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Leveraging complexity for ecosystemic innovation

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ABSTRACT

This paper looks at innovation ecosystems through the lens of complexity science, considering them as open non-linear entities that are characterized by changing multi-faceted motivations of networked actors, high receptivity to feedback, and persistent structural transformations. In the context of the growing organizational complexity of economies, driven by their adaptation to high uncertainty, and the central role of collaboration, we differentiate the innovation capacity of various types of business networks by the complexity of their internal interactions, thus identifying the place of innovation ecosystems in the world of business networks, as well as the place of innovation clusters among other innovation ecosystems. We observe how innovation ecosystems have been viewed in four different research streams: management literature; the inter-firm and business network stream of economic and sociological literature; the innovation policy and competitiveness agenda in economic literature; and the dichotomy of localized and economy-wide innovation ecosystems in policy studies (in economic literature, evolutionary geography, and regional research). We then describe generic properties of innovation ecosystems in terms of complexity science, viewing them as complex adaptive systems, paying special attention to the complexity of innovation clusters. We compare complexity thinking of modern economies, deriving from their emerging ecosystem design, with traditional thinking conceived for industrial era, drawing insights for a better transition to innovation-led growth. We conclude with a summary of key findings, practical and policy implications and recommendations for further study.

1. Introduction

1.1. Non-linear innovation and the emergence of innovation ecosystems

Under enhanced global competition and global proliferation of information communications technologies (ICT), economic activities have become more knowledge-intensive, and industrial economies have accelerated their transition to knowledge-based systems.

In various sectors, the linear model of innovation (a downstream cascade of knowledge flows from fundamental science to applied research, and further to application) is giving way to a non-linear model, in which ideas for innovation come from many sources and stages of economic activity, and a growing number of institutions have become involved in the production and diffusion of knowledge (OECD, 1999). This implies that innovation is becoming highly interactive and collaborative, often multidisciplinary and multidirectional (National Research Council, 2012).

Driven by global forces of non-linear innovation, the modern systems of production and economic governance are also obtaining a non-linear nature to become decentralized, diffused and dispersed along network nodes (Elsner, 2015; Nieto and Santamaría, 2007; Smorodinskaya, 2015; Todeva, 2013). Their development is increasingly characterized by uneven leaps, multi-vector fluctuations and other manifestations of nondeterministic behavior. In contrast to linear systems, non-linear ones evolve disproportionally: in some cases, minor behavioral changes in a system's separate elements may lead to large-scale changes in its state, while in other cases, major changes in the state of elements may produce weak or even no impacts on the system as a whole (OECD, 2009).

The objective paradigm shift from linearity to non-linearity brings about a non-equilibrium, constantly changing global environment, which generates a situation of unprecedented high uncertainty, unlike has been witnessed ever before (Kidd, 2008). Facing this challenging situation, businesses and economies in different parts of the world are searching for new ways to enhance their innovativeness, strengthen their competitiveness and adapt themselves to non-linear global realities.

In particular, to maintain sustainable growth under high uncertainty and manage the growing complexity of technological systems, economies of all levels are simultaneously enhancing their social and

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organizational complexity, tending to assume agile network-based designs (Smorodinskaya and Katukov, 2015). In fact, since 2000s, the creation of new goods and values is seldom singularly producer-led or user-driven; instead, today's technological, service and social innovations are increasingly co-created interactively by participants of collaborative networks. Individuals and companies, as well as regions and nations are more and more engaged in the formation of multifold network partnerships, in which actors develop multilateral cooperation and create new values together, thus jointly responding to continuing technological and market changes. Economic advantage now accrues to those entities that can quickly transit from their traditional hierarchic model to a horizontal network structure and start participating in collaborative activities with similar network entities (Friedman, 2005; Seppä and Tanev, 2011; Smorodinskaya, 2015). The emergence of manifold social networks and innovative business milieus is accompanied by the development of shared perceptions and systems for value co-creation (Russell et al., 2011). Network of affiliations bridge social worlds, which were formerly less or not well-connected (Powell et al., 2013).

This organizational transformation of businesses and economies toward a higher complexity and more agility catalyzes the emanation and proliferation of innovation ecosystems. Not just networks as such but rather heterarchical ecosystems formed by interactive activities and collaboration of networked partners are shaping the dynamic industrial landscape of knowledge-based economies. Taking various scales, configurations and profiles, such ecosystems are seen in literature as a new typical way for producing goods and values in the twenty first century (MacGregor and Carleton, 2012).

Today, the idea of promoting the persistent emergence of localized innovation ecosystems and of creating an economy-wide ecosystemic landscape, typical for systems with innovation-led growth, stands high on the policy agenda of many developed and developing nations (Bramwell et al., 2012; Warwick, 2013; WEDC, 2009). The World Economic Forum now directly associates the new model of industrial policy, as introduced recently in different countries for developing advanced manufacturing, with the prospect of building powerful innovation ecosystems in the manufacturing sector (WEF, 2013).

1.2. Motivating questions, focus and logic of analysis

In this paper, we explore organizational foundations and generic features of innovation ecosystems, including innovation clusters as their sophisticated sub-variety, in concert with non-linear development, collaborative mode of production, and the ongoing transition of entities and economies to innovation-led growth. Our aims are to more precisely define the notion of the term "ecosystem" versus "system", to disclose the origin of synergy effects that make innovation ecosystems and particularly innovation clusters "the new face" of the industrial landscape in the twenty first century, as well as to highlight the emerging ecosystem-based design of modern economies and its key role in facilitating their innovation dynamics. We associate the emergence and evolution of innovation ecosystems with the proliferation of collaborative networks aiming to produce innovation interactively, through a collective action of legally independent actors (Bramwell et al., 2012; Russell et al., 2015).

The quest motivating this analysis is to better understand the organizational setup of emerging knowledge-based systems as compared to the traditional industrial landscape conceived for the linear world, as well as to conceive a supposed interplay between the growing complexity of modern economies and their innovation capacity.

We look at innovation ecosystems through the lens of complexity science, considering them as *open non-linear systems* that are characterized by changing multi-faceted motivations of networked actors, high receptivity to feedback, and persistent structural transformations, induced both endogenously and exogenously. Such ecosystems rely on the agility of network relationships (Adner, 2017) and the collaborative, non-hierarchic models of governance, which enables their *self-adaptability to rapid change*. Their further proliferation demands decision-makers of all levels to provide and support a favorable context (social, economic, institutional, etc.) for continual networking, more horizontal linkages, and the enhancement of *collaborative cohesive milieu within and among entities and economies*.

We situate the analysis of ecosystems in the context of the non-linear world of networks and the central role of collaboration in producing innovation. We then differentiate the innovation capacity of various types of business networks by the complexity of their internal interactions, thus identifying the place of innovation ecosystems in the world of business networks, as well as the place of innovation clusters among other innovation ecosystems. Next, we observe how innovation ecosystems have been viewed in four different research streams: management literature; the inter-firm and business network stream of economic and sociological literature; the innovation policy and competitiveness agenda in economic literature; and the dichotomy of localized and economy-wide innovation ecosystems in policy studies (in economic literature, evolutionary geography, and regional research). We then describe generic properties of innovation ecosystems in terms of complexity science, viewing them as complex adaptive systems, paying special attention to the complexity of innovation clusters. We compare complexity thinking of modern economies, deriving from their emerging ecosystem design, with traditional thinking conceived for industrial era, drawing insights for a better transition to innovation-led growth. We conclude with a summary of key findings, practical and policy implications and recommendations for further study.

2. The world of business networks and the appreciation of innovation ecosystems

2.1. The concept of collaboration and its role in producing innovations

An interpretation of non-linear innovation in modern literature points to its direct connection with the development and proliferation of networks. One of the first descriptions of networks as innovative entities appeared in the early 1990s in the "New Society of Organizations" by P. Drucker (Drucker, 1993), in which he underlined the ability of such organizations for continual "creative destruction" and predicted their future global domination. According to Chesbrough (2003) and Tassey (2008), in order to sustain their competitive advantages, firms move to collective creation of innovation. According to Powell and Grodal (2005), the most effective way to produce innovation involves network interactions of firms with other firms, research institutes and other organizations. The ongoing further proliferation of networks worldwide implies that *innovative goods, technologies and values will be increasingly co-created by networked actors that collaborate with each other to form a certain, relatively sustainable ecosystem of actors, assets and linkages* (Gloor, 2006; Russell et al., 2016; Wessner, 2005).

The term *"collaboration"* (from Latin 'working together') has no universal definition in literature: this term is used both in a broad and in a narrow meaning by different lines of research, each of which applies its own language. For example, some experts argue (MacGregor and Carleton, 2012) that collaboration is important for both R&D and non-R&D innovation but each type uses different networks. Others admit that collaboration involves active and interactive exchange of ideas between two or more people who acknowledge that such exchanges can result in the joint production of co-constructed ideas, some of which may be novel (WEF, 2015). Taken in a loose definition, collaboration denotes various forms of interactive communication between networked actors.

By a more exact definition, accepted in economic literature, collaboration is described as "the process of formal and informal negotiations between autonomous actors, during which they create common rules and organizations to regulate their interactions and fields of activity, or tackle common issues cohesively, with these common rules

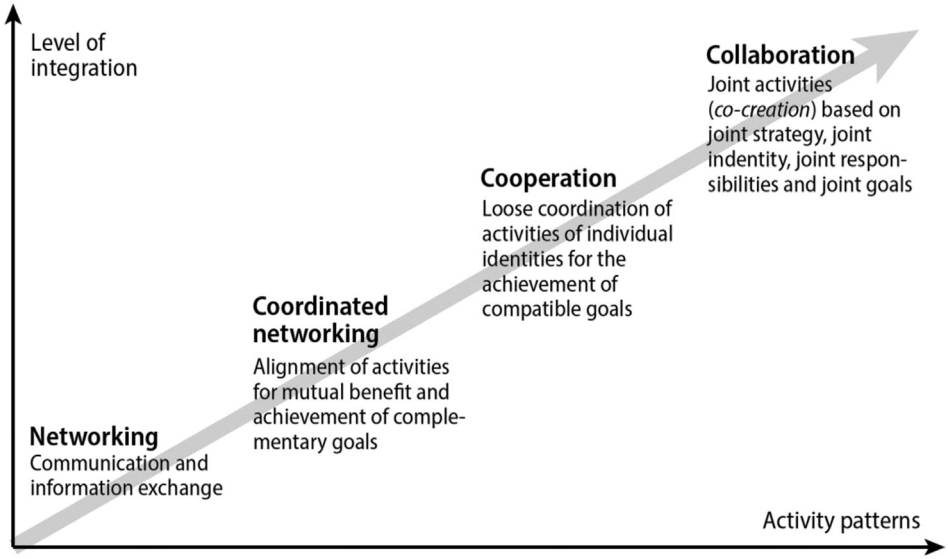

Fig. 1. The growing complexity of interactions and integration of activities from networking to collaboration.
Source: adapted from (Camarinha-Matos and Afsarmanesh, 2008b, p. 312).

shared by all stakeholders, while negotiations taking place continually" (Thomson and Perry, 2006, p. 23). By another exact definition, coined by multidisciplinary analysis of networks, collaboration is seen as a process in which mutually engaged participants share information, resources, responsibilities and risks to jointly plan, implement, and evaluate a program of activities aimed at achieving a common goal (Camarinha-Matos and Afsarmanesh, 2008b). Taken together, both definitions introduce a certain *concept of collaboration* that speaks of networked actors, their shared objectives, and their continuous negotiations to harmonize mutual interests and coordinate mutual activities.

