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Complexity paths in neo-Schumpeterian evolutionary economics, structural change and development policies

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ABSTRACT

Recently, several authors of evolutionary and neo-Schumpeterian economics have identified in complex systems a common framework for accounting for a range of attributes they have been claiming are present in economic systems: path-dependence, positive feedbacks, micro-heterogeneity, emergent properties, and self-organization. Complexity seems to be broad enough to accommodate very different positions and it has been seen as a unifying approach for evolutionary and neo-Schumpeterian streams. This pluralism is reflected in the fact that many authors that draw upon complexity ideas from neo-Schumpeterian evolutionary theory, make contrasting policy recommendations in terms of if it should be vertical or horizontal or if it should promote bottom-up process or direct interventions. This is possible because the complexity approach has not yet been fully developed and its limits are still somewhat blurred. In this paper, we propose to explore this idea by identifying the theoretical backgrounds and the policy recommendations of different groups of neo-Schumpeterian evolutionary authors. We propose that backgrounds focused on different attributes of complexity lead to different development policies recommendations.

1. Introduction

In recent years, complexity has emerged as a general framework within which different concerns of evolutionary neo-Schumpeterian economics have found a place. Several authors (Dosi et al., 2010; Saviotti, 2001; Metcalfe, 2010a; Antonelli, 2011; Foster, 2005; Arthur, 2009; Arthur et al., 1997; Durlauf, 2005; Potts, 2000, among others) have identified in complex systems a common framework for accounting for a range of different attributes they have been claiming are present in economic systems: from path dependence and positive feedbacks to micro-heterogeneity, emergent properties, and self-organization. Several of these attributes have been mentioned at some point in the history of economic thought by different authors, but modeling and computational capacity in the past constrained these ideas to appreciative theory. Since this constraint began to be loosened up by the development of ICT, the complexity approach has been used as an inspiring modeling toolbox (Frenken, 2006; Durlauf, 2005; Ciarli et al., 2010). Nevertheless, it has also triggered deeper discussion regarding the ontological bases of the evolutionary theory of innovation (Hodgson and Knudsen, 2008;

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Hodgson, 2004; Witt, 1997, 2008) and an epistemological debate on issues like indeterminacy (Hodgson, 2009) and intentionality (Antonelli, 2011).

As a general framework, complexity is broad enough to accommodate very different positions. Fontana (2014) and Davis (2008) point out that complexity is driving innovation economics into becoming a pluralistic research field. Among neo-Schumpeterian evolutionary authors, complexity might even been seen as a unifying approach, since evolutionary theory is made up of different sets of contributions that are loosely coupled with each other. This is possible because the complexity approach has not yet been fully developed and its limits are still somewhat blurred (Rosser, 1999; Colander, 2002; Day, 1983). Definitions of complex systems tend to offer a list of features that systems must fulfill in order to be considered complex, but such lists not always contain the same elements, beyond certain obvious overlaps.

This pluralism is reflected in the fact that many evolutionary and neo-Schumpeterian authors draw upon complexity ideas like feedbacks and divergence or micro-heterogeneity and self-organization in order to make contrasting policy recommendations. The scope of those recommendations includes from selection of sectors under a vertical approach or mission-oriented (Ergas, 1987) through promoting bottom-up processes under a horizontal perspective or diffusion-oriented policies that provoke emergence of variety.

As long as the complexity approach has not yet been fully developed and its limits are still somewhat blurred, this heterogeneity of policy recommendations coexists within the evolutionary economics. Even more, recommendations often combine both types of intervention instead of choose one or the other type. In these cases complexity can provide a common theoretical framework that integrates both perspectives. In this paper, we propose to explore this idea by identifying the backgrounds and the type of policy interventions of different groups of neo-Schumpeterian evolutionary authors. We propose that backgrounds focused on different attributes of complexity lead to different policy recommendations within a framework of epistemological and methodological pluralism (Dow, 1997).

After defining complexity and describing its main dimensions, in Section 3, we identify two possible paths for complexity ideas in the history of economics. The first one was pointed to by Metcalfe (2010a) and others (Beinhocker, 2011); it starts with Smith and ends with Hayek. The common threads of this path are self-organization and emerging novelty, and their focus is on problems of coordination and transformation. The second path also starts with Smith but ends with structuralism and the development school. In this case, the common threads are non-linearity, path-dependence, and divergence. As such, they are focused on aspects like cumulative causation and structural change (Robert and Yoguel, 2011).

In Section 4, we propose that different groups within neo-Schumpeterian evolutionary thinking are followers of one of these two traditions or of a mix of the two. In this section, we propose a possible taxonomy of evolutionary and neo-Schumpeterian authors around five key concepts: Habits and Routines, Self-organization/Self-transformation, Innovation Systems, Cumulative Causation, and Positive Feedbacks (Robert and Yoguel, 2015). At one extreme, the contributions of Metcalfe (2010b), Dopfer (2004), Potts (2000), and Foster (2005) explain coordination (self-organization) and the emergence of novelty (self-transformation), without resorting to the notion of equilibrium. These contributions are closer to the historical path traced by Metcalfe (2010a). At the other extreme are the contributions of those analyzing Innovation Systems at the national (Freeman, 1995; Lundvall, 1992), sectoral (Malerba and Orsenigo, 1997; Pavitt, 1984) and local (Boschma and Martin, 2010; Antonelli, 2011) levels, as well as those considering Cumulative Causation processes between innovation and demand (Dosi et al., 2010; Saviotti and Pyka, 2004; Llerena and Lorentz, 2004; Dosi et al., 1990), all of which are focused on feedback dynamics and path dependence. They have relied on an argumentative line connecting Smithian growth with increasing returns and are closer to the development school. In an intermediate position, there are Habits and Routines (Nelson and Winter, 1982; Hodgson, 2009; Teece and Pisano, 1994; Cohen and Levinthal, 1990, among others) and Positive Feedbacks (Arthur et al., 1997; Axelrod, 1997; David, 1985) groups. While the former is closer to the first tradition, the latter is related to the second one.

