c1}, American complexity scientists focus mostly on R_{c2}—the *'edge of chaos'* (Kauffman, 1993; Lewin, 1992). What happens at R_{c1} is better understood; what happens at R_{c2}, the upper bound, is more obscure. In between we have the region of emergent complexity, that is, the *melting zone* (Kauffman, 1993; Stauffer, 1987) within which new structures—CASs—spontaneously emerge. The signature elements within the melting zone are *self-organization*, *emergence*, and *nonlinearity*.

Kauffman's '*spontaneous order creation*' begins when three elements are present: (1) *heterogeneous agents*; (2) connections amongst them; and (3) motives to connect—such as mating, improved fitness, performance, learning, etc. Remove any one element and nothing happens. *Self-organization* results in *emergence*, that is, new order of some kind. Bak (1996) argued that to survive, organisms have to have a capability of staying within the melting zone, maintaining themselves in a state of '*self-organized criticality*', where they make never-ceasing moves to adapt. In this state they may adapt by making many small changes or a few of avalanche proportions.

Bak (1996) found that at the state of '*self-organized criticality*', the frequency of small to avalanche-size changes was Pareto-distributed, and if plotted in double-log graph would show the power law signature—an inverse sloping line. Arthur (1990) focuses on how positive *feedback enables* initially small instigation events to lead to large effects on firm size and profits. Casti (1994) and Brock (2000), by continuing the focus on power laws, presented a vision of *coevolution* as a 'driver' of complex system adaptation. According to Holland (2002), emergent phenomena are characterized as *multiple level hierarchies*, *bottom-up and top-down causal effects*, and non-additive *nonlinearities*. Nonlinearity is manifested in two particular ways: the *butterfly effect* and *scalability*. These are the founding concepts of the *Econophysics School* phase.

The Econophysics Phase

The *Econophysics School* dates back to discoveries by Pareto (1897), Auerbach (1913) and Zipf (1949) that income and communities ranked by population form a Pareto-distributed rank/frequency. Its focus is on how order creation actually unfolds once the forces of emergent order creation by self-organizing agents are set in motion. Key elements of this third phase are *fractal structures*, *power laws*, and *scale-free theory*. Brock (2000) goes so far as to say that *'scalability'* is the core of the Santa Fe vision. Gell-Mann (2002) concludes his chapter on '*What is Complexity?*' with a focus on scalability.

Consider the cauliflower. Cut off a 'floret'; cut a smaller floret from the first floret; then an even smaller one; and then even another, and so on. Despite increasingly small size, each lower-level component performs the same function and has roughly the same design as the floret above and below it in size. This feature defines it as fractal. Fractals can result from mathematical formulas—the very colorful ones figuring in Mandelbrot's *'Fractal Geometry'* (1982). We are more interested in fractal structures that stem from adaptive processes—like the cauliflower—in biological and social contexts—i.e., in living systems (Gell-Mann, 2002). In fractal structures the same adaptation dynamics appear at multiple levels. Andriani and McKelvey (2009) list 141 kinds of power laws, which are presumed indicators of fractal geometry, in physical, biological, social, and organizational phenomena. Stanley *et al*. (1996) find that, taken as a whole, manufacturing firms in the U.S. show a fractal structure—a result confirmed by Axtell (2001).

Barabási (2002) shows how networks in the physical, biological and social worlds, are fractally structured such that there is what is called a *'rank/frequency'* effect, wherein there is an underlying Pareto distribution showing many sparsely connected nodes at one end and one very well connected node at the other. If plotted on a double-log graph, the Pareto-distributed progression of increasing numbers of connections from, say, small airports to giant ones like Heathrow and O'Hare, appears as a negatively-sloping straight line. This is the now famous power law 'signature' dating back to Pareto, Auerbach, and Zipf.