Keeping to this concept, we use for the purpose of this paper a strict interpretation of collaboration, viewing it as *the most developed form of interactive communication*. Particularly, more mutual activity and higher levels of intentional integration differentiate collaboration from other types of relationships, such as networking and cooperation, implying that co-creation of new values is a sophisticated stage of interactions, demanding actors to have a common strategy, joint identity, joint goals and joint responsibilities (Fig. 1). This definition corresponds to collaborative innovation networks able to achieve dynamic sustainability in a non-linear environment. It should be noted that in practice, complex types of relationships may emerge in a non-linear way at varying stages of interactive activities, not necessarily moving in a strict progressive way through all the stages presented in Fig. 1.

Importantly, *collaboration within an ecosystem by no means excludes competition between its actors and with the rest of the world*. To increase mutual benefits, the ecosystem firms cooperate on certain business projects, while remaining simultaneously in fierce and open competition on other business projects, which illustrates a new business reality known as "co-opetition" (Drucker, 1993; Porter, 1990). *Co-opetition* implies a dynamic, continually changing balance between cooperation and competition of legally independent agents, thus constituting a much greater complexity in relationships as compared to linear innovation models of the past (Baldwin and von Hippel, 2011). At the same time, within a long-term common project on developing the whole ecosystem (which is typical only for ecosystems with a joint institutionalized identity, such as innovation clusters), the participating actors collaborate with each other relying on relational contracts and coordinating their activities under a joint strategy. The aim is *to commonly meet the challenges of a vigorous global competition*. The stronger the direct and feedback linkages in the ecosystem, the higher are the mutual benefits in terms of co-created value added, and vice versa (Porter, 1990). So, collaboration implies several types of complex relationships as well as specific dynamic balances within an ecosystem.

The report "Future Knowledge Ecosystems" (Townsend et al., 2009) posits that within 20–30 years, thanks to development of ICT, production processes will be dispersed among numerous small groups of actors, uniting producers, consumers and intermediaries into flexible, temporary networks formed ad hoc for the period of joint projects. No surprise that the authors call the knowledge-based economy *a group economy* (Townsend et al., 2009), while other scholars name it *a network economy* (van Winden et al., 2011). Both definitions are complementary and highlight the collaborative and ecosystemic nature of the future industrial landscape, connecting the new mode of production with *a project-based organization of mutual activities by networked actors* (Bigham et al., 2015).

2.2. The place of innovation ecosystems in the world of business networks

As literature and evidence suggest, the current world of social and economic networks embraces a very broad variety of network milieus, including networks of different nature, functional specialization, design and scale, extending from local to global entities. A large and well-explored part of this variety belongs to business networks (Smith-Doerr and Powell, 2005; Todeva, 2004), describing interactions both within the business sector (inter-firm networks) and among businesses and other institutional actors (inter-organizational networks).

Literature on networks treats non-hierarchic business networks as relatively stable systems of interactions between legally independent but economically interdependent enterprises. Such networks are numerous and varied; they may be either open-ended or focused on a concrete project task. They can emerge both from value chain relationships (Williamson, 1993) and from agglomerations of co-located companies (Ketels, 2012). Despite widespread opinion, not all business networks rely on collaboration or jointly produce an outcome of mutual benefit (Romero and Molina, 2011; Vargo et al., 2008).

Literature on technical change and social networks explores business networks under different classification criteria, including diversity in pattern and level of mutual activities (Breschi and Malerba, 2005). Networks that can develop more sophisticated patterns of interactions, or display higher organizational complexity, tend to generate more dynamism, agility and innovativeness. According to Ivanova and Leydesdorff (2015), *the innovation dynamics of economic systems, and hence, the efficiency of their performance are proportional to their complexity*; economic efficiency rises with an increasing number of non-linear network interactions that catalyze self-organization among the system's elements.

The logic of increasing complexity in interaction patterns gives us grounds to differentiate the numerous and varied business networks in

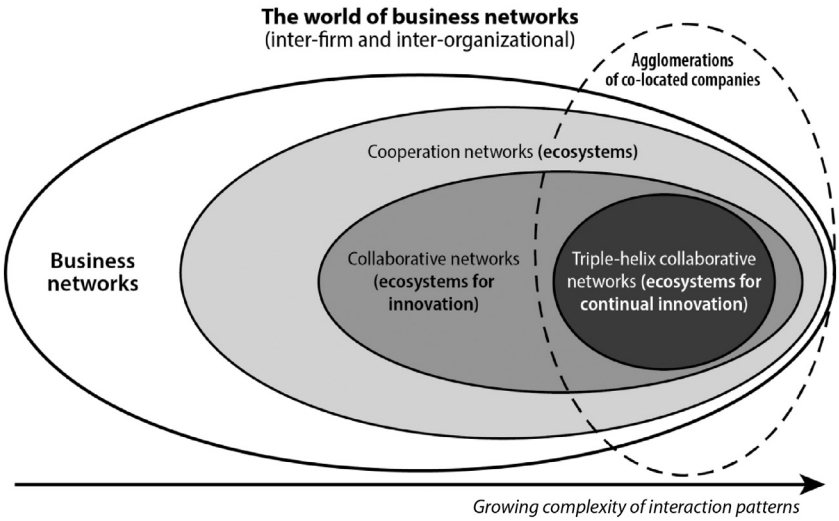

Fig. 2. Differentiating innovation capacity of business networks by their internal interaction complexity.
Source: authors' elaboration based on literature on networks, clusters and innovation.

terms of innovation capacity, and hence, in terms of their role in facilitating innovation-led growth. To better understand the origin of innovation ecosystems and their place in the world of business networks, we single out three overlapping varieties, namely, cooperation networks, collaborative networks, and triple helix collaborative networks (Fig. 2).

We refer to *cooperation networks* a broad variety of business networks in which the development of mutual activities shapes a sustainable *ecosystem* of interactive linkages. This implies a certain loose coordination of activities but does not necessary include shared responsibility or joint action. Such networks may stay at a relatively low level of organizational complexity in terms of inter-firm and inter-organizational interaction patterns, and hence, may play a supporting or indirect role in facilitating and sustaining innovation-led growth. Cooperation networks enable an environment in which new actors may emerge and abandoned actors may quickly begin again. Sociological literature on networks posits that the formation of a sustainable ecosystem happens at the moment when a spontaneous distribution of horizontal linkages per node in the given network reaches a certain critical level (Barabási, 2002).

The variety of cooperation networks contains a sub-variety of a higher interaction complexity that can be associated with collaboration in its strict definition (as shown in Fig. 1). We regard this sub-variety as *collaborative networks* and identify their ecosystems with *innovation ecosystems*, i.e., ecosystems of a higher level, enabling not just support of innovation but co-creation of innovations (new goods, services, assets, etc.). Collaborative networks are usually described in literature as *'collaborative innovation networks'* to denote typical organizational forms of production in the age of digital technologies. This term was first popularized by P. Gloor (2006) and further explored conceptually (Camarinha-Matos and Afsarmanesh, 2008a) and empirically (Nieto and Santamaría, 2007; Tsai, 2009) by other authors. Such networks may be local, national, transnational or global; they may have different configuration and patterns of collaboration (Camarinha-Matos and Afsarmanesh, 2008a).

In our interpretation, *innovation ecosystems are essentially the result and derivative of collaboration-type interactions*, i.e., they emerge at the moment when cooperating actors have achieved a certain level of integration concerned with a joint identity, joint strategy and joint goals[1].

This approach stems from numerous literature findings that highlight the crucial role of collaboration in facilitating innovation in modern economies. As evidence suggests, the development of innovation ecosystems usually rests on formal and informal communication platforms tailored to enhancing open dialogue and collaborative activities; it also often involves special intermediary organizations meant for the same purpose (National Research Council, 2007). Economic literature and business leaders both treat the term "innovation ecosystems" as the pattern of developing interactions between networked actors, the mode of their innovative activities and their interrelationship with operational context (Kelly, 2015; Mercan and Göktaş, 2011).

In its turn, the variety of collaborative networks contains a subvariety with even a higher complexity of interaction pattern and mutuality of intention, which we refer to as *triple-helix pattern of collaborative networks*. The triple-helix concept, elaborated by sociologists (Etzkowitz and Leydesdorff, 1995), describes networks developing a simultaneous pair-wise collaboration of legally independent actors from at least three institutionally different sectors, representing business sector, knowledge generating sector (universities, research institutes, other R&D centers) and public sector (government bodies or agencies)[2]. Due to such diversified interactive relationships, these networks can generate a highly sophisticated ecosystem, through which *the exchange of information and knowledge, as well as co-creation of new knowledge and innovation, can be maximized* (Etzkowitz and Leydesdorff, 2000). We identify such ecosystems as *ecosystems for continual innovation*, which follows from the description of innovation clusters constituting the most studied model of triple helix networks in modern economies (Bode et al., 2010; Breschi and Malerba, 2005; Russell et al., 2011; Smorodinskaya and Katukov, 2016; Todeva, 2004). According to Smorodinskaya (2011), in terms of describing the evolution of innovation-driven growth, the triple helix idea is complementary to the cluster idea rooted in M. Porter's theory of competitive advantage (Porter, 1990).

In particular, as follows from cluster literature (Porter and Ketels, 2009), *innovation clusters* constitute a special variety of innovation ecosystems, in which triple-helix interactions enable unique economic effects of innovation synergy, or *co-creation of innovative goods and services on a continual basis*. This literature argues that innovation clusters can develop an ecosystem, or an organizational milieu, in which *motives for continual innovation become maintainable*, thus leading

[1] In this sense, our interpretation of collaborative innovation networks goes beyond their more narrow definition coined by Peter Gloor (Sloan School of management, MIT) in the context of management studies. According to Gloor (2006), a collaborative innovation network is a self-organizing group (a cyberteam) of highly motivated individuals that work together on the basis of collective vision to achieve a common goal by sharing ideas, information, and work.

[2] The metaphor "triple helix", illustrating generation of knowledge across institutional borders, was derived from genetics: a DNA chain, in which different "helices" vine around each other and work together for the same purpose yet still maintaining individual identity within a common ecosystem. Etzkowitz and Leydesdorff (1995).

to a sustainable rise in productivity (Porter and Ketels, 2009), or 'competitiveness upgrading' in terms of Porter (1990). In other words, a triple-helix pattern of collaboration can increase mutual interdependencies within an ecosystem in ways that lead to *synergy effects of self-supportive growth*, less often observed in less complex ecosystems (Porter, 2003; Porter and Ketels, 2009; Smorodinskaya and Katukov, 2015). Accordingly, innovation clusters are considered *the most convenient ecosystem model for both continuous co-creation of innovations and for disseminating them across an economy* (Sölvell, 2009).

Comprehensive empirical evidence on unique innovation synergy effects in triple helix networks is still very limited (due to measurement and methodological difficulties), yet such effects are confirmed by initial systemic findings on clusters as recognized poles of growth (Delgado et al., 2010). Also, firms and organizations involved in clusters have been found more dynamic and innovative than those outside them (Fitjar et al., 2014). According to our knowledge, comparative innovative advantages of clusters among other collaborative networks can be explained by a combination of several factors. Besides triple-helix relationships, *proximity effects matter*, since innovation clusters emerge from agglomerations of geographically co-located actors, which is not typical of more dispersed networks such as transborder value chains. Additionally, in terms of collaboration objectives, the majority of networks are focused on achieving solely individual or mutual economic benefits of participants, while innovation clusters are designed for *aggregate synergy effects* that can persistently improve competitiveness of both the group of participants and the territory of its location (Bode et al., 2010; Ketels, 2012).

