How and why to study collaboration at the level of economic ecosystems

Marcelo Tedesco

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About the Author

Marcelo Tedesco is a Research Affiliate with MIT D-Lab, where he is researching social dynamics in economic ecosystems with the Local Innovation Group. He is the founder and Executive Director of Global Ecosystem Dynamics (GED), an international research initiative affiliated with MIT D-Lab, based in Guadalajara, Mexico. Previously, Marcelo led the MIT Enterprise Forum in Mexico, engaging more than 8,000 entrepreneurs, innovators and scientists through its programs. He holds a PhD in Social & Business Science and has also studied management, philosophy, and social anthropology.

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MIT D-Lab

Massachusetts Institute of Technology
MIT Building N-51, 3rd Floor
265 Massachusetts Avenue
Cambridge, MA 02139 d-lab.mit.edu

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Global Ecosystem Dynamics

Abstract

In the context of discussions regarding the relevance of innovation to the task of building new economic models that foster sustainable development, this paper focuses on clarifying and specifying the term “ecosystem”, which is typically used as a metaphor. Taking into account research concerning biological ecosystems, the article describes the components, structures and dynamics that biological ecosystems share in common with business, entrepreneurial, and innovation ecosystems, which together form one aspect of economic ecosystems as a whole. The paper utilizes primary data that were collected through a mixed methodology involving participatory workshops and an online survey instrument that involved members of innovation-oriented entrepreneurial ecosystems in eight cities throughout Europe and Latin America from June 2019 through February 2020.

Drawing on complex system theory as a unifying approach to describe and explain the components and structural conditions of any ecosystem, whether biological or economic, this paper proposes a theoretical approach and metrics that can be used to attain a better understanding of the social dynamics of ecosystems. Based on observations from the field of biology, it is proposed that such structural conditions tend toward equilibrium when they are constructed mainly through collaborative mechanisms. The results are shown graphically based on the data collected, utilizing metrics taken from complex network analysis and mathematical modeling from the perspective of complex system theory. This paper finds that the ecosystemic approach is more than a metaphor and can functionally describe how an ecosystem is structured and how it works by opening a wider path toward comprehending the dynamics underlying the interactions among components of economic ecosystems and their environment. The paper concludes by proposing that collaboration relationships among actors provide the required characteristics to increase balance and resilience in economic ecosystems.

1. Introduction

In the context of its application to business fields, the term *ecosystem* has been in use since Moore (1993) established the concept to indicate the parallelism between biological and enterprise dynamics. A decade later, Cohen (2006) used this term in the context of entrepreneurship for the first time. Within the last decade, research focused on innovation ecosystems has emerged from two bodies of literature: innovation systems (Hoffecker, 2019) and business science (Vasconcelos Gomes et al., 2018).

Both in the business field and in the application of public policy, the term "ecosystem" has been used by numerous models that have sought to explain its conceptualization, its components and the relationships among its elements as a means of proposing improvements to the general conditions of the social and economic context to which the members of these ecosystems belong (Feldman, 2014; Thompson et al., 2018 and Jolley & Pittaway, 2019).

From an academic point of view, for more than twenty years, theories, models, and approaches have been proposed to describe and understand how these specific ecosystems operate. A constant in the growing amount of available literature is the absence of agreement concerning the meaning of this term. From my perspective, this absence could limit the development of new theoretical and practical approaches in the fields of business and economics.

In the body of economic and business science literature, common phrases such as "ecological metaphor," "biological parallelism," and even "inspired by biology" (More, 1993; Iansiti & Levien, 2004; Moore, 2006; Isenberg, 2010; Isckia & Lescop, 2013) have been used to refer conceptually to business and/or entrepreneurial ecosystems, and their components have also been characterized in such a way. Although Ritala and Almpanopoulou (2017) produced an ironclad and effective defense of using the term "eco", the authors emphasized the use of this concept as an analogy from the field of biology.

In a recent study of the 104 most cited scientific articles and books, the term *ecosystem* is referred to as "adapted from" or "inspired by" the field of biology (Scaringella & Radziwon, 2017), supporting the claim that the concept is the result of Moore's poignant inspiration. The prefix "eco-" and the connected term "-system" have been a source of confusion due to their resemblance to concepts in ecology – the discipline from which this word was drawn (Willis, 1997). Furthermore, many terms used in biology were drawn from observation of human behavior in society (Van Beneden, 1875; Kropotkin, 1889), such as *competition* and *cooperation dynamics*.

In this paper, I will focus on explaining why business, entrepreneurial, and innovation ecosystems should not be considered to be metaphors drawn from biological sciences. Once the use of metaphor as a description of economic ecosystems has been discarded, I will suggest a series of perspectives, theoretical approaches, and techniques drawn from complexity science, biology and mathematics, among other fields, as a more purposeful approach to the study of economic ecosystems.

Finally, a series of results obtained from these theoretical approaches and techniques to be applied to the field of economic ecosystems will be presented from a novel perspective that takes into account the most relevant relationships of mechanisms in terms of their full complexity. An overview of the approaches and structures that I will present in this paper is included below.

Complex Systems Theory (CST)

In the last decade, complex systems theory has been developed and applied in diverse fields of study, such as biology, physics, astronomy, economy, and even sociology. In this paper, I will explain that in the context of studying the components of complex systems, the relationships among elements and measurable aspects will allow me to demonstrate that biological, social, and economic ecosystems share structural and functional features.

Economic Ecosystems

Given that economic ecosystems might be seen as a subset of an extended complex system, I will classify the components that are common to all ecosystems regardless of their origin and conclude by theorizing regarding the interrelation between these aspects. These previous statements will allow for broad discussion of the crucial point concerning the relationships created by ecosystemic structures. Additionally, I will specifically refer in this paper to a cooperation mechanism called *collaboration*.

Complex Network Analysis (CNA)

Once the fundamentals of the study of economic ecosystems are established, I will propose the use of complex network analysis as the main theoretical framework for the study of this type of ecosystem. This powerful tool allows us to create a mathematical observation of socially dynamic behavior and the relationships that are created among the economic ecosystem's actors. Simultaneously, I will propose a series of CNA metrics to focus on aspects that CST finds useful when analyzing economic ecosystems.

Practical Applications

Finally, I will illustrate a series of practical examples using data collected by the Global Ecosystem Dynamics initiative, which mainly pertained to the identification of collaborative relationships within diverse economic ecosystems in the context of eight cities in Latin America and Europe. These examples will be based on properties proposed by CST alongside a list of definitions that will allow me to develop a common lexicon for the study of dynamics of collaboration within economic ecosystems.

2. Data Sources

2.1 Sources for the Theoretical Approach

This research paper draws on the available literature and evidence found in the fields of evolutionary biology, evolutionary economy, general systems theory, and the subjacent complex systems theory. For the development of this paper, I have examined nineteen articles focusing on evolutionary biology and ecology, twenty-one articles rooted in the use of *ecosystem terminology* in business science, and twenty-five articles drawn from the most cited works in the complex network analysis and complex systems theory fields.

Such articles were selected via a comprehensive method, which consisted of an intensive literature search concerning these fields and scientific practice, as previously described. This search was carried out on specialized scientific websites (Research Gate, Academia and JSTOR), and articles that have been widely cited or that have been widely used as references were selected. In the case of the literature concerning evolutionary biology and ecology, I focused on articles related to the origin of ecosystems terminology, ecosystem structures and their relationships, and state-of-the-art research concerning how relationships in biology foster the evolution of species.

For literature concerning business sciences, I selected articles from the most cited works published during the last thirty years in the business, entrepreneurship, and innovation fields. Furthermore, I included an analysis of a fundamental study that comprehensively compiles one hundred and four publications in the business sciences field (Scaringella & Radziwon, 2017.

2.2 Sources for data analysis and practical examples

The dataset used to develop practical and useful examples to explain the potential benefits of my research proposal was drawn from a series of projects implemented by the Global Ecosystem Dynamics (GED) team. Specific data used for this article were obtained and compiled in Mexico City, Buenos Aires, Santiago de Chile, Madrid, Sao Paulo, Montevideo, Valencia, and Barcelona.

