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Artículo

The approach of complexity
and evolutionary economics of innovation

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Abstract

This paper is aimed to be a contribution for the current debate on the future trends of neocshumpeterian evolutionary theory of innovation, and specially, on the role that complexity approach can play in articulating different streams inside evolutionary theory. The thesis of this paper it that these different streams adhere to different but overlapping ontological assumptions, since they aim to address different but complementary aspects of a same reality. In this sense, they can be articulated by an integrating ontolgy. In this paper we propose that complexity ontology can play that role. Be awared on this will allow neoshumpeterian evolutionary theory of innovation to find better way on intagrating, to identify vacancy areas for future research, and to present itself as an articulated research programme, with theoretical foundations and coherent methodological tools.

Resumen

El presente artículo intenta ser un aporte al debate actual sobre el rumbo que está tomando la teoría evolucionista neoshumpeteriana de la innovación, y en particular, acerca del rol que juega el enfoque de la complejidad para articular e integrar las distintas corrientes a su interior. La tesis de este artículo es que diferentes corrientes al interior del evolucionismo adhieren a distintos conjuntos de supuestos ontológicos ya que abordan aspectos diferentes pero complementarios de una misma realidad. En este sentido podrían ser articulados si se considerara una ontología integradora. En este artículo proponemos que la ontología de la complejidad podría cumplir esa función. Tomar conciencia de esto, le permitiría a la disciplina encontrar mejores formas de articulación a su interior, identificar claramente las áreas de vacancia y presentarse hacia afuera como un programa de investigación fuertemente articulado, con fundamentos teóricos y herramental metodológico acorde.

Introduction.

To say that economics is in crisis is almost commonplace. The failure of the Washington Consensus policy recommendations for developing countries during the 90s, the successive crises triggered since the mid-90s (Mexico, Southeast Asia, Russia, Brazil, Argentina), and the current crisis in the central economies, have shown that conventional neoclassical economics had and has serious problems to address the economic reality in both developed and developing countries.

However, in recent years, conventional economics has shown an enormous capability to reinvent itself. In this direction, many of the heterodox criticisms concerning restrictive assumptions, such as the presence of increasing returns, bounded rationality, uncertainty, imperfect information and heterogeneity have been incorporated, although partially and within its basic outline of equilibrium and maximizing agents. Since then, different branches of heterodoxy saw their own questions and concerns assimilated into a broader and increasingly heterogeneous neoclassical economics namely the "mainstream".

Faced with these changes, an intense debate on what course should be taken has been raging within the heterodox groups. Should heterodoxy look for acceptance from the mainstream? Or on the contrary, should they discuss the degree of success of mainstream in incorporating the old restrictive assumptions and try to identify elements not yet considered by the mainstream that clarify where orthodoxy ends and heterodoxy starts?

Within the Neoshcumpeterian evolutionary theory[1] this debate is ongoing. Some key elements refer to whether the main concerns of evolutionary economics should be limited to a theory of technological change or, given the orthodoxy's difficulties, they should expand their goals and become a general theory of economic change. This would imply new developments on relatively unexplored aspects by Neoshcumpeterian evolutionary theory, like a theory of demand, money, financial systems and development. The last one should explicitly recognize the difference in development path between developed and developing countries, setting aside the idea of mono-economics.

Despite the crucial role that demand has in the selection process, this aggregate plays a still unclear role in evolutionary theory. In that direction

1 We call Neoschumpeterian evolutionary theory a segment of the large and heterogeneous economic evolutionism (see Hodgson, 2007). The Neoschumpeterian evolutionary theory refers to the authors that participate in the Schumpeter Society, published in its Journal (Journal of Evolutionary Economics), and attend to its conferences, (Schumpeter International Conference).

Dosi (2010 and 2013) has argued for the importance for evolutionism to follow more Keynes and less Schumpeter. At the same time, Saviotti and Pyka (2011) explored the importance of the expansion of disposable income for the generation of variety[2] within a Smithian and Kaldoriana framework. In turn, different authors that analyzed the relationship between technological change and international trade have highlighted the rol of income elasticity on trade specialization profile and the dynamics of production and technology (Dosi, Pavitt and Soete, 1990). Another aspect of the debate concerns the level of formalization that theory should have. This issue was very present since the beginning of the neo-Schumpeterian evolutionary theory: to what extent mathematical formal models are needed to explain the competitive dynamics and their impact on various aspects of coordination and economic transformation. Should theory remain in an appreciative ground? (Nelson 1991) The latter would be required under the assumption of the existence of creative responses in organizations whose definition by itself invalidates the existence of a formal model that generates them (Schumpeter, 1947, Antonelli, 2007) [3].

As a solution to all these issues (or most of them), Neoschumpeterian evolutionism resorted to complexity approach (Silverberg, Dosi and Orsenigo, 1988; Dosi and Kaniovski, 1994, Dosi and Nelson, 1994; Witt, 1997; Arthur, Durlauf and Lane 1997, Arthur, 1989, 1990, Metcalfe, Foster and Ramlogan, 2005, Foster, 2005; Durlauf, 2005, Frenken, 2005, Antonelli, 2007, Arthur, 2009, Antonelli, 2011) which allows to use their tools to integrate conceptually and formally different levels of analysis -micro, meso, macro- in constant co-evolution.[4]

This paper attempts to be a contribution to the current debate on what direction the Neoschumpeterian evolutionary theory is taking; and in particular what role is complexity approach playing in coordinating and integrating the various trends within. These trends adhere to overlapping sets of ontological assumptions[5], which differ in terms of the main question

2 Both, variety related to the main sectors of the productive structure as well as variety unrelated to them.

3 This issue was identified by Hodgson (2007) in the Austrian thought through the notion of "uncaused cause".

4 Other elements of the discussion refers both to the necessity of a price theory, since they seem to play no role in economic evolutionism and to the possibility of giving an explanation of the economic crisis, considering how little is the contribution of neoschumpeterian evolutionism to explain the current economic crisis.

5 These assumptions define the scope of reality -what are its limits and its constituent parts-, and the nature of reality, -what are the relationships between these parties and the relationship with the totality that they make up. In these assumptions lie a set of clarifications on the scope of the theory beyond its empirical and predictive value, referred to as self-imposed limits on the study object and on its particular "way of see the world". To discover the ontological assumptions, make them obvious, helps to understand the paths taken by the theory, while comparing the

they address. Likewise, each trend finds within the history of economic thought different backgrounds that are consistent with their particular ontologies.

The thesis of this paper is that different groups within evolutionism adhere to different sets of ontological assumptions as they address different but complementary aspects of the same reality. Therefore, they could be articulated if they were considered an integrated ontology. We propose that the ontology of complexity could fulfill this role. Awareness of this would allow the discipline to find better ways of articulation among different inside-groups and groups of authors, to identify vacant research areas, and to stand as a strongly articulated research program with coherent theoretical fundamentals and methodological tools.

Based on different and transdisciplinary definitions of complexity, in the first section we present the ontological assumptions of complexity. The definitions offered by literature in general tend to list the set of attributes present in complex systems. Heterogeneous enumerations of these identified a set of common dimensions, which, in turn, can be articulated with interconnected attributes. These dimensions refer to: (i) heterogeneity, (ii) interactions, (iii) network architecture of connections, (iv) disequilibrium and divergence, and (v) emergent properties.

In the second section of this paper, we identify two traditions in the history of economic thought that refer to complexity. They started together from the most comprehensive and fruitful Smithian premise: "the division of labor extends to the size and density of the markets" but they took different routes in the mid-twentieth century, concerning on one hand the question of coordination, and on the other divergence among economic systems. Meanwhile, both are strung together by a single thread, the ideas of complexity in economic thought.

In the third section, we derive the ontological assumptions of evolutionary thinking in terms of the papers that have discussed these ontological assumptions.[6] Economic evolutionism is characterized by heterogeneous trends and therefore there have been various attempts to establish its limits and related predecessors in terms of different ontological and methodological criteria. After establishing these limits on the basis of the work

ontological assumptions of different trends within a theory allows us to understand the methodological options that will guide the course of the investigation in each case.

6 Evolutionary economics ia characterized by discussing continually their ontological assumptions. A summary of these discussions can be found in a special issue of the Journal of Economic Methodology (2004).

by Hodgson, (2007) and Witt, (2008), we discuss the work of Nelson and Winter (1982) and Dosi et al., (1988) who have developed the foundations of an ontology of evolutionism which was updated and expanded by later works (Dosi and Nelson, 1994, Metcalfe, 1998, Dosi and Winter, 2002). Furthermore, we discuss the ontology built by Dopfer (2004, 2005) and Dopfer and Potts (2004). They have made a significant effort to build the axioms and basic laws of evolutionary economic theory. These two proposed ontologies can generally be identified respectively with the two lines within economic thought discussed in section 2.

In the fourth section the paper proposes a taxonomy of five groups of authors in economic evolution (five different groups within Neoschumpeterian evolutionism). The taxonomy is based on the main concerns addressed by each group of authors. These are **(i)** Habits and Routines (Nelson, Winter, Dosi, Hodgson) **(ii)** Innovation Systems (Nelson, Freeman, Boschma, Antonelli), **(iii)** Cumulativen Causation (Dosi, Pavitt, Soete, Saviotti), **(iv)** Self-organization and Self-transformation (Metcalfe, Foster, Dopfer, Potts), and **(v)** Feedback and Increasing Returns. It is clear that these groups are not mutually exclusive but complementary and indeed there are overlaps noticeable in the simultaneous presence of the same author in more than one group. In building the taxonomy we considered the emphasis on a particular subject and the fundamental contributions made in a specific subject. By asking different research questions, these groups adhere to different sets of ontological assumptions and their works show different emphasis on the various dimensions of complexity.

Finally we present the conclusions focused on analyzing the consistency between the ontology of complexity and evolutionary ontology, the five identified groups of authors and their predecessors.

Towards a Complexity Ontology.