Overall, the world of networks is much broader than the specialized part of them referred to as innovation ecosystems, and the variety of innovation ecosystems is broader than its special sub-variety presented by innovation clusters and other triple-helix networks enabling continual innovation. Such networks operate within the environment of other kinds of networks; they may be born out of the cooperation and collaborative networks or generate new ones; they can form larger and more robust innovation ecosystems through inter-cluster linkages (BSR Stars, 2013). Elements of innovation ecosystems co-exist in the context of both cooperation and competition. All innovation ecosystems based on collaboration are considered *a typical organizational format, or just a new business model, for producing goods and values in the twenty first century* (MacGregor and Carleton, 2012).

3. Innovation ecosystems within different research streams (literature review)

The term *"ecosystem"* was brought to social and economic analysis from biology, through the concept of business ecosystems, coined in mid-1990s by Moore (1996). Over time, this term has been applied within a variety of contexts, including far-reaching impacts of globalization and ICT. The particular idea of innovation ecosystems has been also developing in various complimentary directions to bring about a wide diversity in definitions and approaches (Smorodinskaya et al., 2017). For example, an overview of literature reviews on innovation ecosystems, made by Pilinkienė and Mačiulis (2014), embraces a varied scope of entities with different objectives, which range from industrial and business ecosystems to digital business and entrepreneurship ecosystems. Scholars studying networks of the application programming interfaces (APIs) also use the ecosystem concept in describing the emerging platform economy (Hutamäki et al., 2017). And business consulting literature, while applying scholars' findings to practical purposes, now uses the term 'ecosystem' as not just another management buzzword but rather as an increasingly critical unit of analysis that captures the ongoing innovation-led shift in business landscape and entrepreneurs' mindsets (Kelly, 2015) - *the ecosystem milieu*.

Besides pure academic studies (f.e., Fukuda and Watanabe, 2008; Tsujimoto et al., 2017), literature on innovation ecosystems now embraces a variety of research and expert communities. Policy issues are elaborated within Scandinavian countries (Swedish governmental agency on innovation systems VINNOVA, REG X Danish Cluster Academy), in USA (National Research Council, Council on Competitiveness, etc.), and within international organizations such as the World Bank, the World Economic Forum, etc. (Nallari and Griffith, 2013; Napier and Kethelz, 2014; WEDC, 2009).

In this section, we observe conceptions of innovation ecosystems within several somewhat interrelated, yet different academic research streams: management studies on strategic relationships; studies on business and inter-firm networks; and studies on innovation policies and competitiveness agenda. We also consider existing interpretations of localized innovation ecosystems, including innovation clusters, and of economy-wide innovation ecosystems. An overview of this literature is helpful in differentiating innovation ecosystems from other concepts for technology-based and innovation-led development.

3.1. Management literature on strategic relationships

This literature explores ecosystems through the lens of the Moore's initial concept (1996).

Some management studies advocate *a firm-centric vision of innovation ecosystems*, which seeks to understand how individual agents can best take advantage of the ecosystem that surrounds them. These studies view an innovation ecosystem as *a network of interconnected organizations*, linked to or operating around a focal firm or a technological platform. Such networks usually incorporate platform participants from two sides - both producers and users, aiming to create and appropriate new value through innovation (Autio and Thomas, 2013). The agents, who may compete and cooperate simultaneously, come together due to a shared purpose of value creation and stay in alignment due to interdependency stemming from their constant need for maintaining their network's effectiveness. From a firm-centric perspective, strategies for developing an innovation ecosystem include such competencies as ecosystem creation; ecosystem coordination; optimization of business models to take advantage of ecosystem externalities; and the creation of control strategies to ensure value appropriation (Autio and Thomas, 2013). A computational analysis of key words in business and management literature reveals that core topics of innovation ecosystems focus predominantly on developing and managing innovation, research and knowledge (Hajikhani, 2017).

Other management research advocates a view of *ecosystems as "structures"*, defining them as a certain cohesive configuration of interconnections and inter-dependences of multiple actors, which emerges not around a focal firm but around a 'focal value proposition", i.e., as coherent alignment of assets or decisions, arising from a joint initiative (project, proposal) for co-creation of value (Adner, 2017). This structure-based approach argues that ecosystems matter when the multilateral relationships that underlie a value proposition are not decomposable into multiple bilateral relationships. In other words, it highlights the factor of a motivation-driven cohesion, thus *making a departure from a wider treatment of ecosystems as a certain milieu* that spontaneously emerges or is orchestrated (Wind et al., 2008) either at the level of firms, or industrial sectors, or regions.

3.2. Economic and sociological literature on inter-firm and other business networks

This literature applies the term 'innovation ecosystem' to a broad range of networks that either co-produce innovations directly or co-create a favorable environment for their emergence and dissemination. In this interpretation, innovation ecosystems may assume various scales and designs – be they regional innovation hubs, nation-wide innovation communities, local inter-firm networks, small ad-hoc groups of individuals collaborating under a common project, or global-wide value chains, etc. (Bramwell et al., 2012).

Particularly, some scholars view innovation ecosystems as

communities whose members combine their resources in a mutually beneficial way, with a shared goal of creating innovative results (Chessell, 2008) (cited in Ranga, 2011). Others associate them with *networks of sustainable linkages* between individuals, organizations and their decisions, which emerge from a shared vision of desirable transformations, evolve through agile reconfiguration and provide economic context (milieu) to catalyze innovation and growth (Russell et al., 2011). These scholars argue that the term "sustainable" is of key importance in describing network links in the organic nature of innovation ecosystems, since it reflects functional interdependences and a certain level of integrity between legally independent actors.

The economic sociology research on business networks considers the formation of ecosystems as an *"emergence" process, typical for complex adaptive systems*. In particular, Padgett and Powell (2013) describe the coalescence of separate multi-layer linkages into an integrated network, highlighting the role of personal relationships and business agreements as natural ecosystem infrastructure. Literature on inter-firm networks also analyzes the design of innovation ecosystems as complex network-based structures, with this approach used to study value chain networks and ecosystems in a variety of industries (Adner, 2012; Basole and Rouse, 2008; Rosenkopf and Schilling, 2008).

3.3. Economic literature on innovation policy and competitiveness agenda

This literature is policy-oriented, and hence, directly deals with development of organizational models of innovation. The term 'innovation ecosystem' has been evidenced in this stream since the mid-2000's, as a historical derivative from the previously coined term 'innovation system'. In the late industrial era, prominent economists engaged in innovation studies, known as the conceptual stream of Lundval, Nelson and Freeman (Freeman, 1995; Lundvall, 1992; Nelson, 1993), elaborated the concept of *national innovation systems*, aiming to organize an economy-wide technological support for domestic firms that were competing in international markets (Schot and Steinmueller, 2016). From the very start, this concept treated innovation as a non-linear process, the result of network-based cooperation between innovating firms and various other actors (competing firms, universities, public and private research institutes, as well as suppliers and customers), with governments supporting these complex networks with funding and other incentives (OECD, 1999).

In practice, however, the innovation systems of the 1990s, established by national governments (and later on, by regional and local authorities), were designed largely as static government-led structures, consisting of a predefined composition of actors and a program-built infrastructure. In line with the initial vision of scholars, these systems maintained a government-centric and producer-centric focus in innovation process (OECD, 1999; Schot and Steinmueller, 2016), while decision-makers and managers associated their successful performance not with collaborative interactions but rather with a critical mass of innovative firms and designated infrastructure (WEF, 2013). Within the business sector itself, companies were often engaged in similar programs meant for building formal innovation systems, such as the Microelectronics Manufacturing Consortium (Gibson and Rogers, 1994).

As recognized today, *the early-built national and regional innovation systems failed to meet the growing complexity of the innovation process*, since they were lacking instruments for developing collaboration in its above-described meaning (Schot and Steinmueller, 2016). In order to remedy failures of previous innovation policies, the conceptual stream gave way to the term 'innovation ecosystem', mainly as an analytical tool to consider how public policies could facilitate innovation by strengthening interactive linkages within the existing innovation systems (Wessner, 2005). Meanwhile, since the mid-2000's, the innovation and competitiveness agenda in developed countries has turned to a more complex framing, concerned with so called *systemic, or continual innovation*, oriented toward persistent transformative change in the economy and society (Schot and Steinmueller, 2016). Ever since, relevant studies have assumed a more substantial ecosystem perspective, receiving support from Edquist (2005) and incorporating complementary research streams, such as cluster literature stemming from Porter's competitiveness theory (Porter, 1990) or triple helix concept of Etzkowitz and Leydesdorff (2000).

In this regard C. Wessner posits that *the term 'innovation ecosystem' captures the complex synergies among a variety of collaborative efforts* of large and small businesses, universities, research institutes, laboratories and venture capital firms, all involved in bringing innovation to market (National Research Council, 2007). In other relevant studies, this term is associated with *an innovation business community*, in which participants aim at a continual upgrading of their products, business processes, technologies and business models to flexibly meet rapid technological changes and gain market advantage (BSR Stars, 2013; Nallari and Griffith, 2013). Plainly speaking, the literature dealing with policies to facilitate competitiveness and innovation-led growth describes innovation ecosystems through the lens of their key function - to provide smooth and continual exchange of knowledge flows in bringing innovations to market.

3.4. Interpretations of localized and economy-wide innovation ecosystems

Though networks are not limited by geographical borders and can emerge as virtual structures, economists and sociologists have emphasized the importance of localization in the innovation process. The economic development strategies of various countries are all based on the underlying premise that *co-location of partners matters for co-producing innovations*, since geographical proximity of networked agents (particularly of firms and universities) is crucial for facilitating knowledge transfer, especially in knowledge-intensive industries (Owen-Smith and Powell, 2009; Powell and Giannella, 2010; Sölvell, 2009). As experience of Silicon Valley and similar innovative places shows, localization leads to very important agglomeration effects that enable cost reduction and support innovation (Carlino and Kerr, 2014). As stems from literature on complexity, collaborative networks of geographically co-located actors (such as regional clusters or macro-regional innovation hubs) have a greater innovation potential as ecosystems than organizationally dispersed networks in the form of production circuits, not tailored to the format of sustainable social integrity (f.e., global value chains) (Dicken, 2015)[3]. Taken together, this implies that *national strategies for developing collaboration for the co-creation of new goods and values can be optimized at the level of localities and must also consider the contribution of proximity effects in the innovation dynamics of geographical areas*.

In a strict economic sense, reflecting the complex nature of innovation in the twenty first century, *a localized innovation ecosystem* is a sustainable node of network communications among entrepreneurs, researchers and other institutional actors, which enables them *to collectively generate knowledge, mutually exchange it and transform it into commercial innovative assets through collaboration*. As literature and practice tell, these entities often take the form of *innovation clusters or university-industry partnerships* emerging around specific industries and technologies, or even at the intersection of two or more distinctly different, yet overlapping sectors (Bramwell et al., 2012; Porter, 1998).