Scale-free theories explain why fractals appear as they do and behave as they do. Though scalability may have been at the core of the Santa Fe vision, scale-free theories have only recently begun to be consolidated and featured collectively by the econophysicists (West & Deering, 1995; Mantegna & Stanley, 2000; Newman, 2005). The key feature that sets scale-free theories apart from most social science theories is that they use a single cause to explain dynamics at multiple levels.

Essential Properties Of Complex Adaptive Systems

In this section seven CAS properties are identified using the contributions of all three complexity science schools whose unifying theme is: What are the causes of new order creation? CAS properties are separated into two classes. The first one includes four properties explaining the emergence of CASs at a *single* level of the system in response to each other or to their environment—accounting to theories rooted in the European and American schools; the second class concerns three properties that enable emergent order creation at *multiple levels* of the system, accounting to theories rooted in the Econophysics school.

Properties Of CASs For A Single Level Emergence

A number of researchers have developed concepts and notions to explain CASs: Gell-Mann (1994), Holland (1995; 2002), Axelrod & Cohen (1999), Choi *et al*. (2001), Lane (2002). The basic elements of CASs are agents. An agent in a biomolecule is a gene; in a biological system it is a cell; in an economic system, a seller, buyer or a firm; in an organizational system, an individual or group or department.

Agents are autonomous units that seek to maximize some measure of goodness, or fitness, by evolving over time. Human agents scan their environment, which includes both other agents within the CAS as well as the external environment, and developmental models (schema) representing interpretative and action rules (Gell-Mann, 2002). Actions define the interactions of agents with each other inside and outside the boundaries of the CAS, they involve the exchange of information and/or resources. CAS complex behavior arises from the interaction amongst system agents and between the system and its environment (Mitleton-Kelly, 2003).

An important point emphasized by many authors is that CASs coevolve with a changing environment. That is, the dynamic environment, by interacting with the CAS, forces changes in the entities that reside within it, which in turn induce changes in the environment (coevolution). Kauffman (1993) observes that organisms do not merely evolve; they coevolve both with other organisms and with a changing environment. He describes coevolution as a process of coupled, deforming landscapes where the adaptive moves of each entity alter the landscapes of its neighbors.

Therefore, agents within a CAS self-organize to create new emergent structures, patterns, and properties. The latter arise from the interaction amongst agents without being externally imposed on the system (Goldstein, 1999); they are greater than the sum of the parts and may be difficult to predict by studying the individual system elements. The following four properties are identified based on the foregoing:

Heterogeneous Agents

Agents with different attributes and goals pursue actions that can cause CASs to form. This includes heterogeneous human capital and social capital (networks) (Burt, 1982) and weak ties (Granovetter, 1973).

Melting Zone

Between the *'edge of order'* defined by the 1st critical value (R_{c1}) (Bénard, 1901; Prigogine, 1955) and the *'edge of chaos'* defined by the 2nd critical value (R_{c2}) (Lewin, 1992; Kauffman, 1993), we have a region of emergence that Kauffman (1993) terms the 'melting' zone. In the melting zone a CAS maintains a quasi-equilibrium state, balancing between complete order and incomplete disorder/chaos (Goldstein, 1994). In this quasi-equilibrium state, when perturbed by an environmental jolt, a system (and agents within it) may be attracted either to its original ordered state or toward chaos. That is, as environmentally imposed tension increases so as to overwhelm the system's adaptive capacity, it will oscillate in and out of the melting zone, thereby showing chaotic behavior (Brown & Eisenhardt, 1998).

Coevolution

Agents coevolve with each other to create the more macro CAS structure (Holland, 1995). CASs interacting with a dynamic environment force changes in the agents within it, which in turn can induce changes in the environment. Therefore, coevolution is the dominant means of CAS adaptation (Kauffman, 1993).