In Section 5, we show how each group's policy recommendations are also linked to the historical tradition they belong to. The two paths lead to divergent interpretations of intervention in the economy, and this situation is reflected by the diversity of the policy recommendations made by neo-Schumpeterian groups. They include bottom-up policies such as capacity building and the development of institutions that promote innovation and economic development, and top-down policies such as the selection of specialization sectors and the fostering of structural change. We show that top-down and bottom-up policies are complementary, but they should be promoted to different degrees according to how developed the country in question is. In developed countries – i.e. those that already have diversified and complex productive structures – bottom-up policies make more sense than top-down ones, while in less-developed countries, where production structures specialize in a few commodities, structural change policies must include top-down interventions leading to the generation of new sectors, and, according to Saviotti and Pyka (2004), related and unrelated variety. All the same, in this case, top-down policies should be complemented with bottom-up ones oriented toward improving individual agents' capacities.

Finally, in Section 6, we discuss our main conclusions.

2. Defining complexity

Several authors propose definitions of complexity (Rosser, 1999; Colander, 2002; Kirman, 2010; Foster, 2005) that list the attributes a system must fulfil in order to be called complex. In this article, we stress four attributes included in those definitions because there are clear theoretical backgrounds to them, and they are useful for linking with the policy implications set out by the

evolutionary and neo-Schumpeterian authors mentioned before. These attributes are: (i) micro-heterogeneity; (ii) network architecture, (iii) non-linear interactions, feedbacks, and divergence, and (iv) emergent properties. The four attributes can be articulated in a single definition such that complex systems can be said to be made up of heterogeneous interacting components located within a network of connections that exhibit emergent properties. These attributes overlap with the world described by Smith, Marshall, Veblen, Schumpeter, Hayek, Young, Kaldor, and Hirschman among others, and by current evolutionary neo-Schumpeterian economics.

Micro-heterogeneity refers to variability at the component level. Economic complex systems are made by of economic agents that are heterogeneous in terms of their capabilities, habits, routines, and performance. This micro-variability is endogenous, since each component has capacity to generate novelty – creativity – and the ability to learn from the environment, and each can change its behavior in order to fit in with the environment. This micro-variability will be reduced through the selection process and regenerated continuously on the basis of innovation.

The second attribute means that agents are located in a network of interactions. This explains why information is local and contextual. The architecture of interactions in complex systems presents two main features: (i) hierarchy, in the sense put forward by Simon (1969): complex systems are composed by of other subsystems that are also complex; and (ii) modularity, which means that interactions within subsystems are denser than interactions between them. The latter makes complex systems resilient to a certain extent, since they are able to absorb exogenous shocks and remain functional. In complex systems, global interactions are possible – each component simultaneously exchanges information with the rest of the system's components – but these tend to be weaker than local interactions – each component exchanges information with neighboring components in the multidimensional space (Antonelli, 2011). Thus, the prevailing partial information prevents there from being a global controller, although coordination is possible through the distributed functioning of the systems. Complex systems by definition exhibit a stable macro-behavior on the bases of micro-instability, because the attribute of network architecture explains the emerging order. The Austrian school, especially Hayek, had already noticed that a global controller is not necessary condition for coordination. In his opinion, local and partial information relaying in agents with bounded rationality and limited computing capacity is enough to solve coordination problems. Self-organization is the main emergent property of the system.

In the third place, complex systems are characterized by non-linear interactions, feedbacks and divergence. Interacting heterogeneous agents are located in the network architecture that exhibit the afore-mentioned properties. This means that they share and interchange tangible and intangible assets. When agents introduce an innovation, it can trigger a cascade of changes, since the components of a complex systems are interconnected with one another. The adoption of a given technology will require learning and further innovations, which in turn leads to improved practices that can be adopted. These positive feedbacks in innovation processes show reinforcing interactions between co-located agents, which lead to non-linear dynamics. Since connection networks are incomplete (local interactions prevail over global ones), feedbacks may generate divergent paths between subsystems and lock-in situations. Positive feedbacks make complex systems non-ergodic, which means that systems have a memory. Therefore, different initial conditions and reinforced interactions will lead to idiosyncratic path dependence, and even to divergent paths. Transformation and growth linked to interactions (increasing returns), and cumulative causation processes have been stressed by the development school in order to show constraints on technology diffusion, low growth traps, and divergent development paths.