Economic and business studies on *innovation clusters* clarify that cluster actors collaborate under a common cluster project and create innovations by means of co-production and co-specialization (Eriksson, 2010; Hamdouch, 2007). Cluster literature, originating from M. Porter's competitiveness theory (Ketels and Memedovic, 2008; Lindqvist, 2009; Porter, 1990, etc.), views clusters as innovation ecosystems that

[3] To compensate this disadvantage, such organizationally dispersed ecosystems, such as global value chains, may assume a sophisticated glocal structure by relying on regional innovation clusters as their specialized and geographically localized network nodes. Smorodinskaya et al. (2017).

generate a combination of proximity effects and unique collaborative effects of continual innovation. Upon summarizing findings of cluster literature, N. Smorodinskaya describes innovation clusters in three interrelated dimensions: firstly, as a special class of agglomerations enjoying a glocal (global plus local) flow of resources; secondly, as a special class of collaborative networks relying on triple-helix pattern of collaboration; and thirdly, as a special class of economic projects realized through relational contracts (Smorodinskaya, 2015; Smorodinskaya and Katukov, 2015).

Literature on business networks (Breschi and Malerba, 2005; Huggins and Izushi, 2007), as well as evolutionary geography and regional studies (Asheim et al., 2011; Cooke, 2001; ter Wal and Boschma, 2011) explore a *diversified variety of localized public-private partnerships*, which can be referred to as a class of triple helix collaborative networks. These studies usually emphasize the key role of intermediating institutions in enhancing collaboration in such networks, and hence, in advancing their innovation ecosystems. Intermediaries, in cluster literature also called *institutions for collaboration* (Ketels and Memedovic, 2008), apply considerable intentionality in effectively bridging multiple partners and directing them toward delivering a common agenda. For instance, in USA, localized ecosystems may involve a diverse spectrum of actors (from individual researchers to banks and large companies), with their intermediaries providing both public and private funding, or offering a platform for collaboration (National Research Council, 2012).

As an expression of both collaborative and competitive milieu, the innovation ecosystem concept heralds the newly emerging economic milieu, composed of various multiform and overlapping network partnerships. The population of these partnerships across a country's economy makes up *a national innovation ecosystem*. For example, in the US, the term 'innovation ecosystem' appeared on the national policy agenda by 2005, as proposed by C. Wessner (2005) to highlight the non-linear nature of the innovation process. Unlike the practice of other nations in Europe or Asia, America's national innovation system has not been conceived as a system intentionally planned or designed by the government, but rather as an extremely complex ecosystem characterized by myriad varieties of interactions among government agencies, universities, private industry, financiers, and intermediary organizations (National Research Council, 2012). In some large countries similar complex ecosystems appear at the regional levels, thus constituting *regional innovation ecosystems* (Ranga, 2011).

At the moment, a wide number of jurisdictions (Finland, Denmark, Korea, China, Sweden, UK, Australia, etc.), while following the front-running experience of USA, have established policies and institutions for *advancing the formation of economy-wide ecosystems* (both national and regional, as well as multinational) as means to accelerate their transition to a knowledge-based economy (Bramwell et al., 2012).

4. Properties of innovation ecosystems in terms of complexity science

4.1. The concept of complex adaptive systems

Literature on networks treats non-linear systems as *complex adaptive systems* (CAS), or complex dynamic systems (Jucevičius and Grumadaitė, 2014), which have been studied since mid-1980's by complexity science, also called *complexity theory*[4]. Such systems, irrespective of their scale and origin (be they biological or social), have a universal holistic nature predefining their complexity: individual properties of constituents can be revealed only through aggregate properties of the whole system. Today, literature on complexity refers to CAS many natural and, increasingly, many artificial systems; the variety includes economies, ecologies, societies, human brain, developing embryos, ant colonies, computing systems, artificial intelligence systems, etc. All of them display common features and are often described under the interchangeable terms of complex adaptive, complex dynamic, or complex non-linear systems.

CAS is a dynamic open network of many heterogeneous agents acting in parallel in a complex, unpredictable (emergent) and mutually self-reinforcing way (Holland, 2002). In such networks, overall properties result from the aggregate behavior of individual agents; complexity results from the inter-relationship, inter-action and inter-connectivity of elements within a system and between a system and its environment; and control tends to be highly dispersed (Mitleton-Kelly, 1997). Coherent behavior in a national economy or in a local cluster arises from interactions among the agents themselves, with these interactions essentially implying both competition and cooperation (Chan, 2001), as well as birth and death of entities over the business cycle (Holling, 2001).

CAS is a *dissipative structure*, able to continually adapt in and evolve with its environment, as generated by the dynamic and self-reinforcing interactions of its agents. This implies that a complex system is not separated from its ever-changing environment, thus *making up an ecosystem*, in which each agent operates in an environment produced by its interactions with other agents (Elsner, 2015). As a result, CAS displays a *spontaneous self-organization*: the order can result from various complex feedbacks and mutually self-reinforcing interactions among a large number of agents at different levels of organization (Martin and Sunley, 2007). There is constant action and reaction of agents to what other agents are doing, based on differences in values and goals, and the boundary between the system and its environment is neither fixed nor easily identified (Chan, 2001).

In recent decades, complexity theory has attracted increasing interest of economists and evolutionary economic geographers as a novel and powerful mode of thinking, capable to bring a radical and long-overdue revision of the mainstream economic thought (Krugman, 1996; Metcalfe and Foster, 2004). This has led to the appearance of *'complexity economics'*, a new research stream creating an umbrella for those theoretical and empirical studies that can be directly or indirectly linked with complexity science (Beinhocker, 2006).

4.2. Innovation ecosystems viewed as complex adaptive systems

Complexity economics sees an innovation-led economy as a complex adaptive system, or an ecosystem, constituted by innumerable knowledge flows and multiple inter-connections among diverse and heterogeneous elements that communicate through networks (Martin and Sunley, 2007). From this perspective, *collaborative networks, as well as network-based economies, generate innovation ecosystems as their inseparable and co-evolving environments* and may display, either entirely or partially, the following generic properties of CAS (Chan, 2001; Martin and Sunley, 2007; OECD, 2009):

- *Basic network effect*. Ecosystems are open-ended networks, in which each agent benefits in a non-linear way from any simple increase in the number of network nodes and participants. As a result, network-based ecosystems enjoy competitive advantages in dynamics as compared to linear systems;
- *Emergency, or non-determinate behavior*. Ecosystems are almost unpredictable; they may behave in ways which don't follow from their earlier state or from individual properties of their components. This corresponds to a non-linear behavior that generates abrupt removals of order by randomness, or stability by volatility, and vice versa;
- *Presence of feedback linkages and reflexive cycles, both positive and negative*. The pattern and level of interactions among the ecosystem agents matter more than their own characteristics and behavior of each individually. Quality and quantity of feedback linkages within

[4] The American school of complexity science, dealing with CAS's, began at Santa Fe Institute in New Mexico (USA), largely deriving from the discovery of Ilya Prigogine, the 1977 Nobel prize winner: in his work on "dissipative structures" he showed that not all systems tend toward disorder, some complex systems tend to generate order from disorder through a process of spontaneous self-organization. Anderson et al. (1988); Chan (2001); Holland (1995); Holland (2002).

an ecosystem determine its overall effectiveness, since agents reciprocally react in their behavior to the behavior of other agents, displaying high mutual interdependences;

- *Adaptability, or capacity for adjustments*. In the course of interactions, ecosystem's agents modify their behavior, upon reacting to and considering the behavior of other agents, which adjusts the behavior of the whole ecosystem, implying its high adaptability to any changes;
- *Self-organization, self-regulation and self-governance*. Ecosystems start to move and are advancing spontaneously, similar to self-adaptive living entities. They rely on a dispersed pattern of coordination through network nodes and don't need either external intervention (typical for mechanical or static systems) or any governing center (typical for hierarchic systems). Accordingly, they obtain new sources for growth and achieve dynamic sustainability through internal, self-correcting structural transformations, which may involve a persistent agile recombination of shared assets circulating within an ecosystem;
- *Self-similarity, or fractal-type recursions*. Ecosystems can generate larger or smaller similarities at any scale level: networks form other networks with similar properties within different geographical and institutional spaces;
- *Holistic nature and synergy*. An ecosystem's behavior, its dynamics and innovativeness are an aggregated result of interactions among its agents (and not a simple summation of agents' behaviors and performances), which implies synergy effects that enlarge an ecosystem's productivity always to a greater extent than a sum of individual results of its participants.

The combination of these properties enables complex systems to generate "structural order" in non-equilibrium environments through *interactive relationships* of participants, i.e., by means of continual reciprocal adjustments of their individual non-linear behaviors on the basis of multiple feedbacks. The aggregate result of interactive and non-linear relationships among a significant number of networked agents is expressed in internal structural transformations in the ecosystem, thus lending it *the ability for a spontaneous self-regulation* (OECD, 2009).

We admit that all types of ecosystems presented above in Fig. 2 can share these common properties of CAS to a smaller or larger extent. All of them are populations able to self-organize and self-develop in a similar, agile manner, associated with inter-relationship of networked elements (Chan, 2001). However, we believe that *ecosystems with the highest complexity in terms of pattern of interactions* (*like innovation clusters*), *and hence, the ones with the highest innovative potential, may reveal the highest self-adaptive capacity*, or which is to say, the strongest ability for sustainable development under high uncertainty.

Some essays suggest (Holling, 2001) that CAS are also distinguished by *generativity* as a generic feature, implying that innovation ecosystems display dynamic balances such as coexistence of creation and conservation, learning and continuity, or success and failure among participants, all them supporting an ecosystem's evolution and dynamic sustainability. Basically, these and similar balances found in ecosystems - including inter-connectivity (coexistence of weak and strong horizontal ties), heterogeneity (a critical diversity of actors in terms of their functions and behaviours), or a certain relationship between the level of control and the level of functional independency (Carbonara, 2017) - should be seen as resultants of a CAS's holistic nature and factors fostering its capacity for self-adjustments through interactive relationships of agents.

In terms of a recent classification of the existing analytical ecosystem perspectives, presented in Tsujimoto et al. (2017), our treatment of innovation ecosystems, which relies on the CAS concept, is closer to the perspective associated with multi-actor networks as a phenomenon of non-linear world. It should be also noted that innovation ecosystems and natural ones, although both displaying common CAS's properties, are by no means the same, since their complexity rests on different principles of self-organization and self-adaptation. When describing an innovation-led economy, complexity economics focuses on the key formative role of knowledge flows, rather than drawing any biological analogies (Martin and Sunley, 2007). This literature connects economic growth in the twenty first century with *persistent emergence of innovation and with continual self-correcting structural changes through which an economy obtains new sources for growth and adapts itself to the global upgrading of technologies*.

4.3. Innovation clusters viewed as complex adaptive systems

According to a classical definition, clusters are groups of geographically co-located companies and associated institutions, engaged in a particular field of related industries, and linked through various types of externalities (Porter, 1998, 2003). Modern cluster literature views innovation clusters as collaborative networks initiated through a common project of triple-helix actors (Sölvell, 2009). It directly interprets clusters *as complex dynamic systems*, highlighting their unique synergy effects (European Commission, 2013).