It is difficult to say that complexity is a theory, it is in any case an approach or a way to approach reality that includes a set of conceptual fundamentals and methodological tools. The complexity approach is also associated with theories like dissipative systems and networks, with specific application areas. Prigogine and Stengers (1984) suggest the complexity approach is essentially a new relationship between science and nature that comes in response to a new view of a world characterized not only by its unpredictability but by the impossibility of addressing its structure and dynamics from general and immutable laws. Since then, complexity has been associated with self-organization, non-equilibrium dynamics, irre-

versibility, and uncertainty. While this explanation has been strongly criticized (Bricmont, 1996; Virasoro, 2013, among others) because they argue that all these issues are in contradiction with Newtonian thinking, it is important to note that the notion of irreversibility and uncertainty of the dynamics of systems has gained increasing interest since the development of complexity thinking.

In addition to chemistry, physics and biology, complexity has found various application areas, including social and economic systems. Their conceptual developments have enabled to describe an important set of deep features of how complex systems work. These features can account for a large set of situations. In this sense, a definition of complexity should aim to cover this diversity. According to Rosser (2007), a broad definition of complexity may be attained by discarding what is undoubtedly not complex, *ie* "those systems that do not generate endogenously or deterministically well behaved dynamics". Nevertheless the vagueness of the definition goes against its practicality. Rosser quotes the definition by Day (1994), which indicates that a system is complex if it tends, endogenously and asymptotically, to something different than a fixed point, a limited cycle or an explosion. In this case, the definition becomes more precise but it is circumscribed to the evaluation of the system by its results, not by its composition and characteristics. Besides the results of this type are not always classified as complex dynamic results[7]. Kwapiena and Drozdz (2012) provide a definition that points to a description of the system from its components. According to these authors, a complex system is comprised by a large number of components which interact in a nonlinear way, they exhibit collective behavior and they can easily modify their internal structure and/or activity patterns from data or energy exchanges with the environment. While these approaches are not stringent enough to decide whether a system is complex or not, they are clear enough to indicate which ones are undoubtedly complex systems and which not at all.

Beyond these meager definitions of complexity, and the epistemological explanations of Prigogine and Stengers, the efforts to characterize complexity have gone in the direction of listing the set of characteristics that they have to verify. For example, the definition proposed by Nekola and Brown (2007) identifies eight characteristics that a complex system should present: (i) micro-heterogeneity (ii) interactions among system components and between them and the environment in many different

7 For example, the strange attractors of some differential equation systems (ie, Rossler and Lorenz attractors) fulfill these requirements although deterministically. The same happens in the cases of laminar flux and some atmospherical phenomena.

ways and on multiple spatial and temporal scales, (iii) the interactions give rise to complex structures and nonlinear dynamics, (iv) these structures and dynamics are neither completely stochastic nor entirely deterministic, but instead represent a combination of randomness and order, (v) the system contains both positive and negative feedback mechanisms, causing either amplification or damping of temporal and spatial variation, depending on conditions, (vi) they are open systems which require exchanges of energy, materials, and/or information from extrinsic sources to maintain highly organized states far from thermodynamic equilibrium, (vii) they are historically contingent, so that their present configurations reflect the influence of initial conditions and subsequent perturbations, and (viii) they are often nested within other complex systems, giving rise to hierarchical organizations.

Two definitions of complexity from an economic perspective, also choose to list characteristics of the complex systems. First, Arthur, Durlauf, and Lane (1997b, pp. 3-4) cite six key features of complexity applied to economic systems: i) heterogeneous agents interact with each other within a specific local environment of a given space; ii) the absence of a global controller that can exploit all the opportunities or interactions of the economy, although there may be weak global interactions, iii) a hierarchical organization with many intersectorial interactions iv) continuous adaptation through learning and evolutionary agents; v) continuous innovation, new markets, technologies, behaviors and institutions that create new niches within the system, and vi) non-equilibrium dynamics with either none or multiple equilibrium states, which are unlikely to reach a global optimum.

Second, Heyman, Perazzo and Zimmerman (2011) suggest eight characteristics of a complex system: (i) in this system the whole is more than the parts, which leads to the existence of emergent properties, (ii) it has multiple scales of space and time, which is another way of asserting the existence of emergent properties but now at different levels of analysis, (iii) it shows micro variability consistent with macro stability, which refers to both the emergency and the ability of self-organization, (iv) it possesses hierarchical organization, in the sense of the architecture of the complexity posed by Simon (1969) where the components of the complex system are themselves complex systems, (v) it contains information, in the sense that the parties are communicating somehow together with the environment, generating dynamic organization and assembly. Thus it suggests that the components interact with the environment and it is based on decentralized interaction or dynamic patterns which emerge from the organized system as a whole, (vi) the system has adaptive or systemic learning

based on interaction means, (vii) it shows simplification, ie not all the properties of its components and interactions reflect the overall behavior, allowing analysis to circumscribe a set of relevant properties, and (viii) it has antagonistic regulatory mechanisms whose joint action maintains it in an equilibrium state.

It is interesting to note that when the definitions of systems are based on a list of features, it is not clear in general whether a system is complex if it satisfies one, several, or all of the features listed, therefore a strong underlying definitional ambiguity remains. Moreover, many of these features are associated with each other or are mutually implicated. At the same time, although some overlap predominant characteristics listed, the coincidence is not perfect. For example, to Rosser systems that lead to strange attractors are complex, while stressing that Stengers Prigogine indeterminacy is a key feature. Moreover, while Arthur et. al. stress Drozdz Kwapiena and nonlinear relationships, this point is not mentioned as relevant in the definition by Heyman et al, but they are not ruled out by these authors. Regarding to equilibrium, there are also opposite positions. For example, the definition by Arthur et al seems contradictory in this respect because they claim that complex systems exhibit non-equilibrium dynamics and on the other hand propose that a complex system exhibits multiple equilibria unspecified a priori.

In the absence of an agreed upon definition of complexity, especially for the social sciences, our proposal is that both the composition of a system and its result in terms of meta-stability and self-organization in a critical condition are relevant. Table 1 summarizes a synthesis that proposes five dimensions than account for 15 elements present in different definitions of complexity.

The first dimension refers to ***heterogeneity***, and it is related to the ability of the system's components to adapt and evolve. This feature, in turn, combines on one hand with the possibility of generating novelty endogenously (creative responses of economic agents) and on the other by selecting the relevant attributes on the basis of the interaction with the environment, from the learning process and capability building. These features make complex systems, adaptive ones. Heterogeneity manifests itself at different levels of analysis.

The second dimension refers to the presence of ***interactions*** between the system's components. The interactions are intentional and are located in a multidimensional space. This means that the components can change their location and their specific links from displacement along different dimen-

sions of space. This assumption is related to various issues associated to the characteristics of the information. On one hand, the information is local and therefore partial, however, the overall system can process information based on its distributed operation. While recognizing the possibility of global interactions (each component exchanges information with the rest of system's components simultaneously), they will tend to have less strength than local interactions (each component exchanges information with its neighboring components in the multidimensional space with which it is linked). In this regard, the prevailing partial information prevents the existence of a global controller. The interactions are crucial, and its characteristics are more relevant to the global dynamics of the system than the characteristics of the components by themselves.

Table 1. Five dimensions of complexity ontology

I. Micro-meso-macro heterogeneity	1. Learning and adaptation. Interactions with the environment
	2. heterogeneous learning agents, endowed with creative capacity
	3. heterogeneity among systems (meso-macro)
II. Interactions	4. Linkages more relevant than components
	5. Absence of global controller. Local and partial information
III. Network archiquecture	6 Hierarchy organization
	7. Modular, decomposable structure
IV. Disequilibrium and divergence	8. Positive feedbacks
	9. Far-from-equilibrium dinamics
	10. Uncertainty and indeterminacy
	11. Path dependency and non periodicity
	12. Absence of global controller
V. Emergent properties	13. Multiples scales of analysis
	14. Novelty
	15. Micro variability compatible with macro regularities

Source: Authors' elaboration

The third dimension is associated with the type of a***rchitecture of the***

network of interactions that complex systems present. In this regard, there are two key attributes, on one hand, the presence of hierarchy in the sense of Simon (1969) - according to which a complex system consists of other subsystems that are also complex-, and on the other hand, the presence modular structures, whereby interactions within subsystems are more dense than interacions with each other. The modular system has resilience, ie the ability to absorb exogenous shocks and maintain its functionality.

The fourth dimension refers to ***disequilibrium***. First there are the differences between order and equilibrium, the capability of self-organization arises from the system's ability to exchange with the environment and the existence of nonlinear relationships and positive feedbacks inside it, under conditions of uncertainty. In this context, the system is indeterminate but the uncertainty is not total. The dynamics of the system is associated with its initial conditions and its own history (path dependency). This can result in the system dynamics leading to divergent paths and lock-in situations, therefore there is no guarantee of a global optimum.

Finally, the fifth dimension is constituted by ***emergent*** properties. These properties are the result of multiple interactions at different scales of analysis. The fact that complex systems present various scales of space and time means that the results of each scale cannot be derived linearly from lower scales, and show specific attributes in each case. The macroscopic regularities (compatible with small-scale variability) is in itself an emergent property of the system.

Two paths of complexity in economics history.

Different conceptual elements of the complexity approach that have currently been adopted by several economists can also be read in different authors all along the history of economic thought. Actually, the adoption of the complexity approach by evolutionary economics is grounded on the fact that the contributions of its predecessors are consistent with much of the ontological assumptions of complexity discussed in the first section. In this section we will show two possible paths of the history of economic thought where different aspects of the five dimensions of the complexity ontology can be recognized. The first path, identified by Metcalfe (2010), is focused on issues such as self-organization and self-transformation. However there is a second alternative path, opposed to the first one, that can be identified behind the concepts of feedback and divergence.

According to Metcalfe (2010), there are numerous predecessors of the

ideas of complexity in economics. In this direction, he traces a path from Smith to Hayek, including Marshall, Schumpeter and Knight. In those authors, a connection between complexity and the interdependence between order and economic development can be found. Metcalfe proposes that the ideas of these authors are of great importance, particularly those related to our understanding of the division of labor and the role of innovation to stimulate the processes of coordination and self-transformation. Therefore, the economic system is in continuous disequilibrium generated by innovation -economic growth reflects the growth of human knowledge- and therefore order became a better concept than equilibrium to cope with the problem of coordination (Metcalfe, 2010:46).