Finally, emergent properties are the result of interactions at different scales. The fact that complex systems are present on various scales of space and time means that the results of each scale cannot be derived linearly from lower scales, each of which show specific attributes. Macroscopic regularities based on micro-scale variability are emergent properties of the systems. Examples of this are divergent paths, lock-ins, and cascades of changes. Emergent properties are the key attributes of any complex system. Since there are emergent properties, the system is non-reducible.

As such, the four attributes mentioned above could be seen as the ontological assumptions of complexity. As we will explain below, heterogeneous agents and emergent properties are key features in the work of several authors in the history of economic thought and of evolutionary and neo-Schumpeterian authors. When the main research issue is the coordination problem, network architecture is the complexity dimension that is stressed; but when transformation and growth are the main concern, feedbacks and divergent paths are the attributes stressed.

According with Dow (1997) pluralism involve notions of human creativity and freedom of choice. Complexity provides a plural framework for different traditions and contributions that accept the ontological assumptions described above although they emphasize some of them more than others according to their theoretical concerns. Therefore they keep an open perspective which gives a framework for knowing the reality.

3. Two historical streams of complexity in economics

The adoption of the complexity approach by evolutionary economics is grounded in the fact that the contributions of its predecessors are consistent with the attributes of complex systems discussed previously. Indeed, several authors refer to questions like heterogeneity, interactions, feedbacks, and divergence.

Metcalfe (2010a), and others such as Beinhocker (2011), trace a path of complexity ideas in economics from Smith to Hayek, including Marshall, Schumpeter, and Knight, because a connection between interdependence and order can be recognized in those authors' works. Metcalfe proposes that their ideas are of great importance, particularly those related to our understanding of the division of labor

and the role of innovation in stimulating the processes of coordination and self-transformation.

Following Smith, Metcalfe (2010b) suggests that the division of labor in relation to coordination problems leads to the division of labor in the production of knowledge, and therefore to innovation and transformation.

> When he [Smith] wrote about a third class of division of labour, over and above those within and between firms in the use and production of machinery and the specialisation of task, he meant the division of labour in the production of knowledge for invention, a division reflecting the activities of those (Metcalfe, 2010b: 60).

Consequently, the problem of organizing production is analogous to the problem of generating new knowledge. The former deals with complementarity in the production of goods and services, and the latter with the complementarity between different types of knowledge. This is consistent with a Schumpeterian view of innovation – new combinations of existing knowledge – and with Smith's idea of innovation driven by specialization. According to Schumpeter, the generation of new knowledge is largely produced by combining complementary types of expertise that already exist in the system. Therefore, interactions, although always local, are sufficient and therefore effective in giving order to the system (Hayek, 1945)[1]. In this context, the self-organization (coordination problem) and self-transformation of the system are closely linked. Order, however, is not equilibrium, since requires not global interactions but local ones, and it is exposed to introduction of novelty and endogenous change. Schumpeter argues that the economic system is in disequilibrium, though there is a tendency toward order that is driven by the market selection process.

Marshall is included in the first path because of his conception of order and economic dynamics, which is associated with evolution rather than equilibrium. Variation and selection operate within industries through the entry and exit of individual firms. His conception of economic evolution is centered on both (i) the increasing returns derived from the division of labor and subsequent new form of organization and (ii) the ever-evolving representative – that is, average – firm, which changes continuously with the rise and fall of individual firms (Metcalfe, 2007).

According to Metcalfe, after 1945 the dominant stream in economics favored the idea of equilibrium, a natural consequence of their main concern: "the rational coherence of economic relations" (Metcalfe, 2010a: 47). According to Hayek (1948) the idea of order as opposed to equilibrium is the response to the need to recognize some level of predictability in the economy but also partial information and local interactions. The system can never be in equilibrium because the very nature of the competition process leads to innovation[2]. This issue is present in Hayek's work but can also be found in Schumpeter's, although the latter differs strongly from the former with regard to equilibrating forces. Schumpeter considered that equilibrium is continuously threatened by creative destruction processes and by the continuous introduction of new sources of quasi-rents. In contrast to equilibrium, the idea of order does not eliminate endogenous heterogeneity or emerging novelty. Schumpeter conceived of the economic system in disequilibrium, although there is a tendency toward order that derives from the process of market selection.

Similarly, Metcalfe (2010b: 69) states that Hayek differs from Marshall in his treatment of market equilibrium. Hayek believes that a competitive equilibrium is a contradiction in terms: "to compete 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's main question concerns how a society solves the problem of knowledge processing when information is distributed, and therefore knowledge is scarce and partial. The answer given by Hayek – which is now claimed by evolutionary authors like Metcalfe, Potts, Foster, Dopfer, and Antonelli – is related to the very definition of competition. According to these authors, competition is a process for discovering new knowledge based on the combination of specialized and scarce private knowledge. This has disturbing consequences: in a broad sense, competition is the answer to a problem that is never solved, because each solution process opens up new possibilities and new demands (Metcalfe, 2010b). At this point, Metcalfe breaks with the problem of scarcity and moves on from the question of self-organization to the question of self-transformation. Hayek argues that scarcity is a problem and problems invite solutions, so scarcity becomes the instigator for the search for new knowledge. Therefore, the origin of change is scarcity and the problem of self-organization that derives from it.