A mathematical formalization of the triple helix model (Ivanova and Leydesdorff, 2014) confirms that triple-helix networks may form a very sophisticated ecosystem of social communications and functional interdependences, which has a dynamic nature of non-linear fractal structures and can provide continuous upgrading required for innovation-driven growth. It follows, therefore, that this pattern of collaboration may extend the three institutional pillars to a Quadruple Helix, a Quintuple Helix, and even N-tuple helices (Ahonen and Hämäläinen, 2012; Leydesdorff, 2012). Such complex systems are now increasingly recognized as a typical way to create knowledge, disseminate it across economies and transform it into new values. As argued above (part 2.2), triple helix networks are characterized by more advanced and complex interaction patterns in terms of agility, dynamism, and co-production of innovation on a continual basis. Successful innovation clusters demonstrate these advantages (Porter, 1998; Rullani, 2002).

Successful clusters involve collaborative partners of various profiles, who are engaged in co-production of innovative goods and values (Fig. 3), while staying free to join and leave the open-end cluster network (Ketels, 2012). Each competitive cluster relies on a certain critical mass of participants, provided by the presence of three key categories of actors: firstly, representatives of all the three triple helix actors, co-located in the given territory; secondly, venture capital investors and financial sponsors from private, government or international sectors; and thirdly, the cluster organization as a specialized cluster coordinator (Lindqvist et al., 2013). At critical moments over time, the fluidity of a complex adaptive system and the coordinating work of a cluster organization enable a co-located group of companies to evolve as a self-governed and self-sustainable innovation ecosystem.

As complex adaptive systems, clusters are displaying a holistic model of relationships between geographic proximity and industrial competitiveness (European Commission, 2013). Their high innovativeness is fueled by localized externalities generated within a cluster's ecosystem through *several dynamic balances*, such as inter-firm co-opetition, coexistence of specialization and diversification of activities, an agile and mobile combination of local and global resource flows, etc. (Smorodinskaya, 2015).

In terms of generated innovation synergy, the complexity of a cluster ecosystem arises from the following features of its organizational and institutional design (Smorodinskaya and Katukov, 2016).

First, *evolution of a highly cohesive milieu* enthused through collaboration of co-located triple helix actors, and embracing *a certain critical mass of networked partners*, both in terms of quantity and quality. Successful clusters develop an ecosystem of dense functional linkages among the micro- and macro-level partners of various profiles, from incumbent firms and innovative SMEs to service organizations and financial institutions (Napier and Kethelz, 2014). Collaborations of triple helix actors can reproduce self-similarities on a variety of scales,

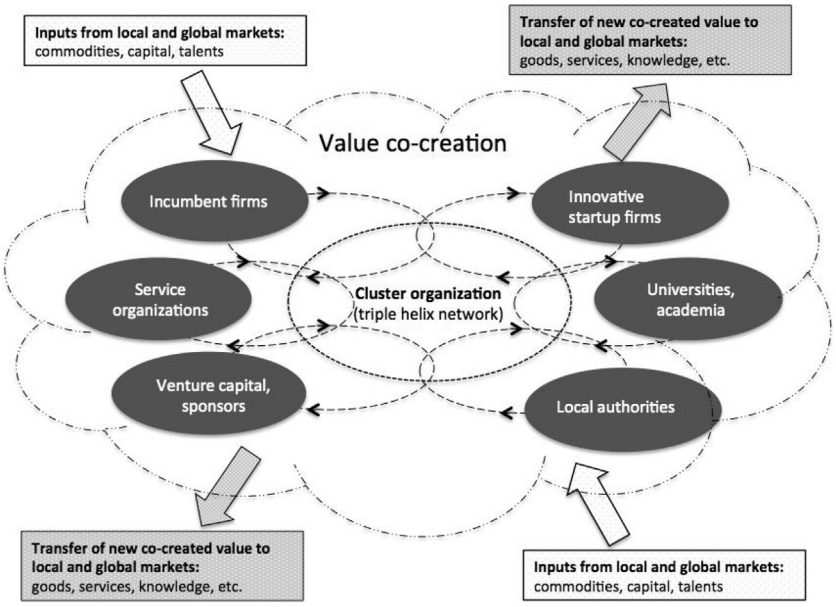

Fig. 3. The complexity of an ecosystem in a regional innovation cluster.
Source: authors' design, based on: (Napier and Kethelz, 2014).

involving other agents within and outside the cluster to form more complex helices.

Second, development of a cluster under *the discipline of a common project* (*cluster initiative*), launched jointly by two or more triple helix actors (Sölvell et al., 2003). Cluster initiatives are network projects realized through collaboration of cluster participants. Collaboration is ultimately oriented toward implementation of joint business projects integrated into global or other transborder value chains (Smorodinskaya et al., 2017), but the success of these projects and the very competitiveness of a cluster directly depend on the intentional development of collaborative interactions as such (Lindqvist et al., 2013).

Third, formation of *a membership-based cluster organization* that guides the cluster initiative, aiming to strengthen the cluster's overall innovativeness. Such organization takes the form of a specialized internal network within the cluster ecosystem, which incorporates the majority of cluster actors via *formal membership*. The membership implies certain commitment plus fees plus *relational contracts*, i.e. specified-term agreements on shared rules, shared objectives, and directions of mutual activity (Bathelt and Glückler, 2011). The cluster organization lends an institutional structure and a communication platform to the cluster, as well as creates special intermediaries (*institutions for collaboration*) that care for the continual face-to-face coordination of plans, interests and complementary activities, aiming to sustain the intensity of triple-helix collaboration, the above-mentioned dynamic balances, and a critical level of mutual understanding and trust within the ecosystem.

Finally, *a regime of collaborative governance* built by the cluster organization for orchestrating and developing the cluster. This regime makes an alternative to traditional patterns of governance, introducing a collective decision-making, in which investment priorities, lines of business activity and conventions are defined through *interactive consensus-building* among functionally interdependent (and hence, commercially interested) network actors (Ansell and Gash, 2007). As follows from CAS' features and argued by Porter (Porter, 1990), *the stronger are interactive linkages and feedbacks within a network, the greater are benefits to participants from the commonly produced value*. Therefore, coordinating efforts of the cluster organization are focused both on enhancing the social integrity of cluster actors (building trust and facilitating collaboration) and on successful realization of their common business projects (Smorodinskaya, 2015). This cultivates a new, leadership style of heterarchical coordination, based on relational contracts and peer-to-peer collaborative interactions, in which common development strategies (for advancing the overarching cluster initiative) and current economic decisions are shaped jointly and interactively, by means of negotiations and reconciliations among all stakeholders (OECD, 2001). Typically, two institutions for collaboration (a cluster governance team and a cluster management group) concentrate their activities on continually removing inner and outer gaps in communication, aiming to bridge cluster actors for a smooth co-creation of innovations and bringing them to market (PwC, 2011; Sölvell, 2015).

Properties of CAS help to highlight *the most general collaborative mechanism of self-supportive growth*. The basic capacity of clusters for continual co-production of new goods and values is fostered through synergies derived from creative and complementary reshuffling (agile combining and recombining) of shared assets, both tangible and intangible, in numerous novel configurations (Sölvell, 2009). This capacity is simultaneously supported by the complexity of a cluster ecosystem, the presence of a highly cooperative, and a highly competitive business milieu that nurtures the generation, survival and deployment of novel assets through those re-combinations (Padgett and Powell, 2013). As a result, well-developed clusters enjoying the complexity of triple helix partnerships can critically enhance productivity, decrease uncertainty, and flexibly start new venture business projects to meet the rapidly changing market demands (Delgado et al., 2010; Jackson, 2008; Ketels, 2012).

4.4. The complex ecosystem-based industrial landscape

Complexity economics helps to coin a new *ecosystemic vision of organizational design of economies*, implying that new goods and values are increasingly created in collaborative ways, through formation of network-based ecosystems that display properties of CAS. As mentioned above, this vision is gaining support in various streams of studies, and particularly, in economic sociology (f.e., Smith-Doerr and Powell, 2005; Padgett and Powell, 2013).

An ecosystem perspective suggests a holistic view of regional or national innovation systems, and hence, of economy-wide production systems, highlighting not just the functional roles of their constituent entities but also the pattern and dynamics of interactions among them (Bramwell et al., 2012). In the term “ecosystem”, the prefix ‘eco’ (in relation to ‘system’) emphasizes the non-linear nature of innovation and the key role of collaboration in generating it (Townsend et al., 2009). In a non-linear environment, development is based on fractal-type

recursions, in which new collaborative networks reproduce basic properties of CAS at any scale, thus progressively increasing the organizational complexity of modern economies. As a result, economies of all levels, from local to global, are gradually assuming the design of open, highly interconnected, self-organizing, emergent and adaptive systems (Martin and Sunley, 2007; OECD, 2009).

In other words, the industrial landscape of knowledge-based economies is emerging as a manifold variety of innovation-inducing ecosystems (network-based organizations, agglomerations, communities, areas, etc.). The milieus of these ecosystems, initially emerging at the level of localities, can further grow in size and complexity through non-linear integration with other ecosystems. Successful innovation ecosystems can generate new networks around themselves and develop collaboration with each other, thus leading to the appearance of more complex and robust innovation ecosystems, embracing clusters of clusters and networks of networks. In some essays, this complex *ecosystemic landscape* is compared with "a multilevel, multi-modal, multi-nodal, and multi-agent system of systems" (MacGregor and Carleton, 2012).

A recent OECD report argues (OECD, 2015a) that during the nearest decades the world economy will progressively increase its internal inter-connectedness and complexity. Already today it should be seen as *a complex non-linear system*, in which micro-level interactions are generating macro-level transformations not equivalent to simple aggregate results of those interactions. Meanwhile, studies describing the new complex world of the twenty first century posit that *the majority of global-level transformations will emerge endogenously*, *while national economies will have to operate in a continually changing, multi-equilibrium environment* (Silim, 2012). These findings give grounds to believe that over time, rather in the long-term prospect, the global economy, as well as its national, sub-regional or macro-regional components will become *an agile and self-structuralizing mixture of inter-connected and overlapping collaborative partnerships* - some local, some global - in which networks are generating new clusters and inter-cluster linkages of various spontaneous configurations, and vice versa on a continual basis - toward mutual economic, and hopefully societal, advantage.

This heterarchical, cohesive yet super-volatile and super-competitive organizational complexity makes a crucial departure from the 'hierarchy-market' dichotomy of industrial era.

5. Ecosystem versus system approach to economic development

5.1. Comparing traditional and complexity economic thinking

The transformation of economic systems into network-based ecosystems provides the organizational basis for their transition to innovation-driven model of growth. This transformation is expected to leverage the total productivity in economies through innovation synergy effects, thus enabling companies and territories to generate a higher additional income (value added) than they could obtain under a traditional, less complex design. Meanwhile, the self-organization capacities of ecosystems do not render intentional interventions redundant (Elsner, 2015). Market forces themselves cannot automatically provide the needed pace of emanation of the new industrial landscape, even in the most liberalized economies. Rather, economies of all types, and especially emerging market economies, need active intentional efforts and program-based support directed toward enabling and facilitating the ecosystemic transformation.

A comparison of ecosystems to systems approaches focuses on the complexity economics dealing with non-linear realities of the twenty first century versus *traditional conceptual models of the past, which dealt with linear development*. The ecosystem approach alters a more simplistic, mostly mechanistic perception of economic systems, putting forward a set of new principles in economic thinking and economic policy making, relevant for non-linear development (Table 1).