Metcalfe suggests that division of labor, closely linked to coordination problems, leads to the division of labor in the production of knowledge, and therefore to innovation and to problem transformation. Consequently, the organization of the production problem is analogous to the problem of the generation of new knowledge. The first one has to deal with the complementarity between production of goods and services and the second one with the complementarity among different types of knowledge (internal and external). The interactions among diverse parts of the systems leads to a complexity approach that can account for subsystems highly connected inwards and loosely coupled with each other. Redundancy of linkages allows the system to have meta-stability properties like the distributed systems described by Simon (1969). All these ideas are consistent with a Schumpeterian view of innovation as new combinations of existing knowledge and the Smithian idea of innovation driven by specialization, which leads to further learning and deeper and more detailed command in different spheres of knowledge. However, the generation of new knowledge is largely a product of the combination of knowledge among complementary types of expertise already existing in the system. Therefore, interactions, although always local (and not only because of the bounded rationality agents but because there is an incomplete net of interactions) are sufficient and, therefore, efficient to give order to the system (Hayek, 1945). In this context, order and self-transformation of the system (development) are closely linked. However, order is not equilibrium, since equilibrium requires global interactions and not local ones, which means perfect connections among all parts of the system. Also, in equilibrium economic agents would satisfy their expectations, and therefore they would not have incentives to introduce any novelty into the system.

According to Metcalfe, after 1945 the dominant trend in economics favored the idea of equilibrium, a natural consequence of their main con-

cern: rational coherence of economic relations (Metcalfe, 2010: 47). The Hayekeian idea of order (1948), opposed to equilibrium is the response to the need to recognize some level of predictability in the economy but also emergent novelty from within the system. Therefore, the system can never been in equilibrium by the very nature of the process of economic competition that leads to innovation[8]. This issue is present in Hayek but can also be found in Marshall and Schumpeter -although the latter differs strongly from the former since Schumpeter considers equilibrium as temporary, almost absent, in the system dynamics immersed in the process of creative destruction. The idea of order does not eliminate heterogeneity or emerging novelty. Order is a basic idea of complexity, present in various concepts of this approach such as self-organization and emergency, discussed in the previous section.

Similarly, Metcalfe (2010) states that Hayek also differs from Marshall, he argues that competitive equilibrium is a contradictio in terminis. According to him "racing is a verb, a verb is a word that expresses a doing, an action a process. However, in the steady state of perfect competition it refers to no action, but a state of inaction". Hayek main question arises as how a society solves the problems of knowledge processing when information is distributed, and therefore knowledge is scarce and partial. The answer given by Hayek -which is claimed by evolutionist authors like Metcalfe and Antonelli- is on the very definition of competition. According to them the process of competition is first, and above all, a process for discovering new knowledge based on the combination of specialized and scarce private knowledge. This has disturbing consequences, says Metcalfe: in a broad sense competition is the answer to a never-solved-problem, because each solution process opens up new possibilities and new demands. At this point Metcalfe breaks with the problem of scarcity and moves on to the question of self-organization to self-transformation. Hayek argues that scarcity is a problem and problems invite to solutions, so scarcity becomes the instigator for the search of new knowledge. In fact, this is the most dynamic of the concepts and more incompatible with the idea of a steady state in knowledge dynamics. Within this line, the origin of the change relies on scarcity and on the problem of self-organization derived from it.

As postwar neoclassical economics is guided by its concern for coherence and rationality, the path that identifies Metcalfe in economics history, is guided by his concern for the introduction of novelty and structural change under disequilibrium but ordered conditions. Nevertheless he is

8 Hayek (1946) suggests that the economy, as human knowledge is restless since both are distributed unevenly across the economy and society.

not interested in studying the causes that lie behind the divergent economic structures with unequal levels of development. In this sense, his idea of structural change refers to the continuous changes that occur in the participation of firms (or sectors) competing in different populations. Therefore, the path that leads to Metcalfe links ontologically this set of authors (from Smith to Hayek) but downplays issues like creativity, feedback and divergence.

Conversely, if the main concern is the divergence of development patterns and their relations with the productive structures, then a different but complementary path can be traced. Some authors share this second path with the one proposed by Metcalfe, but it differs in others. It is a complementary path because it deals with the relationship between feedback and divergence of systems at meso and macro level, while the trace by Metcalfe emphasizes coordination, self-organization and self-transformation. This second path goes from Smith to Myrdal and Hirschman, through Marshall, Young, Schumpeter[9] and Kaldor, and it may extend to the present day if we include new contributions from Latin American structuralism (Cimoli and Porcile 2013). In this path notions of interactions between heterogeneous agents, feedbacks, emergence and far-from-equilibrium dynamics are considered. On the other hand, it is also connected with convergent or divergent dynamics of production systems, be they local, sectoral, or national systems of innovation.

The relation between increasing returns and development has always had an important place in economic thinking. Its original formulation is in Smith's famous thesis about the connection between division of labor and market size. The Smithian perspective refers to productivity gains associated with market expansion, which in turn leads to a greater division of labor and to the subsequent introduction of innovations. However, Walrasian economy led to a shift of interest from a dynamic and evolving economy to a static and equilibrium-focused one, where the mechanism of self-transformation of endogenous structures were absent. Thus, the famous Smithian thesis was set aside off the neoclassical road. There were,

9 Adding Schumpter to this second path requires some clarification. It is well known that in the circular economy chapter of his book Theory of Economic Development (1912), he uses general equilibrium. Nevertheless, as suggested by Langlois (2007), he does it in a merely narrative sense, in order to show the importance of disequilibrium in the development phase. Therefore, his use of general equilibrium conditions is not relevant. Following Langlois (2007) there are no two Schumpeters one of equilibrium (1912) and another of disequilibrium (1942 and 1947). In fact, the way he states the idea of creative destruction in all three texts is the same. In The Theory of Economic Development he uses general equilibrium as a starting point for his pedagogical explanation of a process of continuous disequilibrium, in which the position of the incumbents in the circular economy is challenged by new agents that introduce novelty into the system.

of course, exceptions that are noteworthy.

First, Marshall has made a major contribution by analyzing the micro-complexity arising from the interactions between organizations in a specific territory and the emergence of localized externalities. The Marshallian distinction between increasing returns internal to firms, on the one hand, and those external to the firm but internal to the industry, on the other, not only was important because it allowed to justify why increasing returns not always lead to monopoly but mainly because it gave an explanation of the relationship between market growth, division of labor, knowledge generation and increasing returns in industrial activity (Young 1928). In this sense, Marshall has pointed out the existence of a feedback link between the micro dynamics of individual firms and the generation of external economies at industry level.

Secondly, Young (1928) has linked increasing returns with economic progress including notions of micro-evolution, structural change and disequilibrium. In that direction he has pointed out that the dynamics of economy is characterized by novelty and qualitative change:

> "Out beyond, in that obscurer field from which it derives its external economies, changes of another order are occurring. New products are appearing, firms are assuming new tasks, and new industries are coming into being. In short, change in this external field is qualitative as well as quantitative. No analysis of the forces making for economic equilibrium, forces which we might say are tangential at any moment of time, will serve to illumine this field, for movements away from equilibrium, departures from previous trends, are characteristic of it." (Young 1928, p. 528).

At the same time, he has stressed the importance of both internal and external economies to firms arising from changes in direct and indirect methods of production and labor productivity associated with market expansion. According to Young, the production structure is not an exogenous characteristic of an economy but an endogenous result of capitalist dynamics, which from today's complexity approach would be understood as an emergent property of the productive system. Young has shown that every change in each part of the system changes the composition and organization of the system structure and feeds new waves of technological change through new flows of externalities.

So far it is clear that in this path the concern is on structural change and development as a disequilibrium process, in which industry-level increasing returns and complementarities among sectors prevail, and in which

new sectors appear and disappear within a framework of a strong volatility of entry and exit of firms in the competitive process. If the central question were about self-organization and, in particular, were focused on the understanding of how make compatible development, self-transformation and structural change with economic order, then Hayek would be the one to provide the answer. However, if the central question is about feedbacks and divergence, then, the development school will be the one who collect this background on increasing returns, interaction and structure change to explain the phenomenon of divergence between productive systems. That is, beyond the order exhibited by systems taken as interdependent units, increasing returns at the industry level resulting from interactions cause divergence between them. This is the starting point of development theory: how to account for the differences among economies. Many of their arguments, as it is discussed below, are in line with the approach of complexity.

The school of economic development (Hirschman 1958; Rosestein-Rodan 1943; Prebisch 1959; Myrdal 1957) placed much of this set of issues in a discussion of the specific problems of underdevelopment. From this perspective, the productive structure of the peripheral economies was a key factor limiting their development. This is explained by a pattern of productive specialization where products that use abundant resources (agricultural and mining commodities) prevail. These activities show low presence of increasing returns, short productive chains, and few horizontal and vertical linkages with the rest of the production system. The dual structure with a highly productive sector and others of low productivity tends to generate Dutch disease giving rise to processes of exchange rate appreciation that further limit development of the low productivity sectors.

In this case, the feedbacks do not refer to the interaction among firms but among productive sectors that lead to the emergence of externalities, and among macroeconomic aggregates causing diverging dynamics between developed and developing countries. For example, Myrdal (1957) showed that the divergent paths countries feedback due to the existence of cumulative causation processes between immigration, wages, and employment. He claimed that the investment rate depends positively on the level of income of the previous period, which was reinforced through various mechanisms such as the existence of increasing returns, increased productivity and immigration flows. According to Myrdal (1957), economic growth was generated in the receiving areas and de-growth in the areas that lose population. This dynamics produced additional disparities

in wages and employment, and led to new emigration processes and to a circular and cumulative causation of migration.

In turn, Kaldor has established a long-term relationship between the growth of output and the growth of productivity, popularized as the Kaldor-Verdoorn relationship. He has analyzed the effect of this relationship on the existence of development paths under disequilibrium conditions. During the 60's, Kaldor developed his theory of cumulative causation and its effects on dynamic increasing returns, growth and productivity. In this context, the Kaldor-Verdoorn law summarizes some effects of nonlinear dynamics and feedbacks arising from the relationship between output and productivity growth. Other Keynesian and Structuralist authors (like Thirlwall 1979) followed a similar path and also considered the relevance of the economic structure and the pattern of trade specialization in terms of income elasticities of different exports and imports. Thus, these authors, faithful to the Keynesian tradition, have been thought to demand a key role in explaining the differential rates of growth of output.