Self-Organization And Emergence

Agents interact for some reason, such as tension reduction, learning, fitness or performance improvement, etc., without any entity managing and controlling them (Holland, 1988). In this way they self-organize to create the emergence of new order. The emergent order concerns new properties, structures/processes of the system that come into being in an unexpected way, given the known attributes of component agents and environmental forces. Emergence depends on both bottom-up and top-down effects (Holland, 2002).

Properties Of CASs For Multi Level Emergence

The Econophysics school focuses on the three properties below as key dominant features that become relevant when CASs have some possibility/probability of emerging at multiple levels. These properties are broadly exhibited across physical, biological and social systems (Newman *et al*., 2006; West & Deering, 1995; Andriani & McKelvey, 2007, forthcoming).

Non-Additive (Nonlinear) Interaction Amongst Agents

Interaction amongst agents produces multiplicative effects and not merely additive ones. Therefore, the resulting behavior of the system cannot be derived from the summation of the behaviors of single agents.

Butterfly Effects

CASs behave in a nonlinear fashion. This essentially means that there is not a direct correlation between the size of cause and the size of the corresponding effect. Holland (1995) suggests that almost all CASs exhibit *lever point* phenomena, where small 'inexpensive' inputs cause major directed effects in CAS dynamics. Thus, whilst many small events occur all the time, butterfly effects are small events that spiral into dramatic or extreme outcomes. Holland's point is that some small events can be levered or otherwise instigated such that they have increased probability of producing dramatic outcomes.

Scalability

CASs tend to be self-similar across levels; no matter what the scale of the system, the phenomena appear the same and result from the same causal dynamics. Fractal structures possess the scalability property. Fractals often show Pareto distributions; i.e., the inverse sloping power-law distribution when plotted on log-scaled X and Y axes.

Complexity-Based Theories Of Geographical Clusters

Nowadays there is a growing interest in the application of complexity science to economic and spatial geography (see Martin & Sunley 2007 for a review). Some characteristics of CASs have also been applied to study geographical entities such as clusters, regions, and nations (Arthur, 1994; Krugman, 1996; Martin & Sunley, 2006) but they usually are traced back to the European and American schools, except for Krugman (1994; 1996) and McKelvey (forthcoming) who use scalability and power laws to analyze the ability of an economy to self-organize.

Our paper focuses on GCs and shows that they possess the seven identified CAS properties, accounting to all three complexity science schools. In this way we offer an integrated framework whose novelty is to recognize two levels of analysis for the emergence, i.e. single and multilevel. In what follows we describe why successful GCs are CASs by showing that GCs exhibit every CAS property. Our arguments are based on literature analysis and on qualitative and quantitative data gathered on successful GCs.

Heterogeneous Agents

GCs are composed of several types of actors, ranging from people, single firms, consortia of firms, public and private institutions, social communities. In particular, according to Porter's definition (1998), GCs are geographically concentrated production systems composed primarily of small and medium firms highly specialized in a few phases of the production process, suppliers of specialized inputs such as components, machinery, and services, and providers of specialized infrastructures. GCs often also extend downstream to channels and customers and laterally to manufacturers of complementary products and to companies in industries related by skills, technologies, or common inputs. Finally, GCs include governmental and other institutions, such as universities, standard-settings agencies, training providers, trade associations, etc., that provide specialized training, educations, information, research, and technical support.

Coevolution

GCs interact with the external environment, influencing it and being influenced. For example, technological innovation influences the evolution of GCs, as happened in the Silicon Valley cluster with the development of the microelectronics (Saxenian, 1996). In turn, technological innovations are influenced by GCs, which are interested in driving technological change in order to exploit new technologies so as to improve products and processes (Carbonara, 2005).

GCs are ruled by self-organizing processes of adaptation that occur as a result of changes, selections, and retentions of variables that are best suited to each contingent situation and may or may not be the product of an intentional design and the work of conscious players. In the development of alternatives and the selection and retention of these alternatives, GCs use human and social capital (Burt, 1982) developed through experience that is assimilated into the specific and original structures of each GC (languages, logistics circuits, fiduciary and guarantee systems) (Rullani, 2002).