Modern economies and production systems of all levels are seen as *network-based ecosystems intending innovation*. They are *open non-linear spaces* (*milieus*) that are undergoing persistent transformations, and hence, far from static equilibrium. Instead, they search for a dynamic equilibrium, relying on their ability to proactively respond to changing environment, and to modify their behaviours as experience accumulates (Holland, 2002). If in linear economies agents interact indirectly through market price mechanisms, in non-linear economies agents continually learn from each other and adapt, communicating interactively (on the basis of reciprocal actions and feedbacks) within constantly changing networks. Networked agents, their interactions, and feedback linkages within-between networks are the source of the constant novelty that imbues the non-linear economy with its evolutionary momentum (Beinhocker, 2012; Bramwell et al., 2012).

In traditional systems, macro-level patterns are formed by a linear summation of individual decisions of homogenous agents. Unlike that, *ecosystems are holistic*: their micro- and macroeconomic spheres are closely interrelated, composing non-separable parts of economy made up of networked and interactively communicating agents. This implies *self-development* of economies, in which the emerging pattern of growth at the macro-level is induced and self-supported endogenously, through dynamic network interactions of heterogeneous agents at the micro-level.

Traditional systems are based on rigid hierarchic governance, or top-down decision-making by central bodies. Unlike that, agile collaborative networks and their ecosystems enjoy the advantage of *self-organization and self-regulation*, referred to as resiliency (Crespo et al., 2014), an adaptive nature typical for CAS. This implies that the more the modern economies will advance in their transition to the ecosystem organizational design, the more they will move from hierarchic to collaborative governance, and hence, increase their *self-adaptability to rapid changes*. One can imagine that heterarchical models of social coordination, based on horizontal consensus-building, will gradually evolve across the world, making up a creative functional alternative both to market coordination and to the system of administrative orders. The powerful global competition for the speed in innovation, which has replaced the traditional model of competition for resources in various local markets, will serve to spur on agents to unite themselves in networks and develop collaboration.

Traditional economies rely on linear processes of knowledge flow from science to industry, often identified in literature as 'mode 1' in knowledge creation (Gibbons et al., 1994), and usually driven by 'technology push' or 'demand pull' on the part of individual firms (Godin, 2006). Linear models perceive innovation as an exogenous force, independent from a system's social and structural transformations. On the contrary, in modern complex economies, *innovation is perceived as endogenous capacity of a system*, *resulting from the agility of networks - their facility for persistent structural reconstructions*. As noted earlier in this paper, ecosystems can obtain new sources for growth and achieve dynamic sustainability through internal, self-correcting structural changes - rather than through top-down intervention of any centralized bodies, or from an external intervention, as typical for traditional systems. No surprise that developed economies and a growing number of developing economies are promoting a non-linear model of knowledge creation ('mode 2'), driven by interactive communication of various networked agents across institutional and geographical borders (Gibbons et al., 1994). And since the turn of the century, the most advanced countries are cultivating an even more complex innovation, seen as a continual, or systemic process ('mode 3'), which results from and simultaneously predefines further proliferation of ecosystems, or an increasing organizational complexity of the economy (Carayannis and Campbell, 2009; OECD, 2015b).

Overall, complexity thinking orients modern innovation and economic growth policies to *enhancing collaboration within and among existing and emerging ecosystems across local to global scales*, thus leading economies to more robust development in the global multi-equilibrium environment. Proliferation of networks and their ecosystems shapes the

Table 1
Ecosystem vs system approach to innovation and economic growth.

	System approach (traditional thinking)	Ecosystem approach (complexity thinking)
Economic dynamics	Linear systems - closed, static, in equilibrium	Non-linear systems - open, dynamic, dissipative
Emergence and synergy	Macro-level growth patterns are formed by linear summation of individual decisions of homogenous agents, with few synergies occurring spontaneously	Macro-level growth patterns emerge nonlinearly, out of synergies generated by dynamic network interactions of various heterogeneous agents at micro-level
Network interactions	Network relationships are inessential, agents interact indirectly through market price mechanisms	Network relationships are essential, economic systems of all levels (from local to global) are seen as network-based ecosystems meant for innovation
Predominant model of economic governance and adaptation	Hierarchic model: a rigid, centralized organization governed by administrator through top-down decisions. The economy lacks feedback linkages for self-adjustment to changing environment and, hence, has low capacity for adaptation	Heterarchical model: a dispersed agile network with spontaneous self-organization, self-regulated through horizontal coordination of network nodes and collaborative consensus-building. The economy gets self-adaptable through interactive communication of agents, their feedbacks, their learning and proactive reciprocity
Interpretation of innovation	Limited endogenous capacity of economic system, dependent on a complex of its available resources. Requires external incentives or exogenous sources, not connected with a system's social and structural transformations. Implies linear process of knowledge flow, from science to industry ('mode 1' in knowledge creation)	Sustainable endogenous capacity of economic system, based on internal incentives and new sources, arising from a system's ability for continual self-correcting structural changes. Implies non-linear process of knowledge flow ('mode 2'), relying on interactive communication of various agents, as well as continual, systemic process ('mode 3'), arising from proliferation of collaborative networks and their ecosystems
Model of producing innovations (goods, values, technologies)	Linear models of innovation ('technology push' and 'demand pull'), driven by technological developments of individual firms	Interactive model: co-creation of innovations by networked agents through their collaboration within a generated ecosystem of linkages and assets
Interpretation of innovation systems (regional, national, macro-regional)	Non-cohesive organizational structures that depend on involving a certain critical mass of agents, talents and new infrastructure	Holistic social communities, or ecosystems, with properties of complex adaptive systems, depending on a certain critical mass of interactive inter-linkages among networked agents
Institutional and business environment for innovation	Creation of new institutions, technologies and industries is higher priority than enhancement of cohesive context for a smooth dissemination of innovations across sectors and regions	Priority is given to continual improvements in environment, with the purpose to eliminate barriers and provide incentives for more business networks, more collaboration, more cohesion, and continual knowledge spillovers across and around the economy
Focus of strategies for innovation and growth	To develop R&D and national innovation system by supporting its agents and infrastructure elements, with no focus on collaboration and its innovation synergy effects	To promote localized ecosystems across the economy and enhance their innovation synergy effects by facilitating the dynamics of interactions and collaboration within-between networks

Source: authors' elaboration based on: Beinhocker (2012); Bramwell et al. (2012); Holland (2002); Martin and Sunley (2007); Townsend et al. (2009).

modern mode of production, motivating economies to become both more cohesive to meet the challenges of high uncertainty, and simultaneously, more innovative, to enhance their global competitiveness and self-sustainability.

5.2. Implementation of ecosystem approach

Efforts for developing the ecosystem landscape ultimately aim at providing an intensive diffusion of newly emerging technologies and innovations across sectors and regions. Schot and Steinmueller (2016) argue that in developed countries innovation policies are now less frequently concentrated on program support in the way of inputs into R &D, as took place in 1960–1980s, when the research sector was seen as a single birthplace of ideas for innovation. Moreover, such policies are also progressively less focused on building national innovation systems, as was typical for 1980–1990s and for early 2000s, when non-linear innovation was gaining momentum. Instead, since 2010s, governments increasingly have concentrated their efforts on facilitating the formation of numerous localized ecosystems to realize the so called *system innovation policy approach aimed at providing a continual transformative change in the economy and society* (Schot and Steinmueller, 2016). Plainly speaking, to tackle modern development problems that are mostly systemic in nature, countries are expected to involve manifold domestic and global actors in mutual collaborative activities, or just in ecosystemic format of producing innovations.

In contrast to linear innovation, interactive ecosystemic innovation is compatible with a holistic view of knowledge-based economies, embracing both industrial and social spheres. It expects economies to persistently upgrade their socio-technological structures as means for generating endogenous sources for further growth, and to extend their collaborative linkages further, integrating domestic businesses through new partnerships into new or progressively larger ecosystems formed by transnational and global networks (OECD, 2015a). For example, local cluster ecosystems can serve as multi-faceted tools for upgrading industrial structures of national economies, while collaboration between clusters from different geographical locations leads to the evolvement of global value chains and global production networks that can shape more powerful ecosystems for continual innovation. In effect, the regime of ecosystemic innovation attempts a collaborative institutional environment that goes beyond geography to enable *unhindered, intensive and even unintended knowledge spillovers across an economy and around the world.*

In non-linear economies, which are far from equilibrium, the traditional practice of achieving sustainability by means of monetary and fiscal macro-stimulators becomes increasingly less effective, giving way to *ecosystem-oriented policies focused on organizational incentives for raising productivity*. Such policies look for enhancing innovation synergies generated by collaboration within and between clusters (Ketels and Memedovic, 2008; Warwick and Nolan, 2014; WEF, 2013). They aim to accelerate regional clustering by means of institutional improvements and to achieve a certain critical mass of triple-helix partnerships. The global front-runners in imbedding this approach into economic growth strategies are Nordic nations, who have been prioritizing institutional growth stimulators for more than two decades to further develop an ecosystem landscape across all sectors and build robust and technologically advanced economic models (BCG, 2014; BDF, 2011, 2014; Smorodinskaya, 2015).

The ongoing organizational transformation of economies is accompanied by a deconstruction of hierarchies both at micro- and macro-levels of social activity. In a growing number of countries private firms and public bodies are meeting the challenge of restructuring, transforming themselves from vertically built entities into more flexible and horizontally oriented (Smith-Doerr and Powell, 2005; Sölvell, 2012). In many cases, governments of both developed and developing nations (in

Europe, East Asia, elsewhere) have yet to launch country-wide structural reforms to adjust the domestic institutional context to the global-wide emanation of ecosystemic environment. Many are still path-dependent on excessive hierarchic linkages. This especially concerns emerging markets, as well as some developed countries (like Japan or Korea), whose markets have been much less liberalized than, say, in USA or Canada (Hill et al., 2012). The context-improving policies are usually accompanied by cluster-supportive programs and other measures for encouraging university-industry partnerships across localities and sectors (Christensen et al., 2011; Ketels, 2015; Smorodinskaya and Katukov, 2016).

At the global level, the evolution of the ecosystemic industrial landscape assumes many complex forms, from the overwhelming proliferation of global value chains (Smorodinskaya et al., 2017) to the appearance of so called 'functional regions', shaped through collaboration of networked partners over and beyond administrative boundaries of localities or countries. In addition to Silicon Valley (as an early functional region that has been widely published), various similar ecosystems on a variety of scales now appear in North America, Europe, Asia, worldwide. For example, Denmark and Sweden have commonly created a highly innovative Øresund region, organized as a complex ecosystem of duplicate triple-helix linkages among neighboring partners from both countries (Karlsson et al., 2010). The whole Baltic Sea Region is now developing as an integrated macro-region by means of transnational collaboration of triple helix actors from 10 administrative coastal territories (countries and regions), which are engaged in various joint cluster projects launched under the EU Strategy for the Baltic Sea Region (BSR Stars, 2013; European Commission, 2012). Moreover, since 2010s, upon taking the experience of the Baltic Sea Region as a blue print, the EU is progressively transforming its classical model of European integration into a much more flexible and innovation-oriented model, aimed at formation in Europe of several macro-regional ecosystems through trans-border collaboration (European Parliament, 2015; Interact Programme, 2017)[5]. Recognizing the trans-border nature of innovation ecosystems, the EU also builds new infrastructures across Europe, such as EIT Digital (Still et al., 2014).