Although this article focuses on economic ecosystems (business, entrepreneurial, and innovation) from the perspective of complex system theory, in general terms, the data collected and used in this paper pertain to a subset of these cities' economic ecosystems, specifically their *innovation-oriented entrepreneurial ecosystems*. I will explain the concept of an economic subecosystem and its relationship to the entire economic ecosystem in detail.

Over the past three years, the Global Ecosystem Dynamics team has analyzed more than 5,200 collaborations among more than 2,500 actors in twelve different economic ecosystems in Latin America and Europe. We discarded collaborations that did not meet the definition of "actor" developed by GED in the context of the *innovation-oriented entrepreneurial economic ecosystem*, among other considerations. GED uses the term "actor" in this work to refer to all organizations or initiatives of an organization that exist to and for the benefit of the economic ecosystem to which the actor belongs (Tedesco et al., 2018).

The selection of participants in the aforementioned studies was carried out via a desk research technique. The objective of this selection was to identify the largest possible number of members corresponding to each economic ecosystem. The identification of these participants was carried out using search engines, websites, social networks, databases of governmental and nongovernmental organizations, local contacts, and other resources.

The actors participating in GED's studies were classified according to the TE-SER model (Tedesco & Serrano, 2019) to provide a layer of analysis that identifies the composition of an economic ecosystem based on the role that any given actor potentially plays in such an economic ecosystem as well as the value that such actors can offer.

All identified actors who met the previous classification were invited to a participatory workshop. These workshops were conducted over two four-hour sessions for two continuous days in the cities mentioned between June 2019 and February 2020. The implementation of the workshop was designed using a methodological approach that sought to apply the principles of lean research (Hoffecker et al., 2015; Krystalli et al., 2021). The number of participants in the workshops varied by city, with an average of 21.9% of all actors that were subsequently identified through the mapping process.

The four specific objectives of the workshops were as follows:

1. To obtain quantitative and qualitative data regarding the relationships among actors through an instrument designed for this purpose.
2. To obtain qualitative statistical data related to the results associated with collaboration among actors, irrespective of whether a successful outcome was obtained, the relevance (or lack thereof) of formal agreements, the speed with which each actor agreed, and other characteristics related to the social capital of each city.

3. To develop an approach to knowledge starting from the purpose of each ecosystem, which is one of the fundamental components of a complex system as described by Meadows (2008).
4. To share with participants the theoretical approach for the study of ecosystems, as well as useful lessons learned for the implementation of such ecosystems.

For this paper, I only consider the data gathered in accordance with the first objective from the preceding list[1]. These data arise from the responses of both workshop participants who completed the research instrument and other actors who were mentioned by such attendees and subsequently contacted by the GED team using the snowball method (Hanneman & Riddle, 2005).

The average number of actors who participated in the study of different ecosystems with respect to the number of nodes/actors identified by those attending the workshops was 15.8%, with a maximum of 24.2%. It should be mentioned that, contrary to traditional statistics, in the discipline of network analysis, there is no unequivocal notion of sample size (Kolaczyk & Krivitsky, 2015), and no approximations have been developed concerning the distribution samples of most descriptive statistics used in network analysis, as there are generally no viable ways of identifying populations and extracting samples using probabilistic methods (Hanneman & Riddle, 2005).

For data collection, we used quantitative-qualitative tools and focused exclusively on collaborative relationships among participating actors, since this work is exclusively based on these concepts and not on all relationships that potentially exist among actors. Subsequently, the database created via the information collected was normalized for its use in graphical and mathematical modeling software pertaining to complex network analysis. The technological platform used to process the data as well as the algorithms used are described in Tedesco and Serrano (2019).

The examples provided in this paper are included in the Practical Applications and Findings sections. However, the examples shown in the following sections were taken from data collected from five Latin American cities as well as from Madrid, Valencia, and Barcelona (Spain), where 1,791 actors were identified and 4,085 collaborations were also analyzed.

3. Perspectives on Collaboration Study at the Level of Economic Ecosystems

3.1 Complex Systems Theory (CST)

As mentioned in the Introduction, the term *ecosystem* has been used as a metaphor for economic and business activities. However, biological, social, and economic systems might be studied, analyzed, and described through the same approach of complex systems theory (Foster, 2004; Crawford et al., 2005; Meadows, 2008; Farmer, 2012; Earls, 2013; Thurner et al., 2018).

Meadows (2008) noted that any complex system – whether a football team, a biological system, or a country's economy – invariably consists of three components: the system's elements, the relationships among those elements, and the function or purpose of the system. She also explains that a system is more than the sum of its parts, since they all represent an adaptive or dynamic behavior as a whole.

Social systems are complex and adaptive (Marten, 2001). Moreover, since the beginning of general systems theory, sociocultural systems have been classified at the highest scale of a complex hierarchy (Boulding, 1956).

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[1] The rest of the results have been published in a series of practical workshop reports (Tedesco et al., 2020a)

There is a large body of literature concerning social and biological processes that are characterized as complex and adaptive systems and include all the components described in Meadows' work (2008). Nevertheless, as I will explain in the following pages, the field of ecology field makes a further subdivision of the elements comprising the complex system.

3.2 System and Ecosystem Beyond the Metaphor

The term *ecosystem* was initially used by Tansley (1935), although it was originally coined by the botanist Roy Clapham in the early 1930s in order to describe a set of physical and biological elements in the environment (Willis, 1997), as explained below. Biologist Eugene P. Odum eventually widened the concept and proposed the following:

> Any unit that includes all of the organisms (i.e.: the "community") in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity, and material cycles (i.e.: exchange of materials between living and nonliving parts) within the system is an ecosystem (Odum, 1971).

This exchange of materials or resources constitutes the trophic structure, that is, the transfer of nutrients, that can be found in social and economic ecosystems in the form of diverse resources that flow from the *nonliving* environment of the ecosystem to living elements. An exchange of materials flowing from living to nonliving elements can also occur.

According to the preceding definition by Odum (1971), it can be concluded that the difference between a complex system and an "eco-" system is not a biological origin but the interaction among living and nonliving elements within the system and the exchange of resources among the elements. While any complex system is composed as Meadows (2008) describes, any purely biological, social, and economic ecosystem is defined by at least five components:

- elements (whether biotic or not)
- environment
- resources
- relationships
- function/purpose

The interactions among the elements via the relationships formed in this context create a network through which all types of resources can flow; in this case, the relationship is created among living elements that use a shared infrastructure. This shared infrastructure is evident in both economic and biological ecosystems. These networks and the ways in which resources flow through them, either in terms of social or economic aspects, have been the subject of study for decades (Benson, 1975; Granovetter, 1983; Oerlemans et al., 1998; Lavie, 2008; Neumeyer, & Santos, 2018). Meanwhile, the study of networks in biological ecosystems is the latest approach to this field, and the similarities turn out to be overwhelming.

A research team recently published a complete map of how these networks of resource exchanges operate in forest ecosystems (Steidinger et al., 2019). For instance, a mycelium network is constructed by mushrooms and allows for the sharing of resources such as carbon or phosphorus to improve the use of nutrients coming from nonliving resources such as water or sunlight. Furthermore, some kinds of trees share carbon with smaller plants that do not receive sufficient sunlight (Simard, 2018).

In the same way that a purely biological ecosystem such as the forest shares its biological resources, such as carbon and phosphorus, among living beings, economic ecosystems share money, talent, and knowledge, among other resources inherent to the economic nature of the ecosystem.

In summary, an ecosystem is a complex system consisting of all the components described in the sciences of complexity: either biological, social, or economic components. However, the ecosystem perspective used is biology allows us to differentially describe the elements, whether biotic or not, resources, and environment, as well as the relationships among them. The nature of the shared infrastructure and/or resources does not justify the use of the term *metaphor* or *adaptation* to refer to the concept *ecosystem* in the economic aspect or to limit the use of this aspect for research purposes.

3.3 Economic, social, and global ecosystems

A biological ecosystem can be as small as a lagoon or as large as the ocean; to a greater extent, all these ecosystems are related through living and nonliving elements that interact in multiple ecosystems and subecosystems. Social ecosystems interact with each other in the same way as do biological ecosystems (Luhmann, 1995); therefore, economic ecosystems could also interact with each other by having the same relationship dynamics but with a different function. The level of impact of these subecosystems on other subecosystems and economic ecosystems, just as in the case of biological ecosystems, depends on the level of connection and influence that exists among them (Marten, 2001).