Just as postwar neoclassical economics is guided by its concern for coherence and rationality, the path stressed by Metcalfe is guided by his concern for the emergence of novelty and structural change under disequilibrium conditions that are, nonetheless, ordered and coordinated. As we will argue, Metcalfe is not interested in the causes that lie behind the divergent economic structures with unequal levels of development. His idea of transformation and structural change refers to the continuous changes that occur in the participation of firms competing in different populations via replicator dynamics. Therefore, the path that leads to Metcalfe links this set of authors from Smith to Hayek ontologically, but downplays issues like feedback and divergence.

Conversely, if the main concern is the divergence of development patterns and their relationships with the productive structures, a different but complementary path can be traced. This is an alternative path that can be identified behind the concepts of feedback and divergence; which is much more related to the problem of accumulation and transformation (Prash, 2002).

This second path goes from Smith to Myrdal and Hirschman, via Marshall, Schumpeter, Young, and Kaldor, and it may extend to the new contributions of Latin American structuralism (Cimoli and Porcile, 2013) and post-Keynesian, Kaldorian, evolutionary economists

[1] These interactions are local not only because of bounded rationality agents but because they are in an incomplete network of interactions.

[2] Hayek (1945) suggests that both the economy and human knowledge are restless.

(Llerena and Lorentz, 2004). On this path, notions of interactions between heterogeneous agents, feedbacks, emergence, and far-from-equilibrium dynamics are less stressed. On the other hand, this path is also connected with the convergent or divergent dynamics of production systems, be they local, sectoral, or national innovation systems. This path focuses in the relationship between increasing returns and development, which has occupied an important place in economic thinking. This position was originally formulated in Smith's famous thesis about the connection between division of labor and market size. Smith's perspective refers to productivity gains associated with market expansion, which in turn lead to a greater division of labor and to the subsequent introduction of innovations. However, Walrasian economics led to a shift of interest from a dynamic and evolving economy to a static and equilibrium-focused one, and the Smith's famous thesis was thus set aside from the neoclassical road, although there were, of course, noteworthy exceptions.

First, Marshall (1890) 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. Marshall's distinction between increasing returns within firms and increasing returns external to the firm but internal to the industry was not only important because it justified why increasing returns do not always lead to monopoly, but also because it gave an explanation of the relationship between market growth, division of labor, knowledge generation, and increasing returns in industrial activity. 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. "If one man starts a new idea, it is taken up by others and combined with suggestions of their own; and thus it becomes the source of further new ideas" (Marshall, 1920: 271).

Second, although Schumpeter did not focus on externalities, he did notice positive feedback processes that lead to divergent paths. In his opinion, those systems in which the competition process is based on new combinations tend to diverge from those where competition is based on prices.

Third, 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 the economy are 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 illuminate this field, for movements away from equilibrium, departures from previous trends, are characteristic of it (Young, 1928: 528).

He has also 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 could 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.

Thus far, it is clear that within this path, the focus 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 in which firms' market entry and exit within the competitive process are highly volatile. If the central question were about self-organization and, in particular, how to make development, self-transformation, and structural change compatible with economic order, then Hayek would be the one to provide the answer. However, if the central question were about feedbacks and divergence, then the development school would be the one to turn to due to its references to increasing returns, interaction, and structural change to explain the phenomenon of divergence between productive systems. That is, beyond the order exhibited by systems taken as interdependent units, divergence between systems is caused by increasing returns at the industry level that result from interactions. This is the starting point of development theory: how to account for the differences between economies. Many of these arguments, as is discussed below, are in line with the complexity approach.

Fourth, 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 1960s, Kaldor developed his theory of cumulative causation and its effects on dynamic increasing returns, demand growth, and productivity. Although his work was not undertaken from the complexity perspective, it is related to complex systems in which feedbacks and non-linear dynamics are present. Other Keynesian and structuralist authors such as Thirlwall (1979) followed a similar path and considered the relevance of the economic structure and the pattern of trade specialization in terms of exports and imports income elasticity. Thus, these authors, faithful to the Keynesian tradition, gave demand a key role in explaining the differential rates of growth of output and emphasized how demand-side and supply-side (production structure) interact. Following this tradition, Lorenz and Llerena suggest that in these models there is a relationship between cumulative causation and demand growth. The increase in productivity with a constant mark-up leads to falls in prices and to increases in demand, which are amplified when technical change is introduced.

Fifth, the school of economic development (Hirschman, 1958; Prebisch, 1959; Myrdal, 1957) framed many of these issues in a discussion of the specific problems of underdevelopment. From this perspective, the productive structure of developing countries was a key factor limiting their

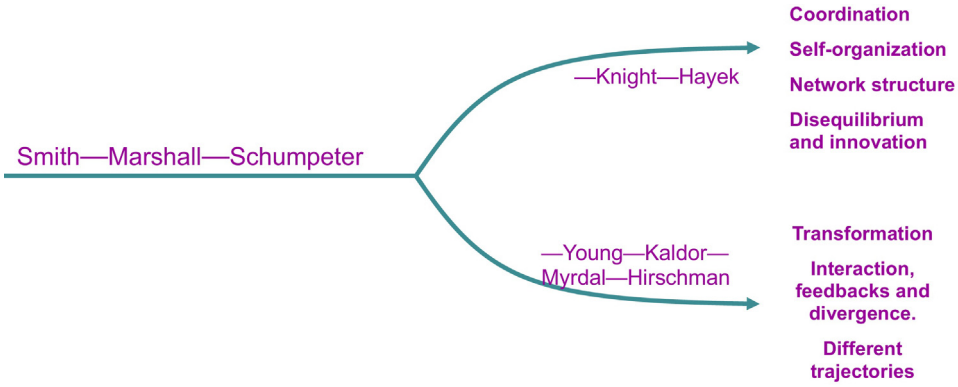

Fig. 1. Two alternative paths of complexity in economic thinking. *Source*: Authors' elaboration.