The policy approach to enable economy-wide innovation ecosystems has become more complex. Today, such ecosystems are seen not as rigid structures, focused on involvement of a certain critical mass of innovative actors and infrastructure, but rather as holistic and agile social communities able to flexibly reconfigure their structure and assets under new innovation projects. Traditional thinking deals with the development of industries and institutes as such (which at present is typical for emerging market economies), while complexity thinking focuses on building a more agile yet cohesive institutional and business environment (which is expected from all modern economies, both developed and developing). As stems from cluster literature (Ketels, 2012; Porter, 2003; Sölvell, 2009) and from the Global competitiveness index of the World Economic Forum (Porter et al., 2008), countries and regions now need *continual improvement of the micro-level business environment* to eliminate emerging barriers that prevent the economy from becoming ever more collaborative and horizontally inter-connected. This policy approach encourages the agile origination of new inter-firm networks, new university-industry partnerships, innovation clusters, and further inter-cluster linkages forming trans-border value chains. The crucial aim, also clearly pronounced in the new industrial policy gaining momentum since 2010s (Warwick, 2013), is to obtain and sustain through facilitation of domestic organizational complexity the needed level of innovativeness, enabling national economies *to achieve a continual rise in total productivity and thus to meet crucial challenges of both the global competition and the high uncertainty*.

[5] Within the EU context, the term 'macro-region' means an area comprised of a number of adjacent countries or territories that share one or more common features or challenges. European Commission (2009).

6. Conclusion

6.1. Main findings

Innovation ecosystems are not built like traditional systems in a top-down way; rather they emanate spontaneously from *deliberate collaborative activities of agents, based on their market-confirmed motivations*. In particular, the design of innovation clusters is evolved through a combination of market forces, organizational efforts of triple helix actors, and value transactions. More exactly, innovation ecosystems constitute *special organizational spaces, or a sophisticated milieu of actors, assets and linkages*, generated by collaborative activities within and among networks. Collaborative networks of various forms, sizes and profiles can play the role of modern-type organizations meant for a collective decision-making and collective action, while innovation ecosystems can be viewed as *functionally inseparable organizational continua of such networks*, relevant for interactive innovation and dispersed patterns of production.

The literature on complexity highlights the interconnectedness of economic activities across the world, suggesting that the global economy should be seen not as a system of interlinked economic units focused on national states but rather *as a complex space, comprised of networks of networks* (Dicken, 2015). This growing complexity of economic space must be taken as a fundamental global trend, driven by ICT-transformation and proliferation of digital technologies.

Proliferation of networks and their ecosystems, in step with digital technologies, accelerates the globally emerging *network order* that manifests horizontal, peer-to-peer linkages among different agents (MacGregor and Carleton, 2012; Slaughter, 2004; Smorodinskaya and Katukov, 2015). Networks are incomparably more agile structures than traditional hierarchies, and simultaneously, more integrated structures than traditional markets, thus making a functional hybrid out of both (Powell and Grodal, 2005; Thompson, 2003). According to Oliver Williamson, the network order rests upon the driving forces of social communications and interpersonal arrangements, which significantly enlarges the speed and variety of economic exchanges (Williamson, 1993). As a result, this new order opens crucially wider opportunities for developing economies and societies as compared both with the market order, which rests on impersonal exchanges and atomistic transactions, and with hierarchic order that personalizes transactions but demands its own model of governance for each transaction (Williamson, 2005). In other words, *economic growth is now connected with formation of a new order based on the ability of individuals and firms to unite themselves in networks and to effectively use information and knowledge in the course of communication* (Hidalgo, 2015).

To better understand these new opportunities for innovation and growth, we clarified differences between agile heterarchical ecosystems and rigid hierarchic systems through the lens of complexity science. This lens helped us introduce additional arguments in favor of applying the ecosystem approach to modern economic development as compared to the system approach, as well as to better explain validity of the term 'ecosystems' versus 'systems' - the issue remaining a point of discussion among scholars (Oh et al., 2016). We showed evident similarities between the holistic and dynamic nature of innovation ecosystems, on the one hand, and complex adaptive systems (CAS), on the other. Evolving and developing as a persistent organizational continuum of collaborative networks, or just as their functionally inseparable environment, innovation ecosystems display such typical properties of CAS as emergence, synergy, self-organization, self-governance, and self-adaptation to a changing context. These properties *interconnect the innovation-driven model of growth, based on interactive and continual co-creation of new values, with the world of non-linearity that generates persistent and highly uncertain changes*. One can imagine the cohesive ecosystem design of knowledge-based economies, as well as endogenous sources of their innovation dynamics, evolving as an aggregate result of collaboration within and among networks.

Managerial, sociological and economic underpinnings of innovation ecosystems, covered by our literature review, articulated from various angles *the key role of collaboration in generating new ideas and bringing them to market*. Particularly, studies on innovation policy and competitiveness agenda have made an indicative terminological drift from "innovation systems" to "innovation ecosystems", acknowledging that the promotion of collaborative partnerships across the economy matters more for achieving sustainable growth than the support of innovative agents as such. We reinforced this argument by considering the very process of collaboration as the result of growing complexity in interaction patterns among networked agents (Fig. 1).

Upon assuming that networks with more sophisticated patterns of interactions can generate more powerful incentives and capabilities for innovation, we identified the functional place of innovation ecosystems in the world of business networks, as well as the place of innovation clusters among other innovation ecosystems (Fig. 2). *The ecosystem approach to innovation manifests an entirely new mode of production, typical for the age of non-linearity*: new goods and values are now co-created at the level of collaborative innovation networks, through interactive relationships of and synergies derived from creative reshuffling (agile assembling and reassembling) of agents' shared assets, both tangible and intangible, in a complementary way and in various novel configurations. Properties of CAS reveal this collaborative pattern of producing innovations, highlighting a holistic integrity, reciprocity and unique functional interdependencies among stakeholders within an ecosystem. A continual co-production of new values shapes the innovation-driven mechanism of self-supportive growth. Importantly, innovation ecosystems constitute a clear departure not just from linear models of innovation but also from the model of open innovation (Chesbrough, 2003; von Hippel, 2005): the latter doesn't imply multilateral coordination of inter-firm activities under a shared project, shared goals, shared commitments, and shared identity, as takes place in collaborative innovation networks.

The key argument of cluster literature says that well-organized clusters can co-create innovations on a continual basis. We illustrated this argument by describing ecosystems of innovation clusters in the context of complexity theory, and their aggregate synergy effects, in the context of triple-helix concept. Though collaboration in innovation clusters is ultimately oriented toward the implementation of joint business projects, *the success of these projects directly depends on the enhancement of collaborative activities as such*. The development of collaboration in clusters, and hence, their competitiveness in the globalized world economy, benefits from effective intermediating efforts of a specialized cluster organization and the discipline of a common cluster initiative. Under the pressures of open global competition, regional innovation clusters are seeking to develop their unique, smart specializations in ways that enable them to become geographically localized network nodes of global value chains (in which new final products are now ultimately assembled and delivered to end users as consumers). By describing a cluster ecosystem (Fig. 3) and its institutional features, we demonstrated *the level of organizational complexity to which modern economies aspire* in order to generate aggregate externalities that can provide innovativeness, harmonization, and self-sustainable growth.

There exists a distinct connection between harmonization of non-linear systems and *collaborative models of governance*, which are now gradually replacing the traditional hierarchic model. In forward-looking innovation clusters, collaborative governance relies on regular face-to face communication between stakeholders, their relational contracts, high mutual trust and exclusively collective decision-making, not depending on individual powers of any major cluster participant. Following the cluster literature findings discussed above, we believe that in the coming decades regions and countries will increasingly use the advantages of localized cluster ecosystems for further embedding collaborative model of governance at the region-wide level, among regions, and further extending this model of horizontal consensus-building nationally and internationally, thus getting closer and closer to *inclusive economic policy-making*, both within countries and across the world. Further proliferation of digital technologies will additionally motivate this direction, increasing interdependence in business relationships – both locally and globally, and enhancing the emergence of ecosystems based on self-organization and peer-to-peer relationships.

We have argued that the ecosystem-based industrial landscape of any economy, from local to global, evolves in a fractal-type way, through increasing organizational complexity. A region-wide innovation ecosystem arises from interactions and feedbacks among many localized collaborative networks. Similarly, a nation-wide innovation ecosystem is the result of a larger complexity of cross-linkages, and so on, that expand through inter-cluster collaboration and transborder networks across localities to encompass new institutional as well as social and geographical connections. However, regardless of the level of an economy, be it a local community (such as Silicon Valley in California or the Basque country in Catalonia) or a transnational macro-region (like European macro-regions now shaped under the corresponding EU strategies), large-scale *innovation-led growth will rely on the same collaborative synergy effects that can be observed in a localized innovation cluster*.

Table 1 in part 5 generalizes our investigation of ecosystems at the level of new economic thinking. It compares linear and non-linear approaches to the organizational design of economies, and hence, to policies on innovation and growth. The linear, or *system approach* reflects a traditional, mostly mechanistic perception of economies as static and closed systems. The non-linear, or *ecosystem approach* perceives economies as open, dynamic and complex adaptive systems undergoing continual transformations. The contrast of ecosystems versus systems is ultimately about the complex non-linearity of the twenty first century versus the more simplistic views of the past.

6.2. Practical implications

In many countries, further innovative and technology-based development is now running into hierarchic barriers built by institutional and political regimes of the past. This is a common challenge for all types of economies, especially for less developed ones. Countries are facing not just a classical market or state failure but rather a systemic failure, concerned with insufficient horizontal interconnectedness of economies to provide smooth knowledge spillovers. To meet this challenge, they need to *cultivate more complex, ecosystem thinking among decision makers of all levels*, both in the field of domestic and foreign policies, in organizations dedicated to knowledge creation and dissemination, and in established enterprises as well as in startups. Government bodies, enterprise managers and program directors, all will benefit from adjusting their strategies and practices to the new thinking.

In particular, to support the self-transformation of economies from systems to ecosystems, governments at all levels are now called to nurture a political, economic and institutional environment that enables a smooth process of a continual emergence of new innovative firms, collaborative networks, triple helix partnerships, transborder value chains, and other ecosystems. The enhancement of trust and collaboration between various market actors (among businesses, between business and academia, etc.), as well as within the existing networks, constitutes the primary objective of the new industrial policy of the 2010s (Warwick, 2013).

At this background, the heart of the agenda on increasing the organizational complexity of economies should be seen in *promotion of regional innovation clusters and other triple-helix partnerships* as key building blocks of knowledge-based economies. To provide a favorable context for the self-emergence and development of strong clusters, national and regional governments are advised to follow a set of widely recognized 'golden rules' in their cluster supportive policies (European Commission, 2016; Ketels, 2013; Smorodinskaya and Katukov, 2016). Cluster programs must adapt at the speed of change. Both the internal

business environment and the whole institutional context of the region require adjustments that are favorable for inter-firm competition and inter-firm collaboration alike (Porter, 1990).

At the level of major companies, the ecosystem thinking implies *a more intensive transformation of traditional hierarchies into agile and dispersed global networks* able to enter any local innovation cluster throughout the world (Sölvell, 2012). With a network-based design and networking strategies, businesses can reduce actual and opportunity costs to influence new technological standards (van de Kaa, 2017). According to Karakas (2009), in the world that increasingly celebrates creativity, connectivity, collaboration, convergence, and community, this new thinking provides *advantages also inside organizations*, calling managers to empower rather than manage employees. It is the expansion of ecosystem thinking that allows companies to tap into the formation of the global brain and bring best global talents together to form cross-disciplinary teams.