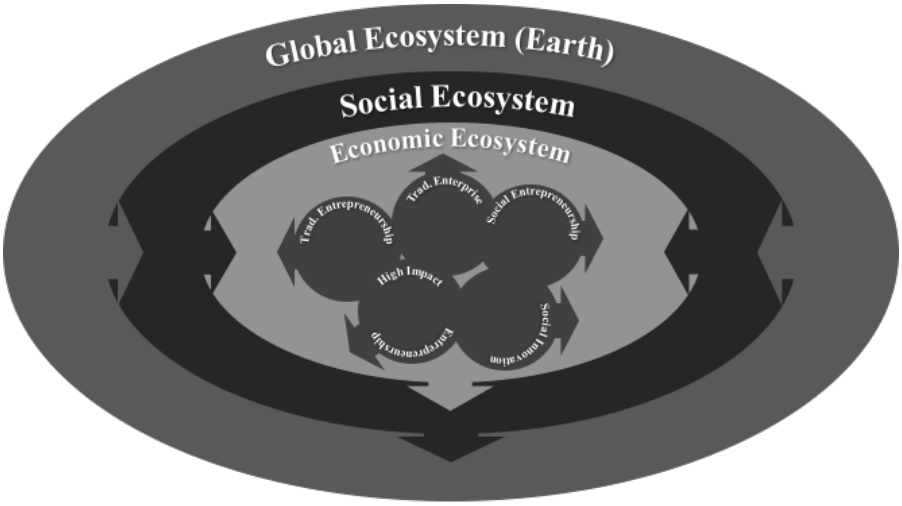

Figure 1 – Integration of Ecosystems Framework (Tedesco & Serrano, 2019).

Within the economic ecosystem, it is possible to observe diverse subecosystems that interact with one another. For example, diverse entrepreneurial ecosystems constituted by actors, entrepreneurs and innovators with multiple combinations could include those of the social-entrepreneur or innovation-oriented entrepreneurial or enterprise ecosystem, as Moore (1993) described.

The factors that determine which actor belongs to which ecosystem depend on the alignment that the actor has in terms of the ecosystem's function or purpose, which in turn, determines what the ecosystem produces. As occurs in every ecosystem, regardless of its origin, the interactions among subecosystems and ecosystems (economic, social, and global) are the result of certain elements and resources that flow among them.

Perhaps the most important reason to recognize this interrelation among ecosystems is that they all interact with each other and are affected either positively or negatively by external actions. Additionally, as previously mentioned, the dependence on the level of interaction and influence will finally have an impact on its results within a social and global ecosystem that hosts them. There is no way that economic and/or social activity does not affect, to a lesser or greater extent, the global ecosystem. All resources used for economic activity come from the Earth, and waste therefore ends up there (Georgescu-Roegen, 1971).

3.3.1 Components of an economic ecosystem

Various authors have suggested descriptions of the components found in an economic ecosystem, whether a business ecosystem (Moore, 1993), an entrepreneurial ecosystem (Reynolds et al., 2000; Koltai & Muspratt, 2016; Absher et al., 2018) or a local innovation ecosystem (Hoffecker, 2019). Each of these systems, to a lesser or greater extent, describes the different structures of an economic ecosystem. However, in my opinion, Hoffecker (2019) provides a better understanding of all the elements and their nature due to her theoretical and practical support.

Thus, the term "local innovation ecosystem", as described by Elizabeth Hoffecker (2019), refers to "place-based communities of interacting actors engaged in producing innovation and supporting processes of innovation, along with the infrastructure and enabling environment which allows them to create, adopt, and spread solutions to local challenges."

One of the author's most interesting contributions is the inclusion of natural resources as part of the innovation ecosystem, which has the same practical level of importance for entrepreneurial ecosystems and for the entire economic ecosystem. In other words, it is not possible to separate the impact of human activities from the global ecosystem.

Each of the components identified by Hoffecker (2019) exists and interacts in a complex way to yield results that can be either diverse, controlled, collateral, intentional, and even addressed to a specific purpose or a mere serendipity arising from the actual dynamics.

Therefore, the components described by the author are the following:

- Actors (classified in accordance with their functions and attributes) and elements (living) according to CST (Meadows, 2008).
- Resources (natural, human, financial, social, and geographical).
- Environmental or environment (market, culture and institutions, public policy, and regulations).

As pointed noted, actors engage with each other and, in turn, with the environment by exchanging and/or benefitting from resources. This exchange of resources creates an energetic exchange with an economic and social scope (Foerster, 1981; Bertalanffy, 1981; Foerster, 1991), thus supporting the development of the economic ecosystem as well as the trophic chain in the context of a biological ecosystem.

Therefore, based on previous analysis, I can define as an economic ecosystem a community of actors and individuals who interact with each other and with their environment in a delimited region, which is determined by its social and natural dynamics, in which resources are exchanged with the function and/or purpose of creating some kind of economic value.

The role that actors play and the value that they offer to the economic ecosystem and its differentiation according to classic triple or quadruple helix models (Etzkowitz & Leydesdorff, 1995 and Carayannis

& Campbell, 2009) have already been described in Tedesco and Serrano (2019), who partially establish the theoretical frame of this work.

3.3.2 Cooperation and collaboration in economic ecosystems

Bunge (2014) states that everything that has driven and continues to drive the development of this world is more a product of collaboration than of competition. Meanwhile, Moore (1993) explains that growth does not exist in a community without the coevolution of its members. Bunge (2014) states that *"cooperation overcomes personal limitations and what humanity knows, humanity knows collectively"* (p. 180).

It seems that when relationships are guided by a common need, both in lower and higher species, joint collaboration may arise naturally (Boucher, 1985; Serrano, 2020). In fact, the evidence provided by Nowak (2006) shows that in the most cooperative communities, competitive individuals begin to collaborate to avoid being abandoned by the same community's dynamics.

Following Meadows' work (2008), complex nonhuman systems have a function, while human systems have a purpose, as long as those humans are conscious. That is, complex human systems have a specific function, which emerges when a purpose is agreed upon. In this same sense, collaboration is not a mechanism operative in nonhuman biological interaction, since agreements and conventions are required for this collaboration to exist (Mattessich & Monsey, 1992).

Having said that, collaboration is a cooperative mechanism. Cooperation is divided into several types of relationships that range from simple networking, as in biology, to collaboration that involves joint planning and operation, depending on the degree of intervention and sustainability (Yoo, 2010).

In the previous arguments, I described the fundamental difference between cooperation and collaboration. The former is a trait of all organisms, superior and inferior[2], human and nonhuman. The latter can only exist when human beings agree on an conscious exercise in pursuit of a common purpose (Bunge, 1967, Rev. 1998).

3.3.3 Ecosystemic equilibrium

Ecosystemic equilibrium or balance, which is known as ecosystemic or ecological homeostasis in the context of biology, is the dynamic balance produced through relationships among natural communities and their environments. When this balance is broken, whether it is through predation (competition mechanism) or through abrupt changes in the environment, the ecosystem is altered and loses its homeostatic capacity. The greater the maturity of an ecosystem is, due to its robustness and resiliency, the greater the possibility for life to prosper (Lovelock & Margulis, 1974).

Conditions that help to maintain this dynamic balance are biodiversity and positive or beneficial relationships among individuals in the ecosystem, such as cooperation. The more numerous and better relationships of cooperation among a greater variety of individuals in the ecosystem, the more robust the capacity to respond to abrupt changes (Cleland, 2011; Dyke & Weaver, 2013).

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[2] In biology and ecology, the terms "superior and inferior species/animals" are no longer used and have been replaced by the word "niche" (MacKenzie et al., 1997 and Pocheville, 2015). Nevertheless, I will use the previous terminology since this terminology provides a more accurate description and is still widely used in social sciences outside the scope of natural sciences (Bimbenet, 2011 and Eriksen, 2015) and since it does not change the meaning of the terminology for the purposes of the hypothesis and conclusions of this work.