Melting Zone

GCs are characterized by a quasi-equilibrium state, given that they tend to maintain the same configuration (equilibrium or point attractor position), characterized by the following features: small firms, division of labour among firms, manufacturing specialization of firms, co-localization, informal and non-hierarchical relationships. However in some cases, due to environmental changes, the most competitive GCs are pushed far away from their original configuration, switching from the original attractor position to a new one, characterized by, for example, the presence of a leader firm, more structured relationships and processes of de-localization and vertical integration (Corò & Grandinetti, 1999; Pilotti, 1999).

Self-Organization And Emergence

GCs typically generate intense levels of interactions that create dense networks of interconnections. Interactions occur among firms operating at different stages of the supply chain, among similar firms that perform the same production phase, between firms and institutions. On the one hand, the interactions are motivated by the need to exchange products, services, components, etc. On the other, firms interact because they cooperate to carry out joint market research programs, technology acquisition, training or technology transfer, permanent exhibition, etc. (Brusco, 1990; Digiovanna, 1996; Saxenian, 1996; Corò & Grandinetti, 1999).

Interactions among firms and institutions may involve university and research centers and, thus, are motivated by the need to transfer state-of-the-art technological knowledge, best practices, and competencies. In all cases, actors operate according to self-interest in pursuing their performance improvement (Albino, *et al.*, 2003). The system of interactions is organized through spontaneous forms of coordination (Corò & Grandinetti, 1999). An 'invisible hand' determines the strategies of the system and guarantees coordination within the firm. Neither hierarchical nor structured principles govern the system (Cooke & Morgan, 1998).

GC structures and dynamics are emergent phenomena resulting from the self-organization of heterogeneous agents. Such emergent phenomena are unexpected because they result from non-additive interactions among agents. Examples of emergent phenomena shown by the most competitive GCs are: (1) development of more innovative manufacturing processes and products; (2) emergence of large firms holding a leader positions within their GCs; and (3) GC internationalization. These depend on both bottom-up and top-down effects. In fact, the level of GC innovative capacity results from the incremental innovations developed by its firms (bottom-up effect). The level of innovation of each firm can be, in turn, influenced by new technology standards, laws, and policies imposed by local actors, e.g., leader firms, governmental institutions, and agencies (top-down effect).

Non-Additive (Nonlinear) Interaction Amongst Agents

The local interactions amongst the actors of GCs determine a system behavior that is different from the behavior of its components and cannot be derived by summing the behaviors of each single component (Fioretti, 2001). Interactions are potentially multiplicative and/or with the possibility of positive-feedback amplifications. An example of this property is the capacity of the entire system to behave in a very flexible way.

In fact, GCs are able to achieve a high level of volume and product-mix flexibility even though a GC's firms do not posses the same level of flexibility. The flexibility is a property of the system as a whole because it is the result of both the specialization of firms in few phases of the production process and the network of interactions that set up differently every time a specific volume or product mix have to be provided to satisfy the customer demand (Piore & Sabel, 1984).

Butterfly Effects

GCs are characterized by nonlinear dynamics, in which cause and effect are related in nonlinear ways. For example, a simple action carried out by a GC firm, such as the participation at an international trade fair, may lead to a substantial change in the internationalization policies of the GC, or a large change, such as the localization of production activities outside the GC, may produce a very small change in the GC organizational structure.

Scalability

Some power laws can be recognized in GCs. In particular, we found that the size of GC firms follows a power law distribution. In Table 1 the number of firms for each size measured as number of employees calculated on 156 Italian GCs is reported. Figure 1 shows the distribution of the size of firms plotted in a double-log graph: the curve follows the power law signature. Note that most firms (78.6%) have a small size (1-9 employees) and only few firms are large.