Despite presenting a largely sectoral approach, these authors represent a concern for the weaknesses of capability development and learning processes at the micro and meso and technological accumulation derived: (i) from the relation between international competitiveness and local technological capabilities, (ii) the lack of exploitation of increasing returns, and (iii) the reduced importance of knowledge complementarities in production structures in developing countries.

Table 2 Two alternative path of complexity in economic thinking

	Order	**Transformation**
Monoeconomics (unique economic system)	**1st path:** Smith-Marshall-Schumpeter-Hayek-Knight	
Divergence among systems		**2nd path:** Smith-Marshall-Young-Schumpeter Kaldor-Myrdal-Hirschman

Source: authors' elaboration.

Sumarizing, in a stylized description, these two paths could be organized in terms of two key dimensions: prevalent order -*vis á vis* transformation-

in production systems and the prevalence of heterogeneity and divergence between production systems as opposed to the consideration of a single economic system that does not distinguish between developed and developing economies. In the first, tradition can be localized in the box "order and unique system", while the second tradition would be on "transformation and divergence among systems" (see Table 2).

These two paths are taken up by different authors of the current evolutionary economics discussed in the following sections. It is relevant to note that both complementary elements have been collected from a complexity perspective. Although from a development perspective, the second trend looks more attractive, a convergence between the two would enrich it from the perspective of associated self-organization and self-transformation, ie giving more prominence to competition in microeconomic processes. To do this we need a greater convergence within evolutionary ontologies, as presented in the following sections.

The ontological assumptions of evolutionary groups in economics.

Current evolutionary trends in economics and, in particular, Neo-Schumpeterian evolutionism are strongly heterogeneous. Although this heterogeneity is reflected in higher specificity ontological assumptions, there are some common starting points accepted by most. In turn, there are other assumptions that without been shared can be considered complementary and lead to different classifications of ontological evolution. As we suggested in the introduction, study of ontological foundations allows us to clarify this heterogeneity.

Evolution has made a major effort aimed at the discussion of its ontological bases. Some examples of this are Dosi and Nelson (1994), Metcalfe (1998), Potts (2000), Dosi and Winter (2002), Dopfer (2004; 2005), Dopfer and Potts (2004), Hodgson (2004; 2007), Witt (2004; 2008) and Vormen (2004). These works are not only the basis for the construction of evolutionary ontology, but have also established the specificity of the current Neoschumpeterian evolutionary economics, from another group of evolutionary thinking in economics, related to the old American institutionalism and other trends.

Therefore, in this section, we present Witt (2008) and Hodgson's (2007) suggestions for placing evolutionary thinking among other streams of thought, based on a discussion of its ontological and methodological assumptions. Then we discuss the construction of an ontology of Neoschum-

peterian evolutionary economics by Nelson and Winter (1982) and Dosi et al. (1988), and further developed by Dosi and Nelson (1994) and Dosi and Winter (2002). And finally, we consider the contributions of Metcalfe (1998) and Dopfer (2004, 2005). The latter has made a significant effort to build the axioms and basic laws of evolutionary economic theory.

Witt (2008) makes a distinction between different currents of evolutionary thinking in terms of the ontological assumptions and heuristic strategies they have adopted. His analysis and classification are based on the premise that there are two ontological levels, a monistic one according to its continuity hypothesis, which considers that nature and economy are two interrelated spheres of the same reality. And a dualistic one, which states that economy is independent of nature, marking a break between natural and social laws. In turn, he considers two heuristic strategies, independent from the ontological perspective. On the one hand a heuristic strategy based on the use of analogy and metaphor, which borrows models and analytical tools from biology. This strategy proposes that the three basic principles of Darwinian evolution: variation, selection, and retention can be seen as abstract concepts able to be applied to any other domain. The use of analogies and metaphors can be very useful for advances in theory. However, it can also can present problems because analogy may be incomplete or may have aspects of biological evolution that cannot be transferred to the social field. A second heuristic strategy refers to the use of a generic concept of evolution, in a broad sense. This concept can be applied to any entity that evolved genes, languages, technology. Although these entities may change over time in response to exogenous shocks, their genuinely evolutionary feature is that they can transform endogenously.

From this, four possible groups emerge, of which the current economic evolutionary thinking (Nelson, Winter, Dopfer, Metcalfe, Saviotti, Dosi, Antonelli, Arthur) is located in a heuristic based on an abstraction of Darwinian principles and ontological dualism, and a heuristic strategy based on the use of metaphors to conceptualize Darwinian development in economics. Meanwhile Schumpeter is aligned with the group that subscribes to a dualistic ontology and a heuristic that has a generic concept of evolution that uses metaphors but without accepting that there might be some connection between economics and biology. For example, although Schumpeter argued that the creative destruction process that revolutionizes the economic structure endogenously constituted a mutation process continuously destroying the old and creating new elements, he apologized for using the word 'mutation'.

Within the ontological assumption of continuity Witt identifies (i) the naturalists identified with the institutionalists (North, Veblen and Hayek), and (ii) the environmentalists (Georgescu Roegen) and (iii) generalized Darwinism supporters (like Hodgson (2002) and Hodgson and Knudsen, 2004; 2005) among others subscribing a monistic ontology. In short, most of the authors who contributed to the evolutionary theory of innovation –and we include in the analysis of the next section– collected from a set of biological evolution metaphors or analogies that apply to technological, productive and economic processes, but differentiate natural and social spheres of reality.

Hodgson suggests that the specificity of evolutionary thinking lies in the intersection between an ontological criterium based on the relevance of change and transformation and a methodological criterium that refers to reductionism-antireductionism. Change as ontological criterium is inherent to evolutionary economics, in this case innovation is a result of transformation. For Hodgson, the root of ontological change is related to the uncaused cause of Austrian economics, ie. a response that cannot be explained by any existing situation, a concept akin to Schumpeter's creative response (1947). This ontological assumption sets him outside evolutionism to Spencer and Marshall, although these authors frequently resort to biological analogies. It also leaves out classic authors such as Marx and Smith because, even when they include in their vision change and transformation they do not identify them as a primary cause, but a result of accumulation and markets expansion. Moreover, the anti-reductionist methodological criteria which refer both to the impossibility of explaining the totality from its parts, and also –clarifies the author–, to the ability to understand the parts as a result of the totality[10]. This approach is therefore anti-reductionist and anti-holistic, producing micro-macro co-evolution to the presence of emergent properties. According to Hodgson, this would leave out some Austrian authors such as Schumpeter and others as Loabsby and some aspects of the works by Hayek. In this sense the intersection between the two criteria (ontological and methodological) gives rise to what he calls antireductionist evolutionary economics, reflecting the characteristics of the current Neoschumpeterian evolutionism and includes the authors to be discussed in the next section.

However, Witt's heuristic and ontological dimensions (monistic-dualistic) and Hodgson's methodological and ontological *criterium* (change as uncaused cause), while contributing to understand the specificities of the evolutionary thinking and other, may not be adequate to understand all

10 He says: another version of reductionism (Hodgson, 2007:130).

the ontological aspects neither to clarify the heterogeneity within.

In the rest of this section we discuss Nelson, Winter and Dosi´s ontology and Dopfer, Metcalfe and Potts´s contributions. As anticipated in the introduction, these ideas will allow us to identify, in the following section, five different groups inside the field of economic evolutionary thinking.

Within a tradition marked by Nelson, Winter and Dosi, there is a set of ontological assumption of evolutionary thinking in economics that are repeatedly mentioned. This set of assumptions is made up of the following points.

First, they stress the presence of bounded rationality and environmental uncertainty that i) limits the access to information, ii) restricts the skills and capacity building and iii) limits the perception of preferences and representations of the world that organizations have. Bounded rationality and non-modelable uncertainty explain why firms act through routines, subroutines and repertoires that are generated along their evolutionary path, that shape their productive, technological, organizational and commercial capacities (Nelson and Winter, 1982).

Second, these routines i) constitute the organizational memory through which firms develop their productive and commercial activities, ii) include instructions that allow firms to replicate themselves and imitate other firms, and iii) are tested when conflicts appear and deliberative actions are needed, which will raise changes in the existing routines and give rise to new ones. This routinized behavior[11] and the habit-driven behavior presented by Hodgson (2010)[12] explains why economic agents make choices without deliberations. That is, know-how and know-to choose, which are very different in the neoclassical model[13], are part of the same knowledge in evolutionary models and require automatic use of the routines and habits built in the past.

Third, the firm as a set of routines is common to different evolutionary ontologies, because innovative behavior is printed in these routines. According (Nelson and Winter 1982, p. 133) routines include "all of the pattern of organizational activity that the observance of heuristics produces,

11 Hodgson (2010) has pointed out the importance of habits in opposition to rational choice. According to him agents act within socially preset parameters to cope with uncertainty, complexity and change. These parameters are defined locally depending on the scope of the connections of actors with bounded rationality.

12 As opposed to rational choice, Hodgson (2010) has pointed out the importance of habits in the behavior of economic agents. He considers that agents act within socially pre-established parameters to cope with uncertainty, complexity and change. These parameters are defined locally depending on the scope of the connections of actors with bounded rationality

13 "What to do" or know-how derives from the production function to which they have access and "what to decide" of know-to choose arises from the profits maximizing decision rule.

including the patterning of particular ways of attempting to innovate"

Fourth, the presence of persistent heterogeneity in preferences, endowments, routines and performance and the immanent possibility of novelty are two ontological assumptions that can be derived from the above. Other assumptions, also derived, are the presence of interactions that operate as mechanisms for information exchange and coordination and selection processes, which give rise to differential growth among firms.

Finally Dosi (2013) highlights two issues that will be addressed further in the next section: i) the presence of a system's emergent properties considered as the collective result of unintended far-from-equilibrium micro-interactions among heterogeneous learning firms and ii) the emergence of organizational and institutional forms which are the product of intentional actions of agents. Dosi has made an important contribution when stressing that the assumption of persistent heterogeneity derives mainly from the process of selection within the firm and not through market in the tradition of Schumpeter.