development. This is explained by a pattern of productive specialization where products that use abundant resources (agricultural and mining commodities as well as cheap unskilled labor) prevail. These activities show a low presence of positive feedbacks and increasing returns, short productive chains, and few horizontal and vertical linkages with the rest of the production system. In this case, the feedbacks do not refer to interactions among firms as in the first tradition, 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 between countries are due to the existence of cumulative causation processes. He claimed that the investment rate depends positively on income levels for the previous period, which was reinforced through various mechanisms such as the existence of increasing returns, increased productivity, and immigration flows[3].

In sum, authors from Smith to Schumpeter may share both traditions since various concerns coexist in their work, from order to economic change. With regard to whether one of these two main concerns tends to emerge as being more important than the other, the path is split. (see Fig. 1). Questions regarding economic change lead to more attention being paid to feedbacks and divergence, while a focus on order tends to guide research toward understand decentralized interactions, network structures, and information flux.

Both paths can also be differentiated in term of the role played by empirical data in theorizing although in both cases the time has a major role. First path builds its questions on how theoretical systems evolves in time while the second path takes into account time-rooted empirical data for identifying its research object and for theorizing. Therefore both paths theorize under the ontological assumption of "real time" which means that the future entails novelty and it cannot be derived from the past. The passage of time involves creative evolution, which means that temporal processes imply irreversible changes and disequilibrium (O'Driscoll and Rizzo, 2002).

Real time is a common ontological assumption compatible with two different methodological proposals of each paths: while the second path theorizes from empiric problems within an inductive logic, the fist path departs from a set of theoretical assumptions using a deductive logic[4]. This difference may explain why the first path concerns coordination while the second concerns transformation and divergence. Although the very same ontological assumption of real time can be related with different research concerns, the methodological and theorizing strategies are not neutral to the identification of research problem. Therefore, empirical evidence on divergence leads to second path authors to be concern with cumulative causation and feedbacks processes. Meanwhile, deductive methodology positions first path authors nearer to the coordination question.

Different authors working with current evolutionary economics have taken up these two paths (see Fig. 1). It is relevant to note that both traditions ultimately derive from a complexity perspective, although from a development perspective the second path seems more attractive. Nevertheless, it could be enriched from the perspective associated with self-organization and self-transformation, i.e. giving more prominence to competition in microeconomic processes. To do this we need to understand the extent to which the different streams within evolutionary thinking are coherent. That is the aim of the following section.

4. Five conceptual groups within neo-Schumpeterian evolutionary approach

In the last 30 years, a heterogeneous corpus related to the evolutionary and neo-Schumpeterian historical traditions mentioned in the first section has been built up. In the process of building this body of theory, evolutionism has made a major effort to understand its

[3] According to Myrdal (1957), economic growth was generated in receiving areas and de-growth in areas which saw decreases in population. These dynamics produced additional disparities in wages and employment, and led to new migration processes and to circular and cumulative causes of migration.

[4] Actually, divergence appears as a theoretical problem in development economics after that the empirical evidence showed divergence in national economic growth rates as a historical regularity.

epistemological and ontological bases and its connection with complexity theory (Dosi and Nelson, 1994; Antonelli, 2011; Metcalfe, 1994; Potts, 2000; Dopfer, 2004; Hodgson, 2004; Witt, 1997). Following the Schumpeterian tradition, evolutionary theorists have argued that competition manifests itself as a process of creative destruction that involves change, transformation, disequilibrium, and development. Although the dimensions that make up complexity – heterogeneity, network architecture, interactions, disequilibrium, and emergent properties – are considered explicitly or implicitly, they taken into account in different ways by each group of authors. While some evolutionary authors closer to the first historical tradition stress that heterogeneity and divergence refer to components in a system and their interactions (Nelson and Winter, 1982; Metcalfe, 2010b), those linked to the second historical tradition focus on the idea of heterogeneity and divergence among productive systems (Dosi et al., 1990; Saviotti and Pyka, 2004).

According to the self-organization/self-transformation group, the system solves coordination problems derived from the division of labor where heterogeneous agents have local and partial information. This group is characterized by its strong evolutionary and Austrian roots (Dopfer, Metcalfe, Potts, Witt and Foster, among others). The evolutionary roots can be seen in the interest in explaining the self-transformation of economic systems and population dynamics driven by variation and selection. The Austrian contributions conceive of economic system change by emphasizing economic order as being an endogenous result of decentralized disequilibrium interactions among system components[5]. From Metcalfe's (1994) perspective, evolutionary competition is understood as a process of structural adaptation to immanent innovations, therefore the creative roles of the markets are stressed. Competition is not perfect in the sense of free entry and equilibrium, but an open process that enhances exploration and experimentation. Thus, order or transformation are not contradictory. Schumpeterian order is unstable within a stable system of rules that organize and guide the self-transformation of the system. The concerns these authors have about the division of labor do not affect the organization of knowledge production because there cannot be order without change, nor change without order.