Firm Size	**Number of Firms**
1-9 employees	166,941
10-49 employees	39,510
50-249 employees	5,459
> 250 employees	437

Table 1 *Number of firms for firm size in the Italian industrial districts (source: Istat 2001).*

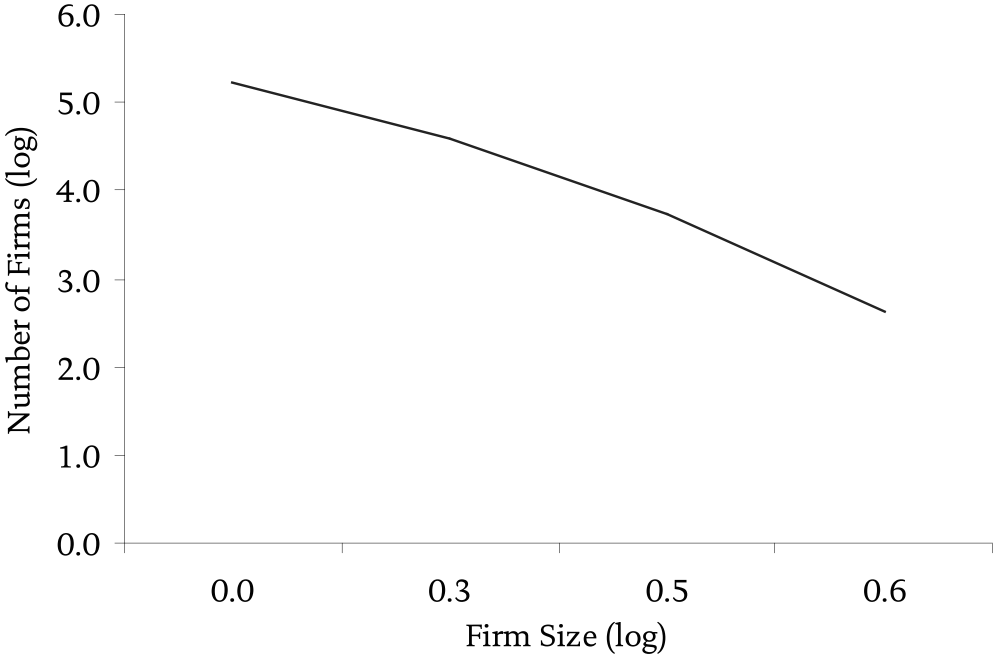


Figure 1 *Distribution Of The Firm Size In The Italian Industrial Districts Plotted In A Double-Log Graph.*

Policy Guidelines For Geographical Cluster Success

Empirical evidence shows that GCs are evolving to face competitive pressures. The most successful GCs are evolving so as to keep their CAS properties, but there is also evidence of failing GCs, such as: the Pittsburgh steel cluster (Hall, 1997), Vibrata-Tordino-Vomano clothing district in Italy (Sammarra & Belussi, 2006), Detroit's automotive industry (Helper, 1990), minicomputer firms located in the Route 128 area (Saxenian, 1996), the knitwear district in Baden-Württemberg (Staber, 2001), and the Akron tire cluster (Sull, 2003).

The immediate causes of each crisis are different, but all these causes can be traced back to the loss of the key properties of CAS that foster adaptation. For example:

- In the Vibrata-Tordino-Vomano clothing district the firms show a high degree of homogeneity in terms of size and ownership-control structure, that limits the development of new technological capabilities and innovations (Sammarra & Belussi, 2006).
- The decline of the Akron tire cluster has been due to the organizational inertia of the GC, as shown by the historical analysis carried out by Sull (2003). In fact, although the firms clustered in Akron initially led the industry in innovation, later they failed to respond effectively to the introduction of radial tire technology because they maintained the same strategies, processes and behaviors even when the competitive scenario changed. The failure to re-

spond to changing conditions also explains the recent bankruptcies of General Motors and Chrysler in Detroit.