Another important contribution to set up an ontology of evolutionary thinking was developed by Dopfer (2004). He has proposed an axiomatic construction that explains the workings and dynamics of a neo-Schumpeterian evolutionary system. Departing from the non-explicit objective to specify the ontology underlying Nelson and Winter's (1982) evolutionary dynamics, Dopfer (2004) argues that evolutionary ontology is based on four laws and three axioms. The first law –discontinuity manifests itself in mutation and differentiation of components of the system (firms, institutions, etc.). The second law –adaptation refers to the existence of relationships between parts of the system, whose characteristics influence differential development of capacities. The third law –selection gives specific directionality to the system dynamics. Finally, the retention law refers to the meta-stable condition. Variety, selection and retention are common elements to various evolutionary ontologies, but not always all authors refer to these as laws. For example, Dopfer's discontinuity law can be identified with the principle of generation of variety (Metcalfe et al 2006, Nelson and Winter, 1982, Dosi and Winter, 2002, Dosi, 2013) that accounts for the introduction of novelty among components of a population in at least one relevant feature considered from the viewpoint of selection. This is similar to the idea that changing organizational, technology, production and marketing routines of the firms –what Nelson and Winter (1982) and other evolutionists call innovation.

The principle of selection includes the second and third law that Dop-

fer proposes. It accounts for the institutional mechanisms that reward or punish business decisions with temporary economic profits. In Metcalfe (2010), these mechanisms have an institutional character. They are manifested in the evolutionary process of competition (Metcalfe 2013), which includes a wide range of institutions such as rules for appropiability of rents, competition policy, intellectual property rights, among others. Besides, in the selection process, the characteristics of the components of the population are not relevant per se, but those that are subject to an environment that exerts common selective pressure. Being in competition with each other, selection characteristics are mutually interdependent. The retention principle can explain the way in which a characteristic spreads and is embodied in a routine, either within the organization (Bottazzi and Dosi 2010) or between organizations in the copying, imitation, and diffusion processes (Metcalfe 2010).

This set of laws - of discontinuity or generation of variety, adaptation, selection and retention-are an evolutionary scheme. They require the fulfillment of three axioms: First, real phenomena are a physical actualization of matter-energy and information in a rule, which means that this can lead to multiple actualizations (axiom 1). Second, actual phenomena are manifested as relationships and connections (axiom 2). Third, these real phenomena are path dependent processes (axiom 3). According to the axiom 2, the linkages are information updated as process (axiom 3) and they represent knowledge. The contribution of this ontology is relevant because it stresses the articulation of the micro and macro levels based on the meso level. While the meso level is characterized by various features to actualize a rule generated at the micro level (different sets of routines corresponding to the production of goods and services in a population of firms competing in the same market), the macro dimension includes the set of rules generated at the micro level with multiple actualizations, ie it represents the state of the technological and organizational practices at a given moment of time (without annulling its heterogeneity within each population) of all goods and services available and traded in the market. Thus, according to Dopfer this ontology is not reductionist from the macro to the micro[14]. It is a non-plane epistemology that retains analytically the set of rules and their multiple actualizations both at a meso and macro levels.

This evolutionary ontology considers the existence of agents with cre-

14 This ontology allows us to understand that the overall characteristics of the system, that are consistent with individual behavior, may not be deduced from the behavior of a representative individual agent.

ativity and imagination that give rise - in a Schumpterian sense, to new combinations in an environment that while affecting agents' supply and demand decisions is also disturbed by their behavior and the introduction of novelty. The trajectory of the economic process begins with the introduction of novelty in the firms, which is followed by different reactions and processes of adaptation and selection that finally lead to a metastable state. The process begins with the creation of novelty, conceived as the result of creative skills and imagination of the agents manifested in the generation of a new rule (organizational, productive, technological and commercial) at the firm level. This new rule can be assimilated to the set of routines, subroutines and repertoires that Nelson and Winter consider as the skills of the firms. In a second step the rule adapts both at a firm level and within the environment. This occurs through a process of actualization of the rule according to which each agent, within a population of competitors, adopts the rule idiosyncratically resulting in a strong variety of the same rule. Finally, in a third step, the rule is retained in a context of much less heterogeneity of actualizations, which were tested in a selective context.

Evolutionism-cum-complexity: The current trends in complexity and economy of innovation, common elements and conceptual differences.

In this section we present a taxonomy of evolutionary authors according to their main concern and the main contributions they have made to the theory. This taxonomy is composed of five groups: (i) Habits and Routines, (ii) Innovation Systems, (iii) Cumulative Causation, (iv) Self-organization /Self-transformation and (v) Feedback and Increasing Returns. We will focus both on adherence to the ontological assumptions and on the degree of agreement with the five dimensions that account for the complexity ontology: (i) heterogeneity, (ii) interactions, (iii) network architecture, (iv) disequilibrium and divergence, and (v) emergent properties.

The first group, Habits and Routines, includes the contributions of Nelson, Dosi, Winter, Hodgson, Teece and Pisano, among others. This group is defined by their interest in learning processes at firm level and in the behavior of economic agents and institutions within a framework not always strictly evolutionary, though it relates to institutionalism on one hand and management studies on the other. The dynamics of organizations is explained by the routine building processes under the assumption of bounded rationality and by the changes in an uncertain environment. The

authors of this group aim to contribute to the development of a theory of the firm, its behavior and organizational learning. In this regard, they are classified by the relevance assigned to habits and routines in order to explain capability building and evolutionary dynamics of organizations, firms and institutions. According to Nelson and Winter, the firms are made up of a set of routines and subroutines and different repertoires that are executed by members of the organization in disequilibrium. Hodgson shows that habits –contrary to rational choice– are the main driver of agents' behavior. Habits are not contradictory with deliberative actions, because they can be seen as based on it all along the evolutionary process. Habits are also coherent with the limited computational capabilities of the human brain and the uncertainty of the environment.

The second group, ***innovation systems***, includes authors who have emphasized the systemic dimension of innovation and technological change on the basis of concepts such as clusters, local, regional, sectoral and national innovation systems. This group is the largest because of the large scope of the subject matter. It includes authors like Freeman, Edquist and Lundvall associated to innovation studies, Nelson Malerba, Breschi, within an evolutionary framework and Boschma, Martin, Frenken and Antonelli, closer to the complexity approach. All these authors have in common their taking into account the systemic nature of innovation. They place the innovation and learning process in a central place, they adopt a holistic, interdisciplinary approach and they employ a historical perspective. In this regard, they emphasize the differences between systems and recognize the existence of divergent paths among them. Their analysis highlights elements such as interdependence, nonlinearity, and the centrality of institutions (Edquist et.al. 2001).

The third group is called Cumulative Causation because they emphasize the complementarity of Keynesian, Schumpeterian and Kaldorians sources of growth. This group includes authors like Dosi, Saviotti and Pyka and the contributions that evolutionary authors made to international trade (Dosi, Pavitt and Soete). In the latter we can recognize the centrality of absolute advantage for developing successful (or pernicious) types of insertion in international trade on the basis of exploiting opportunities of an expanding demand. Beyond their contributions to economic development and their efforts to generate a theory of structural change, in recent years these authors have advanced onto a rather neglected issue in evolutionary theory –the role of demand and cumulative causation mechanisms of variety generation. In this regard, with unequal strength, they prioritize the analysis of macro regularities.

The fourth group –called Self-organization/Self-transformation– is characterized by its strong evolutionary and Austrian roots. The former can be seen in their interest in explaining self-transformation of economic systems and population dynamics driven by variation, selection and retention. The latter emphasizes economic order as an endogenous result of nonequilibrium decentralized interactions among system components. The authors included in this tradition are Dopfer, Metcalfe, Potts, Witt Foster and Antonelli among others.

Finally, the fifth group, which we call Feedback and Increasing Returns, consists of a large stream of thought identified with complexity economics at the Santa Fe Institute (Arthur et.al 1997, Durlauf , 2005, Holland, Blume, Maxfield, Sheikman, among others). They have been applying different ideas of the complexity approach to economics. Especially decentralized interactions at micro level and feedback and non-equilibrium dynamics derived from it. These feedbacks lead to the presence of increasing returns and divergent paths among systems[15].

As expected, the proposed classifications have not clearly defined boundaries. Each group is named based on the main contribution made, therefore some authors (Dosi, Nelson, Antonelli) belong to more than one group, while others are assigned to a specific group despite having made contributions in other dimensions of evolutionary thought (Saviotti, Malerma, Boschma, among others).

In table 3 we present the relationship between the authors' taxonomy and the five dimensions of complexity ontology discussed in section 1.

In the group Habits and Routines, ***micro-heterogeneity*** is seen in terms of heterogeneity of routines, habits and capabilities. This heterogeneity is the result of differentiation strategies of the firms endowed with bounded rationality and interacting in an uncertain environment. Differentiation is the starting point to analyze the dynamic of competition, where organizational learning process, developed through firms' evolutionary path is a key factor. In this framework, the routines are changed in order to solve non trivial problems. Therefore problem-solving and differentiation strategies lead to the emergence of innovation process, which in turn will increase the initial heterogeneity.

In this group, the ***interaction*** with the environment and the firms' access

15 They have applied non-linear dynamics not only to innovation processes but also to other economic fields like finance and stock markets. They have also emphasized that feedback mechanisms can even be perceived between behavior and institutions. This direction includes the contributions on competitive technologies and standard diffusion (Arthur, 1989) and economics of qwerty (David, 1985).

to local information let them complement their internal capabilities. With different emphasis, these authors make an analogy with biological systems[16]: The firm's individual behavior is partially determined by systemic conditions and idiosyncratic traits. Institutions bounded by the behavior of the agents' economic thought, micro interactions based on local learning and imitation can lead to changes in rules an institutions (Hodgson and Knudsen, 2004), which can be seen as emergent properties of the system.

In this group the ***network architecture*** is both hierarchical and modular. The hierarchy is an important aspect, because it refers to the learning processes of individual agents interacting with the environment. The passage from individual learning to organizational learning in Nelson and Winter (from skills to routines) and then to economic systems, shows that there are complex systems at different levels of analysis that can be seen as Chinese boxes. On the other hand, there is modularization in the way routines and sub-routines are articulated. Definition of the firm as a set of routines ordered in a modular structure (subsystems of routines highly connected inside and loosely couple among them) let firms maintain functionality beyond exogenous shocks. In the same direction, according to Hogdson, habits, beliefs and procedural rationality are the effective ways with which firms and institutions face uncertainty.