Predation, parasitism and competition are nonbeneficial interaction mechanisms that might severely unbalance a biological ecosystem when present to an excessive degree (Ernest & Brown, 2001; Thébault & Fontaine, 2013). In ecological terms, competition is a biological relationship in which all individual participants within the community are ultimately negatively affected (Wootton & Emmerson, 2005; Le Roux et al., 2020).

However, if cooperation mechanisms remain superior to competition and other negative interactions, the ecosystem tends toward balance, becomes stronger and increases its resilience capacity (Lovelock & Margulis, 1974; Dyke & Weaver, 2013; Zakharov & Trofimov, 2014).

Therefore, balance within the ecosystem is not usually a mere product of competition. Instead, it does not seem possible to achieve an ecosystemic equilibrium if competition predominates; rather, such an achievement can only occur through multiple relationships that are constructed among all living beings, primarily those of cooperation.

If trees cooperate with each other to survive and evolve (Simard, 2018), perhaps we as human beings are missing the opportunity to evolve by emphatically driving competition in the economy.

Consequently, given the importance of cooperative relationships in all biological ecosystems, which are more relevant than competition (Clutton-Brock, 2002; Nowak, 2006; Gardner et al., 2009; Milinski, 2011), in this work, I mainly focus on describing and explaining the collaborative relationships operative in economic ecosystems from a theoretical and practical perspective.

3.4 Complex Network Analysis (CNA) as a Means of Understanding Economic Ecosystems

The origin of the available literature concerning complex network analysis (CNA) dates back to the first half of the previous century (Moreno, 1934). Since that time, research and development in the field of CNA have grown exponentially. This growth has had a significant impact on many disciplines, especially in social and behavioral sciences, agriculture, political science, communication, and even law (Nunes & Abreu, 2020).

Complex network analysis techniques have been used to study all types of complex networks, whether biological, social, or economic. Regarding the latter point, one of the most cited cases is that discussed Granovetter (1973), who used CNA to understand how weak connections resulting from acquaintances who belong to other social groups, were more effective in producing labor mobility and exchange of different types of information than were strong connections with relatives or closer friends.

The recently awarded Nobel laureates in economic sciences, Duflo and Banerjee, used CNA in an investigation conducted alongside Breza, Chandrasekhar, Jackson, and Kinnan (2018) to analyze how the exposure of formal credit markets through microfinance affected the social structures of different towns in Karnataka and Hyderabad in India, resulting in a reduction of networks and a significant loss of relationships among inhabitants.

Considering diverse examples and the well-known literature concerning network analysis, Hidalgo (2010) highlighted the fact that the success and survival of organizations depend on their internal structure as much as on their business ecosystem and the position of such organizations therein.

Hidalgo and Hausmann (2009) have also extensively used CNA to study the “economic complexity” concept of using a country’s exports as an alternative means of understanding the concept of economic development. Additionally, those authors made notable advances in understanding the intersection between economic development and complexity science.

In contrast, Hausmann et al. (2014) focused on studying the complexity of an economy by analyzing the capacity to produce products and the position within a network that they called “the space of the product”. Unlike the work of these authors, this paper focuses on the study of collaboration relationships targeted to local economic ecosystems (cities) and the ecosystemic structure developed through these relationships.

In summary, CNA consists of an investigation process concerning relationship structures through the use of networks and graph theory. This process is characterized by featuring structured networks in terms of nodes - these nodes can be individuals, organizations, institutions, or other actors that constitute the networks - and links or edges, which represent the relationships or interactions that create connections. The networks themselves are composed of actors that are connected to one another through socially meaningful relationships. These relationships can be analyzed using structural patterns that arise among these actors. In this way, when CNA is used, the actors’ patterns and their relationships within the network become feasible to observe (Prell et al., 2009).

For years, therefore, network analysis techniques and the resulting maps have been used to understand interactions among individuals, specifically in terms of their economic behavior. That fact notwithstanding, little has been published with respect to the task of understanding collaboration as a source of development in economic ecosystems using these powerful tools. This task is the focus of the remainder of this paper.

3.5 Measuring collaborations within an economic ecosystem

The approaches taken to measure collaboration in different contexts have been diverse, and more recently, such measures have been dedicated to the inner aspects of organizations and networks (Rethemeyer, 2005; Thomson et al., 2007; Westphal et al., 2007; Michelino et al., 2014).

Available proposals in the literature have addressed collaboration measurement primarily via complex and multidimensional models. These approaches are all valid proposals, although they have focused on interpersonal collaboration or pertained to inner aspects of organizations. However, such approaches have not been applied at the level of a complex system among organizations or in terms of the measurement of the structural conditions created by these relationships, which is the central point of this paper.

As noted, the maturity of an ecosystem is determined by its robustness and capacity for resilience. In this context, Thurner et al. (2018) suggested four properties of any complex system that must be taken into account: *efficiency*, *robustness*, *resilience* and *proneness to collapse*.

That said, to understand the condition of an economic ecosystem – beyond the different perspectives that collaboration may adopt and the variety of definitions – I propose that a set of these structural conditions might be measured. These conditions are developed from the relationships created among the actors within the ecosystem itself.

Therefore, once the behavior of a network has been analyzed via its graphical representation (sociogram or graph) and its metrics have been obtained from the application of CNA, it is possible to approach the interpretation of this network through complex systems theory.

Based on the CST proposal and taking into account the fact that the economic ecosystem's *health or maturity* and its structures are determined by the previously mentioned variables, I propose the following three fundamental aspects:

1. The efficiency of communication among different actors (elements) and their capacity for collaboration.
2. The robustness of the ecosystemic structure.
3. The structural resilience of the ecosystem, both in terms of its adaptability to change and its capacity to prevent collapses (homeostatic capacity).

While these characteristics may not provide a complete description of an ecosystem, we can study the relationship dynamics operative within any type of ecosystem and its structure, whether entirely biological, social, or economic, through the unifying theory (CST) and the combination of tools adopted from other disciplines, such as mathematics, physics, biology, and social sciences. Therefore, complex network analysis demonstrates its usefulness to attain a closer look at reality in terms of behavior and the ways in which members of these ecosystems build, survive, and evolve in and with the ecosystem itself from the dynamics of their relationships.

I propose the following series of useful indicators for the study of economic ecosystems by combining complex systems theory and complex network analysis[3]:

Table 1. CNA relationship indicators proposed to analyze collaboration relationships and structure in economic ecosystems based on the conditions established by CST.

Metric*	CNA Meaning*	Proposed interpretation for economic ecosystems[4]	Useful features to be measured	Values
Average shortest path length	The average number of steps or connections throughout the shortest routes for all possible pairs of nodes on the network.	The average number of contacts or connections that separate an actor from any other actor in the ecosystem.	Ecosystem's efficiency.	From 1 to n-1
Central Point dominance	Average of the differences among the betweenness centralities metrics for all nodes to the maximum betweenness centrality in the graph.	How centralized the system is. How much power the most influential actor in the ecosystem has.	Ecosystem's proneness to collapse	From 0 to 1.
Clustering coefficient	Centrality is assigned to a node via the density of its egocentric graph. The graph is restricted to its neighbors.	The extent to which collaboration is observed among the collaborators of an actor.	Ecosystem's robustness	From 0 to 1
Global efficiency	Inverse of average characteristic path length among all nodes in the network.	How well information can travel through the network.	Ecosystem's efficiency.	From 0 to 1

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[3] Although these are not all of the metrics that can be obtained by the CNA's application for the study of relationships among elements within a complex system, I propose the mentioned indicators based on GED research and the category of indicators that help to attain a broad understanding of the behavior of the dynamics operative within the economic ecosystem.

This table does not consider aspects other than those that are measurable using CNA, which could be interesting in other contextual frameworks to deepen the relationship dynamics. For example, such frameworks might study the flow of information or resources and feedback loops that are considered in the reports published by GED. In this work, I only emphasize the metrics specifically related to complex systems theory. The potential of CNA to measure diverse ecosystemic conditions is broad. I recommend reviewing the available literature in regard to Section 3.3.