Dopfer has proposed an axiomatic construction that explains the dynamics of a neo-Schumpeterian evolutionary system. He articulated the micro and macro through the meso level. The micro level is the set of each individual's routines that compete within a specific population. On the meso level, individual routines are modified (updated) through the competition process, giving rise to a structure of routines that cannot be reduced to a characteristic agent. Finally, the macro level is made up of the set of populations, including their current routines and the interactions that exist between these. Thus, the ontology present in Dopfer is not reductionist from the micro to macro and it is strongly associated with the first historical tradition. This is because he is mainly interested in the issue of coordination and the competition processes within populations. Finally, while heterogeneity and divergence are found within populations, their emergent properties – order and structure – guide their policy orientation

The habits and routine group is near to the first historical tradition. It is concerned with the learning process generated at the level of system components, and its starting point is the key role of routines (Nelson and Winter, 1982) and habits (Hodgson) in explaining the dynamic of firms and institutions. The idea of habits and routines were complemented by the advances of organizational capacities theory, which is coherent with that of neo-Schumpeterian evolutionary authors (Cohen and Levinthal, 1990; Cohendet and Llerena, 2003; Cowan et al., 2000, among others). This group is defined by its interest in learning processes at the firm level and in the behavior of economic agents and institutions within a framework related to institutionalism (Hodgson, 2009) and management studies (Teece and Pisano, 1994; Cohen and Levinthal, 1990). This group has defined a set of ontological assumptions for evolutionary thinking in economics. It stresses the presence of bounded rationality and environmental uncertainty, which limit access to information, capacity building, and the organization's perception of preferences and representations of the world. Bounded rationality and non-modelable uncertainty explain why firms act through routines generated along their evolutionary path (Nelson and Winter, 1982). These routines constitute the organizational memory through which firms develop their productive and commercial activities and search for quasi-rents. These routines allow firms to act without deliberation. They include instructions for the replication and imitation of one firm by another. The routines are tested when conflicts appear and deliberative actions are needed. In such cases, innovation emerges in the form of changing existing routines and creating new ones (Nelson and Winter, 1982; Pavitt, 1984). This routinized behavior is coherent with Hodgson's habit-driven behavior, in which he stresses the importance of habits over rational choice in the behavior of economic agents. He considers that agents act within socially pre-established parameters to cope with uncertain and changing environments. These habits are defined locally depending on the scope of the actors' connections. This group focuses mainly on the micro dimension and therefore on firms competition based on habits and routines. That is why these authors are related to the first tradition. Finally, the emergent properties they stress as guiding policy design are institutional structures, rules, and habits.

The Innovation System group includes contributions that emphasize the systemic dimension of innovation and technological change on the basis of concepts such as: (i) the local innovation system (Boschma and Martin, 2010; Antonelli, 2000), where the network of interaction is stressed because of its importance to knowledge flows in the local environment; (ii) the sectoral innovation system (Malerba and Orsenigo, 1997; Pavitt, 1984), and (iii) the national innovation systems (Freeman, 1995;

[5] Metcalfe et al. (2006: 664) states "Hayek, above all Austrians, challenged the peculiar notion of economic equilibrium, the role of knowledge in understanding the market process and the particular economic problem facing societies arising from the way in which knowledge is dispersed and localized. Indeed it is because individuals are globally ignorant but locally wise that the economic problem arises at all".

Lundvall, 1992; Nelson, 1993; Edquist and Lundvall, 1993). The idea of innovation as having a systemic nature is common to all these contributions. They place innovation and the learning process in a central position, adopting a holistic, interdisciplinary approach and employing a historical perspective. Their analysis highlights elements such as interdependence, nonlinearity, and the centrality of institutions. As they emphasize the differences between systems and recognize the existence of divergent paths among them, they are more related to the second historical tradition. Some contributions in this group also make great efforts to explain the mechanisms through which systems at different aggregation levels diverge. Furthermore, interactions between firms and their environment lead to different dynamics of economic aggregates. Some of this literature favors the discussion on development policies and structural change, since it stands that productive and trade specialization may constrain technological learning dynamics at the national, regional, or sectoral level. In this group, heterogeneity and divergence refer to different systems. Policy prescriptions aim to favor the emergence of complex innovation systems, focusing on interactions and feedbacks between system components.

The Cumulative Causation group emphasizes the relevance of demand on cumulative causation processes, the micro and meso dynamics, and the complementarity of Keynesian, Schumpeterian, and Kaldorian sources of growth. It includes contributions such as Dosi et al. (2010) and Saviotti and Pyka (2004), who stress both the demand side of the growth process, and evolutionary contributions on international trade such as Cimoli and Porcile (2013) and Dosi et al. (1990). The key role of absolute advantage in determining the specialization pattern for international trade – based on exploiting the opportunities of expanding demand – can be recognized in Kaldor's ideas about feedbacks between demand and productivity. Therefore, within these contributions, the presence of persistent heterogeneity in preferences, endowments, routines, performance, and the immanent possibility of novelty are taken as two strong ontological assumptions (Dosi and Nelson, 1994). Other authors (Llerena and Lorentz, 2004) stress the relationship between cumulative causation and evolutionary micro-founded technological change.