In relation to the fourth dimension, ***disequilibrium*** and divergence, the authors of this group believe that the dynamics of the system is always path dependent and out of equilibrium. As discussed in relation to the way heterogeneity works, firms change their routines and therefore innovate when nontrivial problems appear (Nelson and Winter 1982). Disequilibrium is also reflected in the presence of positive feedbacks in the learning processes at the micro level and by the complete absence of determination, because of the very nature of the innovation process (Nelson 1991).

Regarding ***emergent*** properties, although it is not specified by Nelson and Winter, the meaning of emergent properties can be read as multiple spatial and temporal scales that are present in its book (1982). According to this group implicit or explicit, institutional structures, rules and habits emerge. Firms are complex systems because feedback mechanisms between variables and emergent properties are present. Therefore, the firm exhibits the traits of division of small-scale knowledge and labor on a micro scale.

Within the Innovation Systems group, heterogeneity is also a very important factor, as the development of these systems is the product of the con-

16 Nelson and Winter consider routines as genotypes and firms like phenotypes.

tinuous generation of micro-diversity and its resolution via local diffusion processes of knowledge and technology and its feedbacks operate locally (Antonelli, 2008). Particularly in this case interactions lead to local diffusion of knowledge and technology, because of the specific characteristics of technology and knowledge (synchronic and diachronic complementarities) and the functioning of the institutions, embedded in the territory (Maskell and Malmberg, 1999). Therefore, for this group heterogeneity is present both within and between systems.

The role of ***interactions*** is key to understanding the dynamics of firms and systems to which they belong. Interactions between components of the complex system can generate positive feedbacks that amplify individual responses, resulting in aggregated dynamics that cannot be deduced from the linear aggregation of its components. In turn, these feedbacks generate divergent dynamics among local systems that can lead to persistent heterogeneity. The responses of each firm to changes in environmental conditions or to changes made by other co-located firms lead to answers that can be multiplied at the system level. Thus, interactions that generate externalities multiply through feedbacks leading to increased returns and divergent dynamics. In the discussion held within evolutionary geography on the role of the territory in a context of ICT diffusion, various authors have stressed the need to expand the dimensionality of space beyond the geographical dimension. In particular, Boschma and Antonelli are interested in analyzing the network structure in multidimensional space in a framework of incomplete connections. For example, social distance is taken into account by using social network analysis (SNA). This tool also allows to consider the network structure and the relative position of firms in the network and is relevant to understanding both the individual dynamics (central or peripheral or bridge positions are not equivalent) and global (some network structures favor differentially the creation and circulation of knowledge).

Linked to the last dimension, ***network architecture*** is central. Modular structures allow organizations to maintain the operation of a cluster or local system beyond the firms' turn over therein. A hierarchical architecture is generally implied, in particular within the vision of the national innovation system as complexity unfolds at different scales of analysis: firms are in themselves complex systems and then the systems that they make up are also complex at local, sectorial, and national level.

Table 3 Complexity ontological assumptions in different groups of authors.

	G1. Habits and Routines	G2. Innovation systems	
A1. Micro-heterogeneity	Heterogeneity in routines, habits and capacities derived from differential processes of learning and adaptation to the environment.	Heterogeneity within and between systems.	
A2. Interactions and partial information	Interaction with the environment for capability building	Connections between agents are incomplete and have costs. Multidimensional Space	
A3. Network architecture	There is a structure hierarchy of routines and subroutines.	Complex systems at firm, local, sectorial and national level.	
A4. Desiquilibrium	Uncertainty about the nature of the innovation process. Disequilibrium and dynamic path dependent .	Feedbacks associated to local learning processes and local externalities	
A5. Emergency	Institutional structures, rules and habits..	Local, regional, sectorial). Innovation systems. Innovation as a result of micro-macro simultaneous determination (Antonelli).	

Source: Authors' elaboration

	G3. Cumulative causation	**G4. Auto-organization/ Auto-tranformation**	**G5. Feedback and increasing returns**
	Heterogeneity of productive and technological trajectories. Priority is given to the analysis of macro regularities	Micro-heterogeneity is the fuel of the evolutionary process.	Heterogeneous agents interacting locally in a decentralized way.
	The network structure is not key in the analysis. Priority is given to the role of demand	Partial local information is articulated from network interaction to give rise to collective knowledge that leads to self-organization	Location determines connections and network structure. No global controller Information can be local or global (externalities)
	No modular structures. There is hierarchy because the analysis is micro/macro	Micro heterogeneity is retained at meso level and the meso structure is retained at macro level	Hierarchical organization and multiple scales of analysis.
	Feedback processes with demand, and structural change derived from path-dependent dynamics.	Distinction between order and balance. The adaptive process producespositive feeback and generation of variety and selection.	There are multiple equilibria (or attractors) undetermined a priori. Positive feedback and increasing returns, network economies and network externalities.
	Structural change leading to the emergence of new sectors and complexity of the existing sectors.	Emergence of order and structure, that does not invalidate micro heterogeneity.	Order: arrives at an attractor of the system between different possible attractors No guarantee of global optimality.

In relation to the fourth dimension, the authors agree with the previous group in that the dynamics of the system is path dependent and it is always in ***disequilibrium***. At the same time, there are positive feedbacks between heterogeneous agents that are manifested in particular externalities and knowledge spillovers to which firms can access according to the development of their internal capabilities (Antonelli). These externalities represent increasing returns, and lead to a divergence of paths between systems. Moreover, as it happens in modular architecture, this divergence occurs both between firms, and between regions or countries (Boschma and Frenken 2007).

In relation to ***emergence*** there is some heterogeneity especially in the case of literature on National Innovation Systems where no explicit treatment is stressed, whereas in the literature on the new evolutionary geography (Boschma) with strong links with the complexity approach, emergency precisely refers to innovation systems on the basis of local interactions. Especially in Edquist et.al. (2001) and Edquist (1997) innovation systems are considered emergent because they are the result of a historical process within a framework of interdependence and nonlinearity which results in co-evolution of knowledge, institutions and organizations and the fact that innovation is not only determined by the elements of the system but also by their interaction.

Antonelli, additionally postulates that innovation is an emergent property which he considers the result from both intentional and creative actions of firms and meso-macro conditions. The introduction of novelty is the combined result of the conditions of the system as a whole and the characteristics derived from idiosyncratic firms' capabilities. In this sense, Antonelli states that innovation is an endogenous variable. Here he moves away the formal treatment that Nelson and Winter give to innovation, where random[17] aspects holds in spite of considering innovation as endogenous changes in routines.

In the Cumulative Causation group, micro-***heterogeneity*** is partially present[18] since a macro or industry analysis prevails. When included it is only in agent based models to account for the macro or sectorial emerging dynamic.

In surn, ***interactions*** and the ***network structure*** become evident not only at the micro level, but especially between different sectors and ag-

17Antonelli refers to the Nelson and Winter's formal models of innovation which uses Markov Chains.

18 For example, in the Saviotti and Pyka's TVCOM model it remains as an assumption but is not included in the analysis.

gregates. In turn, in Dosi, Pavitt and Soete (1990) following Thirwall, Perroux and Kaldor-, micro interactions would be absent or arise from externalities (global interactions). In this case global interactions predominate over local ones at least within the system regardless of the scale of analysis. The authors of the group have a special interest in understanding long-term growth processes based on interactions generated by an expansion of demand. The Smithian idea that market expansion is an engine of economic diversification, creating opportunities for innovation, appears as the key link between Keynesian and Schumpeterian dynamics of growth. In this context, the possibility of emerging externalities that trigger growth and diversify the productive structure, relies on the characteristics of the productive structure itself, which would lead to feedback growth in the framework of Kaldor-Verdoorn relation. In this case we argue that interactions are mostly global, since the structural conditions act as a signal to all agents within a system. In the research on interactions between demand and economic growth, this group does not emphasize the question of the architecture of the network in terms of modularity and hierarchy. The hierarchy appears only on the micro-macro analysis.

Regarding ***disequilibrium***, in the TVCOM model Saviotti and Pyka consider that the dynamics of the system is explained by a continuous passage from equilibrium (schumpeterian circular economy) to disequilibrium. On the contrary, Dosi holds there is a dynamic continuously out of equilibrium. The authors of this group put a strong emphasis on the processes of feedback with demand. The processes of cumulative causation and the Smithian and Kaldorian mechanisms they consider bring them close to structuralist positions and lead them to understand divergence between economic systems beyond feedback related to knowledge and technology. In this context they stress the importance of path dependence because the dynamic processes they propose mark temporal and structural irreversibility. The issue of global optima does not obviously concern this group, since it stems from a growing economy, not considered an optimal position to aim to. However, as in all cases where feedback processes play an important role, they stress the possibility of lock-in situations caused by the nonlinear interactions. These authors refer to learning and adaptation processes that lead to co-evolution between demand conditions and technological and production conditions.

For Saviotti and Pyka, structural change is an ***emergent*** property: new sectors (unrelated variety) and new products and quality in the existing sectors (related variety) emerge as result of a larger disposable income. Dosi's ideas of organizational forms and institutions emerge. They are the

unintended result of the collective ***interactions*** of the agents in a learning situation. According to Dosi (2013) ***micro-heterogeneity*** and far-from-equilibrium interactions induce the co-evolution of aggregate variables (employment, production, etc.), where the statistical properties could be interpreted as emergent properties micro-founded in persistent disequilibrium. That is, stable relationships observed between these aggregate variables might arise from interactions and turbulent microeconomic disequilibrium. Moreover, Dosi (2013) argues that this emergence may be present at different levels of aggregation: they are aggregate collective phenomena (eg macro regularities) but also appear at industrial level and firm level.

In the Self-organization/Self-transformation group, ***heterogeneit***y is present mainly at a micro level. Heterogeneity is the fuel of the evolutionary process of variation, selection, and retention.

Local and incomplete ***interactions*** lead to the presence of partial information. This local information is articulated in a larger network of interactions, giving rise to collective knowledge. In turn, links and information are more important than system components (Kirman, Potts) in order to explain system dynamics.

In this group, ***network architecture*** is hierarchical because multiple scales of analysis (micro-meso-macro) are considered. In Dopfer, micro heterogeneity is preserved at meso level and the meso structure heterogeneity kept at macro-level. The significance of hierarchy and modularization can be seen in their definition of complex system (Dopfer and Potts, 2004):

> "a complex system is modular, open and with hierarchies. It is modular because it is formed by a set of specific parts, functional and connected. It is open because the parts interact with some degrees of freedom and can therefore continually change their connections. Finally, it is hierarchical because each module is a complex system by itself"

In this group the authors distinguish order and equilibrium and they claim that competition is a disequilibrium process[19].