[4] While the mathematical meaning of the metrics remains unchanged, the final interpretation depends, to a large extent, on the type of network that is being constructed (Hanneman & Riddle, 2005)

Average eccentricity	Average of the centrality that assigns to each node the shortest path length possible to another node in the graph.	How far an actor can be from another within the ecosystem itself.	Ecosystem's compactness and size.	From 1 to n-1
Average degree	The average number of edges incidental to the total number of edges to the node; the total number of edges in the network divided by the total number of nodes in the network.	The average number of collaborations in which an actor has participated.	Number of collaborations within the ecosystem.	From 0 to infinity
Modularity	The fraction of edges that fall within the given groups minus the expected fraction, if edges were distributed randomly.	How sparse the connections are among different modules or communities in the system.	Ecosystem's proneness to collapse	From -1/2 to 1
Average weight of edge	The average weight or strength of the edge incidental to a node in the network.	The average intensity of an actor's collaborations. These intensities can depend on different factors such as time, allocated resources, or type of relationship as decided during the study.	Collaboration's intensity.	From 1 to 5 *Self-defined range*
Transitivity	Fraction of all possible triangles shown in the graph; density of triangles.	How likely is it that two actors collaborating with the same actor are also in collaboration with each other.	Ecosystem's robustness	From 0 to 1
Rich club coefficient	Maximum density possible of the graph if restricted to the nodes with degree at least *k*, up to election of *k*.	How much collaboration can be observed among the most active agents of the ecosystem.	Ecosystem's robustness	From 0 to 1

*(Börner et al., 2007; Hernandez & Van Mieghem, 2011)

3.5.1 Nodal metrics (actors)

In addition to the metrics mentioned above that facilitate understanding of the general conditions of structurality within the economic ecosystem, the CNA allows other metrics related to the nodes (actors) to be identified. For instance, the centrality within the network helps to identify the nodes that have the greatest quantity of connections (degree centrality), how close a node is relation to other nodes on the network (closeness centrality), or which nodes are found more frequently on the shortest path connecting two actors (betweenness centrality).

Knowing which nodes (elements/actors) have the best centrality metrics in an economic ecosystem allows us to more efficiently determine what relationships enable a better connection with most of the network within an ecosystem. That is, we can understand which actor (node) could act as the best "spokesperson" to convey certain information or resources to a greater number of actors or which organization could represent the interlocutor's ideal for an initiative that involves two different communities of actors within the same ecosystem, among further potential analyses.

Table 2. The CNA metrics proposed to analyze the actor's impact, influence, and collaborativeness in an economic ecosystem.

Metric*	CNA Meaning*	Proposed interpretation for economic ecosystem	Values
Betweenness centrality	The frequency with which the node is found on the shortest path between another pair of nodes.	How much the actor can function as a connector or intermediary between different groups.	From 0 to 1
Closeness centrality	The relative distance to the rest of the nodes on the network.	How easily the actor can reach other actors.	From 0 to 1

Eigenvector centrality	Degree centrality proportional to the sum of the degree centralities of the nodes to which it is connected.	How influential the connections of an actor are.	From 0 to 1
Degree	The number of edges that a node has.	How connected an actor is.	From 0 to infinity
Indegree	In a directed graph, the number of incoming edges a node has.	How sought-after the actor is by the rest of actors in the ecosystem. How many times the actor was mentioned.	From 0 to infinity
Outdegree	In a directed graph, the number of outgoing edges a node has.	How proactive one actor is in the ecosystem.	From 0 to infinity
Weighted degree	Sum of the weight of all the edges of a given node.	How connected one actor is and how strong those connections are.	From 0 to infinity

*(Jackson, 2008)

3.6 Sociograms and their definitions of interest

Below is listed a series of standard terms drawn from complex network analysis, using the commonly accepted definitions proposed by Jackson (2008) and the ways in which those terms have been operationalized in my research concerning economic ecosystems. After describing each term, I explain how these properties are used to measure social dynamics within this study.

Sociograms

In the CNA, a sociogram refers to the mathematical representation of the social dynamics of a complex system (Jackson, 2008). In this research, I refer to sociograms as the mathematical representation of the social dynamics and structure of an economic ecosystem obtained through CNA, which is based on information collected through the application of the research instrument to participating actors, allowing for the identification and analysis of the set of nodes (actors) and edges (collaborations) that give form and structure to the ecosystem in question. The sociograms in this work show the nodes (actors) as they are classified by the TE-SER model (Tedesco & Serrano, 2019). In this work, sociograms represent collaboration dynamics as reported by the actors included in the study.

Nodes (actors)

Jackson (2008) refers to nodes as “vertices,” “individuals,” “agents,” or “players,” depending on the setting. In the sociogram and in the context of this paper, the nodes represent the actors of the economic ecosystem that participated in the study or those that were mapped by participants through CNA. The size of the node and its relative position are characteristics that allow the *weight* (size) that actors have in the economic ecosystem to be visualized.

Node size

In the context of this work, the size of each node (actor) is calculated by considering the number of times the actor is mentioned by other actors as well as the intensity of such collaborations (*weighted indegree*). In this way, the size of the node of each actor reflects its perceived relevance from the perspective of other actors in the ecosystem with respect to collaboration, avoiding biases due to their participation (or lack thereof) in the data collection.

Edges (collaborations)

In the context of CNA, edges represent relationships or interactions between nodes (Jackson, 2009). In this research, the edges correspond to collaboration relationships that exist within the economic ecosystem.

Width of edge
The width of each edge depends on the intensity of the collaboration relationship between two actors. The thicker the width is, the more intense the collaboration is. The intensity of the collaboration on average describes the level of importance that the actor assigns to one collaboration with another actor, such as human and economic resources allocated to that collaboration,] in comparison with the resources allocated by the other actors in the same ecosystem. The level of importance is shown on a scale from 1 to 5 based on self-perceived qualitative data per actor and quantitative data based on the numerical data per budget and human resources[5].
1. No Intensity – No Relevance – 3. Moderately Intense – Moderately Relevant – 5. Very Intense – Very Relevant.

Relative node position
The position of each node (actor) depends on how connected the node is through collaborations with other nodes on the network when applying CNA's force-directed algorithms that take into account the weight and distribution of such connections, among other factors. The details of these algorithms are explained in Tedesco and Serrano (2019).

Directionality
The edge's curve directionality, whose rotation is in a counterclockwise direction, represents the actor who initiated the interaction between both actors to determine such collaboration. Likewise, the color of the edge reflects the type of TE-SER (Tedesco & Serrano, 2019) role by which this interaction was initiated.

3.6.1 Considerations of nodes' spatial distribution

The CNA provides a variety of ways to visually represent connections among different actors in an economic ecosystem by the implementation of each node, whether manually or through the use of different algorithms. In this field of study and due to the approach that I have used for this work, force-directed layouts are found to have better characteristics to attain an overview of profiles, both technical and executive, which enables me to better cope with certain key characteristics that the graph reveals.

Force-directed layouts such as *ForceAtlas2* (Jacomy et al., 2014) have been used for the presented sociograms, and the name of this layout comes from the algorithms included in repulsion forces among all nodes and attraction forces among those that are connected (Kobourov, 2012).

In this way, it is easier to visually identify nodes (actors) that are more connected to the center of the network, to the least connected peripherally, the closeness among different actors despite not being directly connected due to common contacts, or the possible existence of reflected communities, which are shown as groups of nodes agglomerated in a section of the ecosystem network.

3.6.2 Gravitational centers

I use the term *gravitational centers* to refer to organizations that play a predominant role in any economic ecosystem. The reason for this choice is not only their size as a node but also because of their capacity to connect organizations and generate collaboration with a critical mass of actors, which

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[5] According to the examples shown below, budget and implicit human resources are not taken into account, because in our GED studies we did not initially incorporate these metrics into our research instruments used for data collection, so there is no data available from some ecosystems. However, it is extremely important to consider the methodological context when measuring collaboration since this context can provide even more precise information beyond that perceived by the participating actors within an economic ecosystem.

tends to exhibit high values of closeness and/or betweenness centrality; in turn, these centers become stabilizers of the ecosystem itself.

The identification of these gravitational centers becomes essential in understanding the ecosystem's dynamics, while it also allows for an understanding of the level of maturity of the ecosystem in terms of shared leadership, depending on the quantity and variety of roles for these actors in particular.