The background for such work includes a range of contributions from development theory to the structuralist and post-Keynesian approaches (O'Hara, 2008; Setterfield, 1997). The proximity of the cumulative causation group to the second historical tradition is explained in terms of its interest in understanding long-term growth processes based on demand expansion. Smith's idea that demand growth is an engine of economic diversification, creating opportunities for innovation, is the key link between Keynesian and Schumpeterian dynamics of growth. Finally, the main emergent property they stress is structural change leading to the emergence of new sectors and the complexity of existing ones. Policy prescriptions aim to foster this emergent property.

Finally, closer to the second tradition, there is the group of evolutionary authors identified with complexity economics at the Santa Fe Institute (Arthur et al., 1997; Axelrod, 1997; David, 1985). This group that we call the Positive Feedback group is focused on technology diffusion and lock-in effects. Their contributions – which aim to explain substantive empirical phenomena – have been applying different ideas from the complexity approach to economics, focusing especially on: (i) historical studies, (ii) the identification of data patterns which are consistent with some of the features of complex environments (power law), and (iii) social interactions. Specially, they focused on analyzing decentralized interactions at the micro level and the feedback and non-equilibrium dynamics derived from it. These feedbacks lead to the presence of increasing returns and divergent paths between systems. They have applied non-linear dynamics not only to innovation processes but also to other economic fields like finance and stock markets. This group includes contributions on competitive technologies and standard diffusion (Arthur, 1989) and the economics of "querty" (David, 1985). All these authors, who are more interested in explaining the system attractor than its dynamics, recognize the existence of multiple equilibriums. Their main emergent property is order understood as an attractor where the system arrives between different possible alternatives.

In sum, the plural perspective of complexity can give space for five groups of authors with different historical tradition that stresses different dimensions of complexity. While the authors that focus on innovation systems and cumulative causation stress the relevance of heterogeneity and disequilibrium among economic and social structures and are closer to the second historical tradition, the authors referred to as belonging to the self-organizing and self-transformation and habits and routines groups stress divergence and heterogeneity inside populations and are more related to the first historical tradition. Finally, the emergent properties each group of authors stress are also aligned with their main policy orientation, which we discuss in the next section.

5. Policy implications of the different views on complexity

Although there is room for heterogeneity under the umbrella of complexity, the historical roots of the different evolutionary neo-Schumpeterian groups lead to different policy prescriptions. In this section, we will briefly discuss the policy prescriptions of each group and how they are related to both historical traditions and the complexity dimensions they stress.

In Fig. 2 we have located each of the five groups on a gradient that combines their closeness to each of the two historical paths and their policy prescriptions, centered on the tension between top-down and bottom-up.

The works on policy design from a theoretical perspective have discussed this tension as well as others like: (i) vertical vs. horizontal policies; (ii) mission- vs. diffusion-oriented (Ergas, 1987, Cantner and Pyka, 2001) policies, or (iii) provision of public goods vs. direct intervention associated to market failure literature as new mainstream literature on productive development policy states (Lin and Chang, 2009; Crespi et al., 2014).

Recognizing that there is no a perfect correlation, by top-down policy we mean vertical intervention or

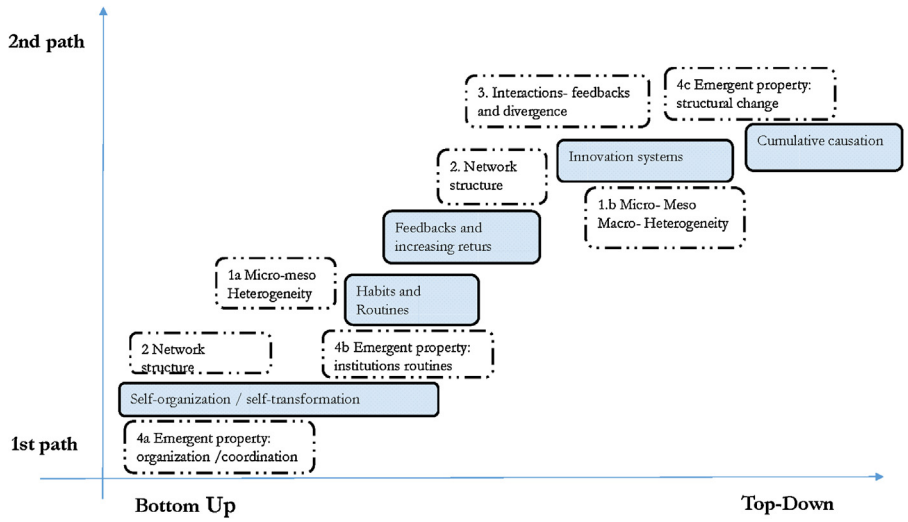

Fig. 2. The relationship between the two traditions of complexity in economic history and the five groups of evolutionary economics. *Source*: Authors' elaboration.

mission oriented policy that not necessarily aim to solve a market failure, but to generate unrelated variety within the productive structure. We recognize that there are some exceptions, i.e.: horizontals top-down policies aiming at the generation of public goods, like massive professional training programs. However, generally, the top-down interventions are mainly vertical policies aiming to induce structural change processes, like the second path propose.