For the authors of the group, faithful to the Hayekian tradition, the notion of order is appropriate and is not ***equilibrium***. Their opposition to equilibrium relies on their understanding of the economic system as a set of

19 The authors note that in a world of ambiguity and uncertainty, the "open ended"nature of market competition is the most distinctive evolutionary aspect of modern capitalism. Metcalfe adds the issue of self-transformation besides self-organization, which was Hayek's basic interest.

incomplete interactions. In this context, they consider that the traditional concept of equilibrium requires the existence of full connectivity between systems's components, which involves accepting the hypothesis of perfect information. Based on the notions of order and Hayek's distributed knowledge, they step away from traditional economic theory in which equilibrium is considered an optimum condition requiring full connectivity between components of the system, which means perfect information (Foster 2005; Saviotti 2001; Potts 2000).

Potts (2000) differentiates orthodox from heterodox economics from the vision of economics as a mathematical field. In orthodoxy, every element of this field is perfectly connected to the others, while the heterodox perspective considers the economic structure as a complex system in which the connections are incomplete and local.

The ***emergent*** properties of this group are order and structure, which does not invalidate micro heterogeneity. These authors are well aware of the assumption of variability at micro scale and constancy at macro level. As Dopfer poses, what emerges depends on what dimension we analyze the system, either at the micro, meso or macro-level. Using a non-flat ontology, every event and every part of the system has effects on what emerges in the three dimensions.

Thus, at the micro level a rule (routine) emerges, at meso level multiple updates of this rule made by the agents of a population emerge, and at macro level there emerge populations of rules and their updates. Metcalfe stresses that the evolutionary process explains how populations change over time and how structure is an emergent property, resulting from the interaction and interdependence among agents. This idea of a path dependent resilient structure sets Metcalfe apart from Hayek for whom only self-organization emerges. More specifically, Metcalfe considers that as a consequence of the competition process dissipative structures emerge. These issues give rise to the possibility of a new selection and structural change. Like Alan Kirman, Metcalfe thinks it is possible to find the idea that the organizational structure of the market emerges. Besides, depending on the level of market organization, structure may or may not reach the point to promote specialization, coordination and economic change.

From this evolutionary perspective, innovation produces changes in the selective features of product and processes within a population. As a consequence it is not a random Darwinian perspective, because Darwinian selection is not cumulative and it is inefficient since there are too many alternatives to be selected.

Finally, in the Feedback and Increasing Returns group, the definition of the economy as a complex adaptive system has as its starting point the existence of ***heterogeneous*** agents interacting locally in a decentralized way, even though many of the models assume homogeneous agents or typologies of agents. In turn, ***interactions*** –to which firms can access through specific linkages– are a key factor. The location of the firms determines the connection and the network architecture. Therefore no global controller exists. Network economies and increasing returns prevailing in this approach are examples of the significance of global information. As in the previous group, some authors use the methodology of SNA (Blume) to handle these interactions. In relation to the third dimension, there are both hierarchy and multiple scales of analysis. The authors of this group support the idea that complex systems can create order from decentralized interactions among dispersed agents. The dynamics of complex systems is essentially "open-ended". Therefore, the idea of a global optimum is useless in itself (Arthur 1989). For these authors, complex systems can generate order from interactions of decentralized and dispersed agents. In this direction the notion of steady state should be replaced by evolution (Durlauf 1997).

> "New niches, new potentials, new possibilities are continually been created, the economy operates far from any optimum or global equilibrium. The improvements are always possible and in fact they occur regularly" (Arthur, Durlauf and Lane, 1997: 66)

The positive feedbacks generate phase transitions that lead from one to another attractor and take the form of increasing returns, network economies and externalities of different types.

Finally, among the authors of this group order ***emerges***. This order shifts to reach an attractor of the system between different possible attractors when going through different phase transitions (multiple attractors). This group differs from the mainstream because the attractor that the system reaches do not guarantee global optimality. Specifically in the field of technology a dominant design emerges (Arthur, David, and also Metcalfe from the previous group) which is discovered, not imposed and path dependence, reaching this dimension a significantly higher relevance than in the previous group and comparable to the weight it has in the first group and especially in Nelson and Winter (1982).

In sum, in the five groups of evolutionary authors we have found similarities and differences in terms of the ontological dimensions of com-

plex systems. Regarding the similarities, the presence of ***heterogeneity*** in the characteristics of organizations (firms and institutions) is a feature that covers virtually all groups. In particular, in many of these authors micro-heterogeneity refers to the variety of technological capabilities, productive, commercial and organizational at the level of organizations (firms and institutions) belonging to the complex system, where micro scale variability is consistent with the macro order. That is, it is possible to describe the core features of the system without having information about each of its components. In the evolutionary theory of innovation, heterogeneity of the components of the system refers to the diversity of firms in terms of i) technological, productive, commercial and organizational skills, ii) linkages and place in the network architecture, and iii) behavior and productive performance. In this context, they discard an approximation based on methodological individualism and the use the idea of population. Another dimension in which the similarities outweigh the differences is the importance of ***disequilibrium*** in the process of capability building and in the competitive process itself.

In the remaining three dimensions we identified some differences and greater heterogeneity among the evolutionary groups considered. For example, the ***interaction*** and the importance of ***networking*** groups are central to Innovation Systems, in the Self-organization/Self-transformation and in the Feedback and Increasing Returns groups. In all three cases the emphasis is placed on local interactions, which are defined by Antonelli and Boschma as a multidimensional space nearby firms. In turn, the hierarchy and modularization also are manifested differently. In the Habits and Routines group it takes the form of modularization of routines with little weight of hierarchy or at most with a micro-meso analysis, in the Innovation Systems group is hierarchical, in the Cumulative Causation group there is hierarchy but not modularization, in Self-organization/ Self-transformation group the hierarchy and modularization are present and in the Feedback and Increasing Returns group hierarchy with multiple attractors for each phase transition prevails. Finally, while the ***emergency*** is key as ontological dimension of complexity, what does emerge in each of the groups differs: routines, habits and institutions in the first group, innovation and systems at different scales in the group of Innovation Systems, structural change in the group of Cumulative Causation, order and structure in the group of Self-organization/Self-transformation, order and dominant design in the group Feedback and Increasing Returns.

Conclusions.

In this paper we have discussed the general idea of complexity from a transdisciplinary perspective proposing an integrative ontology incorporating different definitions proposed in the literature (first section). In turn we have examined some background on the idea of complexity that can be found throughout the history of economic theory in two great traditions or paths, one that focuses on order and single economic system and another on transformation and divergence (second section). In turn we have discussed the ontology of evolutionary thought that emerges from the recent literature (third section). Finally, we have identified several groups of evolutionary authors based on their core research questions. For these groups we have analyzed how the main dimensions of the ontology of complexity are manifested in their conceptual elaborations (fourth section).

We have proposed that this set of evolutionary groups could be integrated from the umbrella of complexity, emphasizing the more specific aspects they claim of the dimensions discussed. In turn, this integration would consider jointly the two complementary historical path that may be considered as background of complexity in evolutionary economics: i) one path that highlights the prevalence of the issue of organization in production systems from the perspective of a theory of competitive in disequilibrium and fueled by creative-destruction process and ii) and alternative path which emphasizes the issue of heterogeneity and divergence between production systems in the Smith-Marshall-Young-Myrdal-Kaldor that concerns by the cumulative causation phenomenon.

The paper shows that all groups of evolutionary authors adhere to sets of ontological assumptions. In particular Habits and Routines and Self-organization/Self-transformation groups have been concerned with making the ontological assumptions explicit. Thus while the first is linked to the ontology of Nelson, Winter and Dosi, the second derives their ontology from Dopfer and Potts. The other groups have a strong association with the ontology of complexity and adhere to most of the building blocks of ontology evolution.

In the Habits and Routines group, evolutionary ontology is consistent with the ideas of complexity posed by Nelson, Winter and Dosi. These authors have emphasized the importance of different evolutionary assumptions of bounded rationality and environmental uncertainty. From these assumption the presence of persistent heterogeneity in preferences, endowments and world views and the immanent possibility of novelty are derived. This

is connected with the possibility of generating capabilities along the evolutionary path of the firms. The presence of interactions are less stressed, although Dosi especially emphasizes the presence of emergent properties arising from micro collective interactions far from equilibrium, from heterogeneous learning and from intentional actions performed by agents. This set of ontological evolutionary assumptions are manifest in a particular way on the five dimensions of complexity ontology: **(i)** Micro-heterogeneity of Behaviors and Routines, **(ii)** Interaction with the Environment in the Process of Learning and Capability Building, **(iii)** Modular routines and Subroutines that Provide Stability for the Operation of the Organization, **(iv)** Disequilibrium and Path Dependency and **(v)** Emergency of Economic Change (based on new routines and habits).

The Self-organization/Self-transformation group has a very clear evolutionary ontology linked strongly with the ontology of complexity that the authors subscribe. In this case the evolutionary ontology was clearly raised by Dopfer. This author proposes a set of laws and axioms -discontinuity, adaptation, selection and retention, laws and some axioms related to multiple updates of the rules (routines signatures) that belong to the same population– and provides the basis for developing a vision of the evolutionary competition process that includes the categories of biological evolution but with different content. This ontology that preserves the heterogeneity at the micro, meso and macro levels is fully compatible with the ontology of complexity and focuses on: **(i)** Heterogeneity as Key Fuel to the Selection Process, **(ii)** Interaction in the Process of Competition, **(iii)** The Presence of Hierarchy (since the differences are maintained to the next level) and Modularization, **(iv)** The Competitive Process always in Disequilibrium (restless capitalism posed by Metcalfe already stressed by Hayek), and **(v)** The Emergence of Self-organization and Structure

Another issue that emerges from the study is that while the above groups are more closely linked to the first historical tradition, in Innovation Systems, Cumulative Causation and Feedback and Increasing Returns groups the issues of divergence identified in the second tradition are more relevant.