It is understood that a mature ecosystem tends to have more connected structures and a greater number of gravitational centers, whose collaboration dynamics provide stability to the ecosystem without any such center becoming individually indispensable for the ecosystem's performance, as I will explain below.

The identification of these gravitational centers on the basis of CST and the use of CNA can help overcome biases (Posada, 2005; Di Cicco-Bloom & Crabtree, 2006), which are created based on the official account of the most relevant actors within the economic ecosystem, i.e., those actors that have a better market presence, greater advertisement, or greater popularity. These features will not necessarily agree with reality from the perspective proposed in this work: the capacity and influence to lead the increase in collaboration and to provide stability for the economic ecosystem.

The following is a method that I propose to mathematically determine a *gravitational center* on the basis of CNA's metrics.

3.6.2.1 Concerning mathematical and graphical representations of gravitational centers based on CNA

Bearing in mind the use of the spatial disposition of the nodes in the sociograms driven by forces and alluding to the forces of attraction and repulsion that include their algorithms, it is possible to apply the name *gravitational centers* to those nodes that have a high centrality and "attract" a great number of other actors toward the center of the network, contributing in this way to the robustness of the ecosystem.

To determine which nodes correspond to the *gravitational centers* of the ecosystem, the following parameters are established:

1. Nodes that belong to the *k–1-core* subgraph[6], in which all nodes have a degree of at least k – 1 after a recursive elimination process, with *k* being the maximum value possible that continues to generate a connected element.
2. Nodes that have an input degree greater than 3 times the expected value if links were generated evenly and randomly. The input degree represents the total incoming connections that a node (actor) has, and the expected value is calculated by taking into account the total number of nodes in the network, the number of participants in the study, and the average number of collaborations mentioned by participating organizations.

The first parameter allows us to ensure that nodes that are identified as gravitational centers are connected to other relevant actors and not merely to low-centrality actors located on the network's

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[6] A subgraph G^' of a graph G is a graph G^' whose vertex set and edge set are subsets of those of G. If G^' is a subgraph of G, then G is said to be a super graph of G^' (Harary 1994, p. 11). More info: Weisstein, "Subgraph." From MathWorld--A Wolfram Web Resource. https://mathworld.wolfram.com/Subgraph.html

periphery, while the second parameter focuses on a significant number of mentions by participants in the study.

3.7 The challenges and limitations of CNA with respect to the study of economic ecosystems

The methods described for the analysis of networks in complex systems face different challenges and limitations that are important to consider. One of the main challenges is the question of how to obtain the necessary information regarding the network and the different biases that may arise throughout this process.

According to Börner et al. (2007), the intention to achieve complete data concerning a complex system that could allow us to grasp with certainty all the nodes and all the connections that constitute the network turns out to be almost impossible when in a great variety of contexts due to practical and logistical limitations, such as time constraints, techniques, or resource limitations.

In these cases, different sampling methods may be possible to allow deductions or even simulations of the network's behavior as a whole. However, there is still no consensus regarding the reliability or efficacy of a given sample size as exists in other applications of statistical practice (Kolaczyk & Krivitsky, 2015).

In the same vein, considering that the information provided in a network very frequently appears to be incomplete due to the absence of certain nodes or connections, Kossinets (2006) carried out an investigation into the main sources of missing information during network analysis and the effects that missing information may cause.

Therefore, it is possible to describe three important sources of bias: 1) The boundary specification problem, in which the observer leaves out of the analysis connections or actors that do not meet a determined profile; 2) Nonresponse effects, in which the lack of participation by only one actor in the data collection could correspond to a loss of a complete set of unique nodes and connections; 3) Fixed choice designs, in which participants are limited to mentioning a specific maximum number of relationships, excluding others that could also be valuable due to the possible incapacity of the participants to remember their own relevant relationships.

Another important area in which sources of ambiguity can be found lies in the evaluation of robustness, resiliency, and proneness to collapse. This ambiguity occurs in part due to the way in which all these factors are intimately related, and both *resilience* and *proneness to collapse* seem to require simulations or dynamic networks that allow for changes to be identified throughout different time series. There are various proposals, such as that offered by Shizuka and Farine (2016), who evaluated the robustness of a community structure by making use of assortativity or another proposal by Malliaros et al. (2012), who made use of expansion metrics as spectral properties of the network.

In another proposal, Gunasekara et al. (2012) measured the change in key metrics of a network after causing disturbing it by removing certain nodes and links as a means of evaluating the system's robustness. However, according to the definition of resiliency, I could argue that the latter is what is measured in this experiment. Similarly, Dorp et al. (2020) evaluated the resiliency of mycelial networks by measuring the loss of connectivity, which reflects a density reduction and a greater vulnerability to fragmentation in ecosystems in forests that were affected by tree removal and that functioned as important hubs.

To evaluate proneness to collapse, Horstmeyer et al. (2020) suggested examining the existence of a single cycle directed through a quantification effect of the node's state. While these proposals are all valuable, the truth is that there is still no consensus regarding the best way to evaluate these important properties, which is why this work develops a series of metrics that directly and independently allow us to take into consideration the concepts of robustness and proneness to collapse.

Now, network resiliency is a condition that seems to be measurable only in the foreseeable future and requires an experiment in its own right. This subject is not part of this study, but it would be ideal to have a closer approximation of the conditions of the network of collaborative relationships within an economic ecosystem.

4. Findings and practical applications

These findings and applications are based on the theoretical approach that I have proposed and following an accurate contextualization of what an ecosystem is from the perspective of complex systems theory and how its dynamics and structures can be measured through complex network analysis. In this section, I provide the results that I have obtained through the application of the set of approximations previously described.

The practical applications of the findings and recommendations made based on their interpretation are available in a compendium of published reports (Tedesco et al., 2020a, 2020b, 2020c, 2020d, 2020e, 2020f) that attempt to support practitioners in economic ecosystems with respect to decision-making with regard to improving their economic ecosystems through collaboration. Therefore, the findings in this section are discussed to expose the metrics and indicators that describe the economic ecosystem's behavior, collaboration dynamics, and structure.

4.1 The performance gap between *desk research* and CNA with regard to identifying actors

One of the first findings that should be highlighted is the substantial difference between the number of actors identified using the *desk research* method vs. those identified using complex network analysis. It is also notable that *desk research* does not appear to be the most sought-after method for identifying actors in an economic ecosystem due to its requirement of economic resources and infrastructure, which are not always available to those who are interested in the identification of actors within an ecosystem. A comparison between the results of both methods are detailed in the following table.

Table 3. Delta results comparing desk research and CNA with respect to actor identification in an economic ecosystem

	Desk Research	CNA	Delta
Mexico City (MEX)	161	299	+85.71%
Madrid (MAD)	167	239	+43.11%
Santiago (SANT)	121	195	+61.16%
Buenos Aires (BS. AS.)	171	228	+33.33%
Sao Paulo (SPO)	128	216	+68.75%
Montevideo (MONT)	125	198	+58.40%
Valencia (VLN)	88	180	+104.55%
Barcelona (BCN)	149	236	+58.39%

It is important to mention that to identify an organization (or another type of agent) in an economic ecosystem using CNA, other methods should first be implemented to identify which actor will provide the information that is to be processed; in this case, the *desk research* method could be applicable.

4.2 The distribution of actors in economic ecosystems

According to the data presented in Table 3, the TE-SER model (Tedesco & Serrano, 2019) shows that the distribution of roles per type remains fairly constant in all economic ecosystems analyzed, even in countries with higher levels of development, such as Spain. This result leads to an interesting conclusion, at least with regard to the Ibero-American region: the development of the ecosystem itself does not seem to be so closely related to the composition of the actors according to the type of roles that they play but rather by the ways in which actors relate to each other.

Nevertheless, the absence of certain key roles, such as "knowledge generators[7]", in an innovation-oriented entrepreneurial economic ecosystem could have a significant impact on its production.

Table 4. Actors' role distribution per type according to the TE-SER model in the economic ecosystems analyzed.