Noticeably, the ecosystem thinking puts t*he development of social capital and interpersonal relationships* at the forefront of public and business practices, which serves, inter alia, as facilitator for the global-wide flow of talent, information and financial resources (Russell et al., 2015). Noticeably, the relational perspective of *guanxi* (connections), which underlies Chinese culture, conceives all entities as coexisting within the context of one another, thus motivating individuals to express alternative views and innovation opportunities (Chen and Miller, 2011).

A special attention should be paid to *orchestration of clusters and other innovation ecosystems*. As complex projects based on collaboration of legally independent agents, ecosystems can't be managed in traditional ways typical for classical public or business managers. Rather they require orchestration and leadership, provided by special *project leaders*. Regarding this experience, the vision of modern economies as complex adaptive systems suggests the following practical approaches:

- *Increase the number of network nodes*, considering the basic network effect. Efforts in this direction are likely to have a positive impact on promoting interaction complexity (Autio and Thomas, 2013; Gloor, 2006);
- *Promote quantity and quality of feedback linkages*, since these parameters crucially determine the ability of an ecosystem for agile reconfigurations (Sölvell, 2009). Ecosystem orchestrators should refrain from creating an overprotective organizational milieu, but rather support a certain level of non-determinant behavior of agents, encouraging them to act in multiple independent ways (to find its own 'path') and thus to enhance their capacity for co-creation of innovation through serendipitous coupling of shared assets and competences;
- *Encourage autonomous relational contracts*. Innovation ecosystems rely on relational contracts of agents and require a collaborative (heterarchical) model of governance, which includes shared vision, dispersed patterns of coordination (Mitleton-Kelly, 1997), self-governance, and multiple independent paths (Martin and Sunley, 2007). All these practices suggest that relational contracts must be created autonomously and persistently revised - a way enabling a continual adaptation of the ecosystem to the complex, continually changing global business environment;
- *Facilitate faster and more directed removal of inner and outer communication gaps*, since such gaps are seen as key barriers to co-creation of innovations in the ecosystem (Sölvell, 2015);
- *Provide monitoring at the holistic level of the ecosystem*. While orchestrating the ecosystem, the leader should focus on its performance as a whole, considering overall knowledge flows and overall cluster goals, rather than measure its results at a granular implementation level;
- *Cultivate shared vision of interdependencies and collective resources*. According to Elinor Ostrom, leadership in innovation ecosystems implies, inter alia, the cultivation of a shared vision of collective resources (Ostrom, 1990). It also implies the leader's focus on functional interdependencies of agents, a continual vigilance to remove barriers impeding the emergence of new fractal-type re-combinations of agents and assets, and a balance of exploration and exploitation (Valkokari, 2015) in promoting growth.

In today's multi-sector environment, innovation leaders must *effectively cross institutional borders to establish partnerships for collaboration, as well as master the practice of collaborative governance and intra-organizational leadership*. In particular, cluster leadership requires a sense of mutuality and connectedness, as well as facilitation of skills and actions that help a diverse group of actors work together effectively. Specialized cluster organizations and management teams that aim to orchestrate and develop sustainable innovation ecosystems should direct their activities at accelerating mutual learning processes, inducing joint commitments and enhancing trust among partners (Russell et al., 2016; Sölvell and Williams, 2013).

6.3. Policy implications

The collaborative approach of producing innovations within ecosystems alters traditional policies for enhancing productivity and growth, thus having serious implications for effective policy-making.

First, public and private sectors have no longer separate purposes in terms of ensuring a sustainable economic growth. Instead, they have to build tools for interactive dialogue and to work jointly, both when elaborating development strategies and when implementing them. For example, such work for establishing nation-wide platforms for communication and networking has been launched in the US by Harvard Business School under M. Porter's initiative (Porter et al., 2013). Many other countries have also started to introduce similar platforms, seeing them as building blocks for developing regional and national innovation ecosystems.

Second, government programs prioritizing certain groups of businesses, industries or technologies, while quite sufficient in the industrial era, are no longer effective in the age of accelerating technological changes and the growing organizational complexity. In our times, *the improvement of institutional and business contexts, in which new technologies are produced and applied, matters more than targeting the improvement of rapidly changing technologies themselves*. Besides, in order to move the economy to the next technological trajectory, governments will be advantaged to not only focus on upgrading technologies for traditional sectors but also on developing new organizational formats for human interactions that can facilitate the institutional adjustments (Ivanova and Leydesdorff, 2015).

Indicatively, OECD's paper on the future of productivity (OECD, 2015c) calls countries to re-design their institutions. Pursuing this point further, we argue that to meet challenges of global competition, countries need active policies to *re-design their institutional and industrial landscape in an ecosystem-based way that acknowledges and leverages global interdependencies*. The better an ecosystem-wide landscape is developed, and the greater the number of new collaborative partnerships that may emerge, then the higher is the innovation capacity of that given economy and, hence, its capacity for sustainable growth under high uncertainty. On the contrary, countries that fail to connect their innovation and growth strategies with the elimination of hierarchic barriers and the promotion of collaborative partnerships face simplification of their industrial structure, and as a result, a growing vulnerability to the pressures of global competition (good examples can be found in a number of post-Soviet economies, including Russia and Belorussia).

Thirdly, *the very nature of government interventions is drastically changing*. In a non-linear and the increasingly 'flat' ecosystemic world, governments can no longer be either a supreme administrator or a 'night watchman'. Though collaborative forms of producing innovations are nucleated by market forces, the competitive advantage goes to

those countries and territories, in which government bodies of all levels are aligning new functional roles of *facilitators and intermediators of collaborative interactions*, both within and among ecosystems (Smorodinskaya, 2015). This implies intentional strategies and programs of various kinds. Noteworthy, even the US, with its highly advanced and liberalized markets, has recently introduced a 'soft' industrial policy which supports triple helixes in localities to help the emergence of 'production ecosystems' for developing advanced manufacturing (Locke and Wellhausen, 2013).

Additionally, the ecosystem approach demands *re-adjustment of the very procedure of strategic planning*. Under non-linearity, economies undergo continual transformative change both at micro- and macro-levels, which makes it no longer productive to forecast future development tendencies through traditional extrapolation of previous experience (Kidd, 2008). Policy-makers should instead consider high uncertainty and rely on principles from complexity science. Particularly, as recommended by OECD (2009), it is more reasonable to reveal trends and probabilities than to forecast events, to build dynamic relationships than fix rules or laws, to focus on policy impacts than concentrate on policy control, etc. Policymakers and forecasting analysts are advised to avoid too heavy reliance on traditional models in elaborating decisions. In many institutional-choice situations, even in the linear world, an informed decision often cannot be found between one alternative and the status quo, but rather among a series of proposed alternatives (Heckathorn and Maser, 1987). They are advised to carefully monitor changes in assumptions made during planning and be ready to implement an approach of late-binding decisions for issues involving substantial ambiguity or rapid change. These cautions are especially relevant regarding the increasingly complex and transformative world of networks: though some complex systems scientists (f.e., Holland, 2002) argue in favour of new modelling to anticipate the future, other scholars, also engaged in studying complexity (f.e., Martin & Sunley, 2007), warn that the model-generated economic landscapes may not be realistic in relation to those actually occurring.

6.4. Further study

Further study of collaborative networks and innovation ecosystems offers many opportunities for scholarly endeavours and for experimentation with practical applications. To facilitate this, the advancement of the ecosystem approach needs *more interdisciplinary research*.

Network interactions make the world more cohesive and interconnected, thus allowing it to adapt to the acceleration of technology development and the high volatility of globalized markets. The level of interconnectedness is rapidly increasing, with new and more legally independent actors self-initiating collaborations that persist over time, as well as new and more types of data generated and accessible. In the modern networked world, knowledge dissemination has become much more democratized (von Hippel, 2005), new experimental models of ecosystems for innovation and technology transfer are appearing worldwide (Butler and Gibson, 2011; Gibson and Rogers, 1994), and new connectivity approaches to learning are emerging (Dabbagh et al., 2016). The direct involvement of consumers in production of goods and services within clusters is further reshaping market economies, with their price coordination mechanisms, into a modern information economy largely relying on relational contracts (Hagel and Singer, 1999). *Collaborative social and business practices are, in many respects, outpacing the existing economic thinking*.

The global-wide transformation of traditional systems into network-based ecosystems needs further research at the intersections of sociology and economics with other studies (business network literature, institutional literature on networks, industrial organization literature, literature on innovation and growth, technology management, etc.). To address the inherent complexity in innovation ecosystems, economists, sociologists, policy analysts, management scholars, and technologists will be advantaged to increase *collaboration* for joint elaboration of conceptual categories, as well as theoretical and empirical approaches that can better describe emergent phenomena, parameters and patterns.

OECD believes the common policy challenge of affording national economies more resilience and robustness under high uncertainty requires a less mechanistic perception of world order, viewing the global economy and its national sections as complex adaptive systems (OECD, 2015b). This stance is associated with *deepening the ecosystem approach in several directions*.

To begin, future studies on science, technology and innovation (STI) and the knowledge-based economy must more explicitly recognize that innovation-driven growth and persistent social transformation are companions. Human actors in business networks also participate in social networks. A critical need exists to understand what constitutes the new economic community, the new civic culture, the nested relationships that inform effective systems for social knowledge management at the local and regional scale (Gertler and Wolfe, 2002). What makes multi-level self-governance effective? How will global models of learning, R&D, and collective intelligence influence forecasting and planning in this transformed world? How fast will they evolve? We need to learn more about *the interdependence between technological and social changes*, on how the growing complexity in technological systems generates complexity in societies and economies, and vice versa. Innovation ecosystems are finally about the social, organizational and cultural shifts that facilitate the formation of the knowledge-based economy.

Second, since multifold innovation ecosystems are becoming typical structural units of modern economies, we need to *develop additional criteria for their classification*. This especially concerns ecosystems for continual innovation: among them, innovation clusters are the most studied model so far, while various other triple-helix collaborative networks (as well as emerging helices with more pillars) await their researchers. We also need further studies of ecosystems as the transactional spaces for co-creation of innovative value under interactive collaboration and globally dispersed production - for both legally interdependent and legally dependent collaborations. Reconciling empirical instances of innovation ecosystems, innovation clusters and cluster initiatives with theories of institutional change may serve to enrich theoretical perspectives as well as illuminate strategies for ecosystem orchestration. Further theoretical thinking can help scholars identify new variables and elaborate new development models relevant for non-linear environments.

Third, scholars can enrich their perception of the emerging ecosystem-based landscape of modern economies by investigating them through the lens of the evolving complexity economics (Beinhocker, 2006), which embraces adjacent research streams that have connotations with holistic concepts, fractal recursion, interaction of direct and feedback linkages, metabolic pathways, synergy effects, mechanisms for network synchronization and quantization, compensatory structures, and the positive effect of negative interactions, etc. In particular, a promising way to explore collaborative models of governance in various types of innovation ecosystems, and particularly, in innovation clusters, follows from *the concept of 'commons'*, developed by neoinstitutional economists (Ostrom, 1990), with important contributions made by cluster literature (Sölvell and Williams, 2013).

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