- Grabher (1993), in his study of the decline of the Ruhr industrial GC, noted how repeated interactions among the same group of economic actors created a rather inward and provincial mentality that discouraged the search for new business activities and partners needed to rejuvenate the local economy.
- In the Bologna machine-packaging district, the higher presence of large multinational firms made small subcontractors more dependent and led to a hollowing out of the district's innovative capacities (Harrison, 1994).
- In the knitwear district in Baden-Württemberg there is evidence of a reduction of the level of interconnection because of a lack of network cooperation as well as of an increase of the firm mortality with the decrease of the firm diversity (Staber, 2001).
- As for the Route 128 district, it is widely recognized that the dominance of large, vertically-integrated producers and the high level of control of the system are the main causes of its decline (Saxenian, 1996; Bathelt, 2001).
- The recent crisis of the entire leather-sofa district localized in Southern Italy is basically due to a small localized cause, namely the sudden and rapid decrease of the sales in the US market of the district's leader firm.

From the above, we see that it is important to assure that GCs keep the CAS properties. Consequently, CAS properties can be used as guidelines to develop policies fostering the GC success. Our policy guidelines, then, recommend complexity-science-based actions that may be instigated by GC managers, other employees and groups, or institutional bodies. In what follows we propose a set of policies that reflect the basic properties of CASs, recommended actions, and examples of real Italian cases of GCs, usually named industrial districts, in which a number of these actions are recognizable and their positive effects are readily visible.

Keep A High Level Of Heterogeneity:

- Barriers that obstruct imitation should be designed, such as patents, punishments for imitative behaviors, brand policies;
- The admission of firms located outside GCs should be favoured;
- Assure that heterogeneity is maintained when hiring people, for example managers coming from different industries, graduates from diverse universities, professionals with varied research experience.

As an example of this policy, to sustain the competitiveness of the Italian industrial districts specialized in the mature manufacturing sectors, regional laws have been enacted. These laws stimulate firms to develop their own brands by means of financial and managerial support. The main result of this policy has been the differentiation of firms so as to reduce direct competition among similar firms within an industrial district firms and, instead, stimulate them to go after non-competing segments of global markets.

Fostering Coevolution:

- Gatekeeper roles that manage the links between the GC and the external environment should be created, namely associations and institutions dedicated to market analysis, customer profiling, search of new technologies and funding programs, acknowledgment and diffusion of new laws, and promotion of the GC brand and products worldwide.

In the technology district of Torino Wireless localized in North-western Italy, the Torino Wireless Foundation was established in 2003 by both private and public actors. The Foundation acts as a gatekeeper because it both addresses and coordinates the district's R&D activities and links the district's firms with external players worldwide, such as universities, research centres, and firms. The existence of this Foundation favours the growth of the district by enabling firms to have continuous access to new and complementary knowledge. This, in turn, fosters coevolution as all the parties mutually influence each other.

Impose Tension On A GC To Move It Into The Melting Zone

- GC firms should not be protected against the forces present in the environment, e.g., new competitors, new technologies, new substitute products, that impose tension in the GC system.
- Management style should be addressed so as to put tension on employees by establishing challenging goals to be reached—i.e., imposing what Hamel and Prahalad (1994) term '*stretch*'.

The story of the Montebelluna industrial district, which is a leader in the sports sector, has been signified by its entry into the GC of direct competitors as well as producers of complementary and substitute products, such as walking shoes, textiles and clothing, and mechanical devices. These entities have given benefits to the entire district. In fact, on one hand, they have enlarged the district's product range, to now include ski and trekking boots, motorcycle boots, bicycle shoes and sports clothing. On the other hand, they have also stimulated the district's firms to continuously develop innovations, improve quality, and search for new niche markets, as well as providing the appropriate skills and competencies to existing district firms for their renewal of products and processes.