Cities	Articulators	Enablers	Linkers	Knowledge Generators	Promoters	Communities
Mexico City	11.0%	66.2%	8.0%	5.7%	6.0%	3.0%
Madrid	12.6%	53.1%	13.8%	9.2%	8.0%	3.4%
Santiago	13.3%	52.6%	14.8%	9.2%	7.7%	2.6%
Buenos Aires	13.6%	55.3%	13.2%	10.1%	3.1%	4.8%
Sao Paulo	8.3%	60.7%	11.6%	12.0%	5.6%	1.9%
Montevideo	16.2%	45.5%	15.7%	12.1%	6.1%	4.6%
Valencia	11.1%	39.4%	26.7%	13.3%	5.6%	3.9%
Barcelona	9.8%	57.6%	15.7%	5.1%	7.6%	4.2%

4.3 The social dynamics of collaboration in economic ecosystems as an outcome of their mathematical representation

The following are the metrics that were obtained and that describe the social dynamics of collaboration and structurality in the economic ecosystems analyzed throughout the development of this work. These metrics are mainly based on characteristics obtained from the use of complex network analysis.

4.3.1 Economic ecosystem metrics

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[7] A detailed description about the actor roles and the value that an actor can contribute to an economic ecosystem is found in Tedesco & Serrano, (2019).

The metrics observed concerning the analyzed structural conditions of the collaboration networks of the economic ecosystems are detailed below. Based on this presentation, it is possible to compare the results obtained by the behavior of the collaboration dynamics in each of these contexts.

Table 5. Potential useful indicators for CST properties drawn from CNA metrics in the economic ecosystems analyzed.

Metrics	BCN	BS. AS.	MEX	MAD	MONT	SANT	SPO	VLN
Average shortest path length	3.43	3.36	3.82	3.78	3.08	3.23	4.32	3.01
Central Point dominance	0.26	0.25	0.20	0.18	0.18	0.53	0.24	0.12
Clustering coefficient	0.26	0.30	0.18	0.27	0.37	0.31	0.30	0.38
Global efficiency	0.32	0.33	0.29	0.29	0.36	0.34	0.27	0.37
Eccentricity	4.88	4.80	5.62	6.08	4.48	5.04	6.73	4.23
Average degree	4.26	4.39	3.66	3.79	7.75	3.95	3.37	6.99
Modularity	0.52	0.53	0.62	0.61	0.36	0.54	0.68	0.37
Average edge weight	3.20	3.24	3.48	3.52	3.23	3.42	3.43	3.54
Transitivity	0.11	0.11	0.05	0.08	0.22	0.10	0.08	0.25
Average collaborations per participant	12.82	13.48	12.33	12.13	13.40	13.04	10.38	15.05
Rich club coefficient	0.58	0.29	0.20	0.22	0.49	0.21	0.25	0.56

Considering the indicators of each of these metrics, it is possible to develop targeted strategies that allow for the development of better structural collaboration conditions in the economic ecosystem.

The objective of this work is mainly to show the importance of the analyzed collaborations in economic ecosystems and the way it is done. These metrics and other relevant measures obtained from the complex network analysis could be correlated with other economic and social metrics indicated to observe the relationship between collaboration in economic ecosystems and sustainable development of the region to which they belong.

4.3.2 Sociograms for each ecosystem and relevant value outcomes drawn from complex systems theory

The following images are the graphical representation of the mathematical values constructed from the observed social dynamics of collaboration. Metrics suggested by complex systems theory to interpret the general condition thereof are included. For this section, only three economic ecosystems analyzed are represented as examples.[8]

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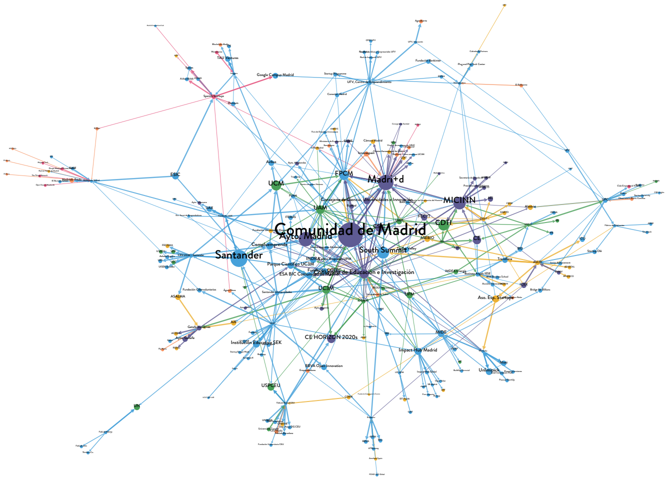
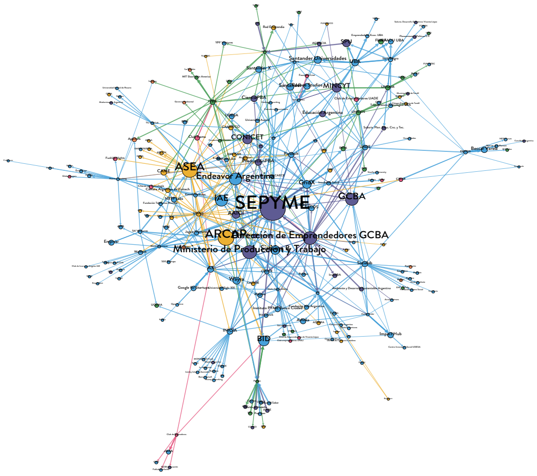
[8] The rest of the graphical representations for the mathematical modeling of the economic ecosystems analyzed are available online: www.globalecosystemdynamics.org



Sociogram 1. Collaborative social dynamics of the innovation-oriented entrepreneurial economic ecosystem of Madrid
(Tedesco et al., 2020a)

CST properties	CNA metrics	Value
Efficiency	Global efficiency	0.29
Robustness	Clustering coefficient	0.27
	Transitivity	0.08
	Rich club coefficient	0.22
Proneness to collapse	Central point dominance	0.18
	Modularity	0.61

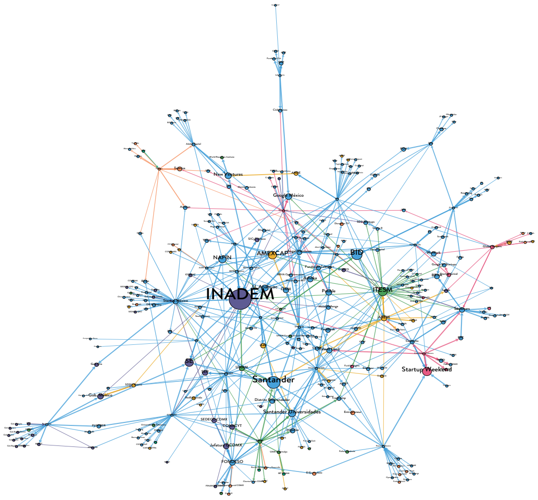
Table 6. CST properties and CNA metrics of the innovation-oriented entrepreneurial economic ecosystem of the city of Madrid.



Sociogram 2. Collaborative social dynamics of the innovation-oriented entrepreneurial economic ecosystem of the city of Buenos Aires
(Tedesco et al., 2020b)

CST properties	CNA metrics	Value
Efficiency	Global efficiency	0.33
Robustness	Clustering coefficient	0.30
	Transitivity	0.11
	Rich club coefficient	0.29
Proneness to collapse	Central point dominance	0.25
	Modularity	0.53

Table 7. CST properties and CNA metrics of the innovation-oriented entrepreneurial economic ecosystem of city of Buenos Aires.



Sociogram 3. Collaborative social dynamics of the innovation-oriented entrepreneurial economic ecosystem of Mexico City
(Tedesco et al., 2020c)

CST properties	CNA metrics	Value
Efficiency	Global efficiency	0.29
Robustness	Clustering coefficient	0.18
	Transitivity	0.05
	Rich club coefficient	0.20
Proneness to collapse	Central point dominance	0.20
	Modularity	0.62

Table 8. CST properties and CNA metrics of the innovation-oriented entrepreneurial economic ecosystem of Mexico City.

4.3.3 Considerations regarding the interpretation of metrics and ecosystemic conditions

The high *central point dominance* value of Santiago de Chile and Mexico City compared to other ecosystems shows that actors depend significantly on a single central node. This situation certainly leads to recognition of the fact that leadership distribution is an important area of opportunity to reduce effects on the economic ecosystem; when it disappears or experiences a change in strategies and priorities, it turns out that such a situation is not the most favorable circumstance for the ecosystem.