A complementarity between all these groups of authors would enrich the perspective of divergence and transformation in authors that put more emphasis on the issue of coordination and give more prominence to the processes of competition in microeconomic analysis of divergence between systems. This convergence of historical and current perspectives could be achieved by reinforcing the idea of multiple emergent proper-

ties that jointly lead to routines and habits, innovation, structural change, order, structure and organization of markets and dominant design. In this direction recent contributions of Latin American structuralism (Cimoliet. al. 2010) that aimed to combine the analysis of the macro / meso structure without belittling the role of micro-heterogeneity and competition processes in the dynamics of development could be integrated. This unification and possible supplementation of evolutionary authors and groups presented from the ontology of complexity could both highlight the fact that their common origins are in Smith showing the potential complementarity between the two historical traditions.

Bibliography.

Antonelli, C. (2008). "Pecuniary knowledge externalities: the convergence of directed technological change and the emergence of innovation systems". Industrial and Corporate Change, 17(5).

Antonelli, C. (2008). Localised technological change: towards the economics of complexity. Taylor & Francis.

Arthur, W. (1989). "Competing Technologies, Increasing Returns, and Lock-In by Historical Events". The Economic Journal, 99(394), pp.116-131.

Arthur, W. (2009). The Nature of Technology: What It Is and How It Evolves. Penguin Adult.

Arthur, W. (1994). "Positive feedbacks in the economy". McKinsey Quarterly, pp.81–81.

Arthur, W. (1990). "Silicon Valley's locational clusters: when do increasing returns imply monopoly?". Mathematical social sciences, 19(3), pp.235–251.

Blume, L. y Durlauf, S. (2006). Economy as an evolving complex system, 3. Oxford University Press.

Blume, L. y Durlauf, S. (2005). Identifying social interactions: A review.

Boschma, R., 2005. "Proximity and Innovation: A Critical Assessment". Regional Studies, 39, pp.61-74.

Boschma, R. y Martin, R. (2010). The Handbook of Evolutionary Economic Geography. Edward Elgar Publishing.

Boschma, R. y Frenken, K. (2006). "Why is economic geography not an evolutionary science? Towards an evolutionary economic geography". Journal of economic geography, 6(3), p.273.

Boschma, R.A. & ter Wal, A.L.J. (2006). "Knowledge networks and innovative performance in an industrial district: the case of a footwear district in the south of Italy. Papers in Evolutionary Economic Geography, 6, pp.1–23.

Bottazzi, G. et al. (2010). Corporate performances and market selection: some comparative evidence. Industrial and Corporate Change, 19(6), p.1953.

Bowles, S. et al. (2006). Poverty traps. Princeton University Press.

Breschi, S. y Lissoni, F. (2001). "Knowledge Spillovers and Local Innovation Systems: A Critical Survey". Industrial and Corporate Change, 10(4), pp.975 -1005.

Brock, W. y Durlauf, S. (2007). Identification of binary choice models with social interactions. Journal of Econometrics, 140(1), pp.52–75.

Cimoli, M., Porcile, G. y Rovira, S. (2010). "Structural change and the BOP-constraint: why did Latin America fail to converge?". Cambridge Journal of Economics, 34(2), pp.389 -411.

Dopfer, K., 2006. The Origins of Meso Economics Schumpeter's Legacy. The Papers on Economics and Evolution, (#0610).

Dopfer, K. (2005). The Evolutionary Foundations of Economics, Cambridge University Press.

Dopfer, K. y Potts, J. (2004). "Evolutionary realism: a new ontology for economics". Journal of Economic Methodology, 11(2), pp.195-212.

Dosi, G. y Kaniovski, Y. (1994). "On «badly behaved» dynamics". Journal of Evolutionary Economics, 4(2), pp.93–123.

Dosi, G. (1988). Technical change and economic theory. Pinter Publishers.

Dosi, G., Lechevalier, S. y Secchi, A. (2010). "Introduction: Interfirm Heterogeneity—nature, Sources and Consequences for Industrial Dynamics". Industrial and Corporate Change, 19(6), pp.1867-1890.

Dosi, G., Fagiolo, G. y Roventini, A. (2010). "Schumpeter meeting Keynes: A policy-friendly model of endogenous growth and business cycles". Journal of Economic Dynamics and Control, 34(9), pp.1748-1767.

Durlauf, S. (2005). "Complexity and Empirical Economics". The Economic Journal, 115(504), pp. F225-F243.

Durlauf, S. (1993). "Nonergodic Economic Growth". Review of Economic Studies, 60(2), pp.349-66.

Foster, J. (2005). "From simplistic to complex systems in economics". Cambridge Journal of Economics, 29(6), pp.873 -892.

Frenken, K. (2006). "Technological innovation and complexity theory". Economics of Innovation and New Technology, 15, pp.137-155.

Glaeser, E.L. y Scheinkman, J. (2000). "Non-Market Interactions". National Bureau of Economic Research Working Paper Series, No. 8053.

Hayek, F. (1945). "The Use of Knowledge in Society". The American Economic Review, 35(4), pp.519-530.

Hayek, F. (1948). Individualism and economic order. University of Chicago Press.

Hirschman, A. (1958). The strategy of development. New Haven, CN: Yale University Press.

Hodgson, G. (2004). The Evolution of Institutional Economics. Routledge.

Hodgson, G. (2009). "Choice, habit and evolution". Journal of Evolutionary Economics, 20, pp.1-18.

Hodgson, G. (2004). "Darwinism, causality and the social sciences". Journal of Economic Methodology, 11(2), pp.175-194.

Hoff, K.R., Sen, A. & Team, W.B.D.R.G.G. and I., (2005). The kin system as a poverty trap?. World Bank, Development Research Group, Growth and Investment Team.

Klaes, M. (2004). "Ontological issues in evolutionary economics: Introduction". Journal of Economic Methodology, 11(2), pp.121-124.

Knudsen, T. (2004). "General selection theory and economic evolution: The Price equation and the replicator/interactor distinction". Journal of Economic Methodology, 11(2), pp.147-173.

Krugman, P. (1996). The self-organizing economy. Blackwell Publishers.

Kwapiena, J. y Drozdz, S. (2012). "Physical approach to complex systems". Physics Reports 515, pp. 115–226.

Lewin, R. (2002). Complejidad: el caos como generador del orden. Tusquets Editores.

Metcalfe, J. (1994). "Competition, Fisher's Principle and increasing returns in the selection

Process". Journal of Evolutionary Economics, 4, pp.327-346.

Metcalfe, J., Foster, J. & Ramlogan, R. (2006). "Adaptive economic growth". Cambridge Journal of Economics, 30(1), pp.7-32.

Metcalfe, J. (2010a). "Complexity and Emergence in Economics: The Road Map from Smith to Hayek (via Marshall and Schumpeter)". History of Economic Ideas, XVIII(2), pp.45-75.

Metcalfe, J. (2010b). "Dancing in the dark: la disputa sobre el concepto de competencia. Desarrollo Económico, Revista de Ciencias Sociales, 50 (197), pp.59-79.

Metcalfe, J. & Foster, J. (2007). Evolution and Economic Complexity. Edward Elgar Publishing.

Metcalfe, J. (2002). "Knowledge of growth and the growth of knowledge". Journal of Evolutionary Economics, 12, pp.3-15.

Myrdal, G. (1957). "The principle of circular and cumulative causation and the drift towards regional economic inequalities in a country". Economic theory and under-developed regions, pp.11-38.

Nekola, J. y Brown, J. (2007). "The wealth of species: ecological communities, complex systems and the legacy of Frank Preston". Ecology letters, 10, pp. 188–196.

Nelson, R. (1981). "Research on productivity growth and productivity differences: dead ends and new departures. Journal of Economic Literature, 19(3), pp.1029–1064.

Nelson, R. & Winter, S. (1977). "In search of useful theory of innovation". Research policy, 6(1), pp.36–76.

Nelson, R. (1993). National Innovation Systems: A Comparative Analysis. Oxford University Press.

Nelson, R. & Winter, S. (1982). An evolutionary theory of economic change. Harvard University Press.

Porcile, G. et al. (2006). "Especialización, tecnología y crecimiento en el modelo Ricardiano". Nova Economia, 16(3), pp.483–506.

Potts, J. (2000). The new evolutionary microeconomics: complexity, competence and adaptive behavior. Edward Elgar Publishing.

Prigogine, I. & Stengers, I. (2002). La nueva alianza: metamorfosis de la ciencia. Alianza.

Rosenstein-Rodan, P.N. (1943). "Problems of Industrialisation of Eastern and South-Eastern Europe". The Economic Journal, 53(210/211), pp. 202-211.

Rosser, J. (2007). Computational and dynamic complexity in economics. cob. jmu. edu/rosser-jb/DYNAMIC, 20, p.21.

Saviotti, P. (2001). "Variety, growth and demand". Journal of Evolutionary Economics, 11, pp.119-142.

Saviotti, P.P. & Pyka, A. (2004). "Economic development by the creation of new sectors". Journal of Evolutionary Economics, 14, pp.1-35.

Schumpeter, J. (1978). Teoría del desenvolvimiento económico. Una investigación sobre ganancias, capital, interés y ciclo económico. México: Fondo de Cultura Económica.

Schumpeter, J. (1994). Capitalism, socialism and democracy. Routledge.

Schumpeter, J. (1947). "The Creative Response in Economic History". The Journal of Economic History, 7(2), pp.149-159.

Simon, H. (1972). "Theories of Bounded Rationality". En Decision and Organization. pp. 361-376.

Simon, H. (1969). The science of the artificial. MIT Press.

Thirlwall, A. (1979). "The Balance of Payments Constraint as an Explanation of International Growth Rate Differences". BNL Quarterly Review, 32(128), pp.45-53.

Vromen, J. (2004). "Conjectural revisionary economic ontology: Outline of an ambitious research agenda for evolutionary economics". Journal of Economic Methodology, 11(2), pp.213-247.

Watts, D. (2006). Seis grados de separación: la ciencia de las redes en la era del acceso. Editorial Paidós.

Witt, U. (2004). "On the proper interpretation of 'evolution' in economics and its implications for production theory". Journal of Economic Methodology, 11(2), pp.125-146.

Witt, U. (2008). "What is specific about evolutionary economics?". Journal of Evolutionary Economics, 18(5), pp.547-575.

Young, A. (1928). "Increasing returns and economic progress". The Economic Journal, 38(152), pp.527–542.