Stimulate Self-Organization And Emergence In GCs

- Motives to connect should be increased, by giving benefits to firms that interconnect each others, such as funding for the formation of consortia, support to the development of joint projects (e.g., research projects, internationalization projects, marketing initiatives); reductions to firms for the use of services, utilities, infrastructures in common.
- Chances of interaction should be increased, promoting periodic meetings among the GC firms, organizing conferences, workshops, and local trade events; creating information and communication technologies infrastructures to facilitate the exchange of information among GC firms.

The recent history of the Riviera Del Brenta shoe district, located in Veneto (North-East Italy), demonstrates the importance of networking among firms organized into a consortium rather than relying on individual initiatives for the success of the district. The main consortium tasks are the formulation of internationalization, marketing, and product innovation strategies. In particular, when in the 1990s the district was undergoing a decline phase, the consortium led the recovery of the district by repositioning its market strategy and moving away from the production of no-brand products to luxury ones.

Balance Top-Down And Bottom-Up Effects In The GC:

- The formation of hierarchical and structured organizational forms should be promoted, for example, consortia and holdings;
- The creation of networks controlled by leader firms should not be avoided even though they introduce a level of top-down control in opposition to bottom-up autonomy—almost any kind of networking is good networking, especially if weak ties emerge (Granovetter, 1973).

There are examples of industrial districts in Emilia Romagna that have profoundly changed their organizational structure by moving from the traditional Marshallian model towards configurations characterized by higher levels of hierarchy and creation of business groups. The existence of firms with leadership/ownership of the other firms favours the adoption of best practices and speeds up the change needed to face the competitive scenario. We note, however, that research by Thomas, *et al*., (2005) shows that irregular oscillation between control and autonomy is most effective.

Exploit Butterfly Effects:

- Identify lever points; these cause significant changes to the system that persist in the long term but need only modest efforts in terms of resources.
- Example lever points are the introduction of product and/or process innova-

tions already developed and adopted elsewhere, the participation at a trade fair that opens the GC to new market opportunities, and the recruitment of highly qualified managers.

In the Prato and Como textile and apparel industrial districts, a few firms have carried out product innovations by developing new textiles using research results in chemistry, mechanics, and nanotechnology, such as: breathable, waterproof, antibacterial, anti-odour, and thermo-regulatory fabrics. These innovations have had positive effects not only for the firms that developed the new products but also on the district's other firms in the apparel sector. The latter have, in fact, used these new textiles to introduce product differentiation and, the, better sales, and more useful products.

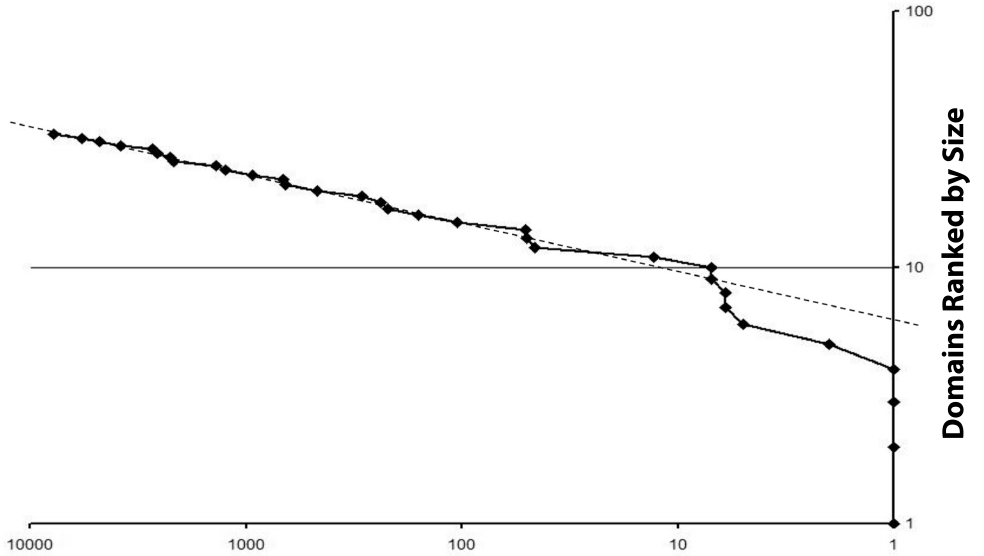
Build in Scalability:

Create fractal structures, e.g., by promoting the formation of meta-organizations at multiple levels, such as: supply chains, consortia, group of firms, as well as associations representative of the GC.