In the particular case of Sao Paulo, the highest metric of results presented for *modularity* and *average shortest path length* reflects the presence of different groups (islands) that have little interaction with each other by generating a disconnection in the economic ecosystem as a whole and possibly causing slower rates of the transmission of resources and information among actors in comparison with ecosystems that have higher values in these metrics.

Montevideo and Valencia report the highest values of *transitivity* and *global efficiency* for the economic ecosystems analyzed. These metrics describe the number of connections among actors as well as the ways in which these relationships are structured in these two economic ecosystems. The high values of these metrics for these locations indicate that the exchange of resources is carried out in a more accelerated way and at the same time, that such exchanges reach a greater number of actors than in ecosystems with lower values in these metrics.

In some cities, such as Barcelona, Buenos Aires, Montevideo, Valencia and Madrid, at least eight actors with the characteristics that were ascribed to gravitational centers can be counted (according to the characteristics explained in Section 3.6.2.1). This condition, in combination with high values for the *rich-club coefficient* and low values for *central point dominance* and *modularity,* describes a strong dynamic of collaboration among leaders in these economic ecosystems. This combination of factors could reduce the ecosystem's *proneness to collapse*. Herein lies the importance of collaboration among leaders within an economic ecosystem.

It should be noted that in the early stages of developing economic ecosystems, one or a few strong and proactive gravitational centers that can coordinate the first collaborative and development efforts could be beneficial and positive. These pioneering leaders should implement strategies that strengthen the rest of the actors within the ecosystem itself. Thus, as the ecosystem grows, a greater number and variety of gravitational centers provides long-term structural benefits.

Finally, the analysis carried out in Mexico City shows that one of the most significant nodes according to its *centrality* metrics and size is an organization called INADEM, which has recently disappeared due to a change of administration in the federal government and new public policy[9]. The absence of INADEM could have caused a strong disruption in the ecosystem due to its relevance and position. These types of events highlight the importance of conducting studies at different times to understand how economic ecosystems adapt to this kind of disturbance.

The initial observations in the field during data collection and the corresponding computational simulations effectively showed that the ecosystem did not have the immediate capacity to adjust to new conditions, corresponding to a potential loss of homeostatic capacity. Experiments with different

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[9] The National Institute for Entrepreneurship (INADEM) no longer exists as of August 13, 2019. No governmental institution has assumed its role, and all its programs were discontinued. Due to the temporary characteristics concerning the data collection methodology relative to the collaborations of this economic ecosystem and its representativeness as an actor, this institute has been represented in the study.

timeframes would allow for greater precision to be attained in evaluating the resiliency conditions from CST as applied to an economic ecosystem.

5. Future research

The concepts, theoretical approximations, proposed techniques, and findings presented in this paper open the door to an exciting field of research concerning the ways in which economic ecosystems operate not only in terms of the relationships among their actors but also in terms of their interactions with their environment. Likewise, it could be important to advance knowledge concerning how resources flow and the results produced in their surroundings as well as that concerning the behavior of trophic structures in the economic ecosystem and finally research regarding the energy exchange cause by all the previously mentioned dynamics.

Fundamentally, it would be relevant to understand the results that the cooperative mechanisms produce among actors, entrepreneurs, innovators and businessmen and between those figures and the actors themselves. Finally, we have a deeper understanding of how a better collaborative structure in an economic ecosystem could contribute to the sustainable development of our cities, countries and the Earth we all share.

6. Conclusions

Over the last two centuries, the capitalist system has dominated the economic and social life of the population in all forms and appearances. Other production and social systems are possible with good or bad results. Recent combinations of the two dominant systems, socialism and capitalism, have grown and performed at certain levels in regions such as Europe through the development of the social market economy.

Over the past fifty years, global poverty has decreased, while inequality and the accumulation of economic power have increased considerably (Alvaredo et al., 2018 and United Nations, 2020). Nevertheless, the most important fact for the future of our species is that the planet is in danger due to uncontrolled predation through human activity. A justification for this predation could exist if we could reach a balance point between global well-being and economic development. That balance does not exist and cannot be achieved by following certain frameworks of the systems that have led us to this historical moment (Tedesco, 2020).

These imbalances not only exist within the economic system but also impact external agents in the system and the environment. An persuasive answer has not yet been found to foster the required equilibrium for the survival of species. According to Georgescu-Roegen’s conclusions (1975), we must cease living in the neoclassical myth that claims that the economy is a mechanical, circular and closed system without inputs or outputs.

Many schools of economics and the economists trained in such schools continue to support these models of neoclassical economics, holding ideas that by this point have turned out to be dogmas and ideological rather than scientific precepts - a concept that Bunge (2014) has called *scholastic economics*. In other words, we need to become more aware of the impact that human activity has on society and the environment.

Biological cooperation mechanisms have drawn the attention of evolutionary experts throughout the last fifty years. However, there is sufficient evidence concerning the evolutionary benefits of cooperation over competition (Gardner et al., 2009). Thus, the evidence seems to show that while superior nonhuman organisms compete for resources, they adapt based on competition, while other, inferior nonhuman organisms such as insects or plants do not compete for resources but cooperate with their environment and share finite ecosystem resources to survive and evolve (Nowak, 2006).

Nevertheless, for diverse reasons, this concept has been neglected from the perspective of the behavioral dynamics of economic ecosystems based on the idea that competition is a way to build value. The little value that competition creates in comparison with collaboration is ephemeral and has brutal effects on society and the environment. This prevailing focus on economic competition could limit scientific research into collaborative social dynamics. The latter is a natural and necessary force of evolution that invariably exists in highly developed economic ecosystems created by certain levels of consciousness among their inhabitants.

This paper has demonstrated that economic ecosystems are ecosystems in all senses of the word in terms of behavior, components and structure, venturing beyond metaphor and the nature of the resources involved. Complex systems theory is a good approach to attaining a better understanding of ways in which these ecosystems function, and complex network analysis is a fundamental tool to observe and measure these behaviors. From the point of view of how an economic ecosystem is developed, the institutions (composed of individuals) that interact (or not) with each other shape the collaborative network of relationships.

The evidence and examples provided in this article show that the development of the structure of an economic ecosystem does not occur efficiently through competition but as in the case of mechanisms found in biological ecosystems, through cooperation. Furthermore, the fundamental fact is that economic ecosystems in which leaders collaborate with each other for the common good of the ecosystem become more efficient, robust, and less prone to collapse - a fact that raises the question of a potentially urgent solution not only for the economy but also for society and the human species in general.

As I have described in the context of the biological sciences, homeostatic capacity (ecosystem balance) is maintained as long as the competition mechanism does not outweigh cooperation relationships. As seen from CST and CNA in the context of economic ecosystems, the greater the collaborative relationships between actors become, the greater the homeostatic capacity. Competition is necessary in certain ways, but it should not dominate the economic ecosystem, as it does not dominate biological ecosystems in their pursuit of equilibrium. Therefore, the possibility of economic equilibrium seems to be impossible in an environment dominated by competition.

In economic ecosystems in which human consciousness and its motivations play a fundamental role, external regulations are also necessary since we have developed as predominant predators. However, these regulations should promote better conditions so that new economic actors are developed and not inhibited, while competition and predation should be maintained at levels below those of cooperation and collaboration, and henceforth, collaboration dynamics in economic ecosystems must be supported to a much greater extent. This approach seems to be the only viable path to the necessary balance among all ecosystems and, therefore, to the task of producing sustainable prosperity.

The fact is that we all belong to the entire ecosystem: an ecosystem that is economic, social and terrestrial. This fact explains the impact of the relationships proposed by the bioeconomy (Georgescu-Roegen, 1975) and the ecological economy (Marten, 2001; Xepapadeas, 2008).

Finally, the theoretical frameworks of study that I have proposed in this paper and the results of the paper's use of CST and CNA make it easy to understand the social dynamics operative in economic ecosystems. Therefore, it is necessary to find the way to deepen the research concerning the most efficient relationship mechanisms that can allow us to attain that necessary balance that the world demands. Then, perhaps, once and for all, the myths of dogmatic economics that prevailed during the last century can be put aside to make a society become evolutive in the fullest sense of the word.

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