Maintain the power-law distribution of different dimensions: thus, the power-law distribution of the firm size could be preserved by promoting the formation of small-sized and potentially more innovative firms if too many large firms appear; the power-law distribution of the firms' performance should be maintained by supporting high-performing firms, as opposed to what is the common attitude of many governments, which is to support declining firms.

Recently, there is accumulating evidence in the more successful industrial districts of the increasing formation of district *sub-groups*, i.e., sets of firms primarily located inside a district—that are legally distinct but nevertheless belonging to the same owner(s) (Cainelli *et al*., 2006). Such district sub-groups mirror both a single-firm organizational structure where the vertex is the Director of a multi-divisional enterprise and the relatively autonomous organizational units are the other subunit businesses [the classic related-multidivisional enterprise (Williamson's, 1975, M-form)] and, on the other hand, a district organizational structure where the business associations and/or the consortia lead the sub-group firm's strategies while still allowing them considerable autonomy in their day-to-day operation.

Research by Stanley *et al*. (1996) shows power laws of profits/losses and gross sales, suggesting scalability is an essential of firms' success. Furthermore, research by Dahui *et al*. (2005), Ishikawa (2006) Podobnik *et al*. (2006) shows that power laws signify change in languages, industries, and economies—in the latter two cases, improved economic activities. In Figure 2, our plotting on log-scaled X and Y axes of all of the ~39,000 firms in Microsoft's ecosystem shows a near-perfect power-law distribution except for the largest firms at one end (due to some missing data).



Number of Companies in Each of Microsoft's Software Domains

Figure 2 *Power-Law Distribution Of ~39,000 Software Firms.*

Conclusion

Whilst geographical clusters (GCs) have had a long period of success, we observe that in recent years there is increasing evidence of adaptive failures ranging across the US, UK, and other parts of Europe, but with new cluster growth in other parts of the world. To explain success and failure in GCs, we use complexity science. In particular, we reinforce the argument that successful GC evolution can happen only if GCs behave as effective complex adaptive systems (CASs)—because they then can produce self-organization and emergent new order so as to create new adaptive structures and behavioral processes.

After reviewing three Phases in the development of complexity science, we identify seven essential properties of CASs, four of a more conventional kind dating to the European and American Schools on complexity science, and three drawn from the most recent Phase, Econophysics. These are heterogeneous agents, melting zone, coevolution, self-organization and emergence, non-additive interaction amongst agents, butterfly effects, and scalability. We argue that all seven of our properties are needed for GCs to effectively self-organize and perform.

Our review of GCs suggests that when GCs lose even one of our seven CAS properties they tend to fail. Even though many Italian GCs are in trouble, we find that a modest power-law signature shows up in Italian GCs. We conclude by proposing a set of policies and recommended actions for managers, employees, and institutions, which are designed to guarantee that GCs retain CAS properties so as to foster efficacious adaptation to the changing world around them.

It seems unlikely that our policies can save all clusters. Some will invariably lose out to lower costs in China, India, and Eastern Europe. But recent research shows that in Japan, for example, some regions self-organize to recover from manufacturing and jobs lost to China, whereas others do not (Colovic, 2004). The lesson from Japan is that some clusters recover but others do not. The same appears to be true in Italy. We believe policies such as ours, if effectively promulgated and implemented, can help many GCs stave off adaptive failure.

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