On the other side, by bottom-up policies we mean the horizontal or diffusion oriented policies aiming to provide a public good or solve a market failure. Here the opposite also applies. It is possible to find bottom-up public policies with a mission oriented perspectives acting on specific strategic sectors, such as the promotion of linkages and the development of capacities in order to favor the emergence of technological clusters. As state by the first path, the role of markets is more important in bottom-up policies than in a strategic vision.

At the same time, we have also located the four dimensions of complexity on the graph. As can been observed, the graph shows the relationship between traditions and policy prescriptions. In general terms, it is possible to associate the first historical path with horizontal policies and the second with vertical ones. However, the figure suggests the existence of intermediate positions that propose the integration of both policy types, with the two historical traditions mentioned above as a theoretical basis.

First, the consideration of heterogeneity leads to a public policy design aimed at increasing variety. In this regard, from a microeconomic perspective the habits and routines and self-organization groups emphasize the relevance of heterogeneity as the fuel of the selection process. Therefore, these groups promote public policies designed to improve individual skills, which would trigger innovation processes and therefore an increase in variety. From this evolutionary perspective, the goal of innovation policy is to enhance agents' dynamic capabilities and their learning process, so novelty and variety are continuously recreated. The policies mainly promoted by these groups can be labeled as horizontal bottom-up.

Second, from a theoretical perspective, the structure of the network and its impact on innovation and economic development has been analyzed in depth. Studies have distinguished between different morphologies and types of network and have analyzed their impact on knowledge generation and circulation. Nevertheless, the public policy instruments emerging from such theoretical developments are still in the experimental stage. Therefore, policy recommendations lead to a deepening of linkages between organizations regardless of either the quality thereof or the resulting kind of structure. The differential stress that each group placed on the relevance of the network structure leads to differences in the policy type in relation to this issue. The self-organization and local systems groups are characterized by the fact that they emphasize linkages as more relevant than components when explaining the global dynamics of the system and the emergent order (Potts, 2000). From this perspective, public policy should aim to encourage

> dynamic coordination among the variety of heterogeneous players involved in the generation of knowledge as a complex and collective process. The state can favor the activity of interface bodies that have the specific mission to increase the dissemination of scientific knowledge and its communication to potential users. The creation of such interface agencies can increase the efficiency of the workings of the knowledge governance systems (Antonelli, 2011: 179).

Boschma and Martin (2010) show

> that region-specific contexts provide opportunities but also set limits to what can be achieved by public policy. Consequently, policy action should avoid 'one-size-fits-all' and 'picking-the-winner' policies. Instead of copying best practices or selecting winners, policy should take the history of a region as a starting

> point, and identify regional potentials and bottlenecks accordingly. To avoid the problem of regional lock-in, Nooteboom and Stam (2008), among others, have argued that public policy should stimulate the entry of newcomers, encourage new policy experiments, and enhance the establishment of extra-regional linkages. (Boschma and Martin, 2010: 25).

Third, the "disequilibrium, interactions, and divergence" dimension of complexity gives rise to a set of public policies aimed either at promoting the positive feedbacks associated with virtuous dynamics and unlock blockades in order to reverse divergence phenomena. In this regard, the cumulative causation and the feedback and increasing returns groups have emphasized the divergence between systems caused by feedback processes derived from capabilities and interactions between components. In particular, the cumulative causation group has emphasized divergence processes arising from the feedback dynamics between productivity and demand. Finally, the presence of increasing returns is considered to be the cause of the divergence phenomena, derived from interactions. "Interactions are causal in nature and have implications for policy in terms of magnifying the effect of agent-level policy interventions" (Hartmann et al., 2008: 3). In these cases, the policy should recognize the presence of divergence and act accordingly in order to generate catch-up processes and unlock the lock-in phenomena.

Fourth, the emergent properties considered by each group should be in themselves the policy aim. In the self-organization/self-transformation group the emergent property of the system is organization and coordination. Therefore, public policy should aim to smooth the way for this to emerge. "Innovation policy must center on assisting the development and the evolution of the underlying knowledge structure that generates operation outcomes in a market, and not in the operational outcomes themselves". In other words, this mean developing capacities and intervening "at the level of constitutional rules in order to provide the adequate underline structure of regulations, financial institutions, and public infrastructure, and allow flexibility of the legal framework to facilitate adaptation process and accommodate novel forms of transformation and transactions" (Bleda and del Río, 2013: 1050). In this regard, the self-organization group is closer to habits and routines group in conceiving institutions as an emergent property as well. However in the case of the latter group the emergence of institutions is not given because of a set of elementary constitutional rules but it is based on the habits that govern the behavior of agents. According to Nelson and Winter, policy should focus on the creation of micro- and even intra-organizational conditions that ensure the emergence of routines.

The groups that are closer to the first tradition stresses that the specialization profile is naturally an emergent property of the system. In this case, the regulations that have been derived from the theory refer to the need for bottom-up-type intervention that focuses on improving market selection processes (as a set of socially established norms), and raising the minimum capacity thresholds of firms and institutions that fits variety on which selection process work. In fact Metcalfe et al. (2006) have stressed that "policy would follow from a bottom-up rather than an aggregate economy-down perspective; that they would depend on the stimulation of enterprise and entrepreneurship; and that they would depend upon the open, unbiased operation of market institutions" (Metcalfe et al., 2006: 29)

Contrary to these mainly bottom-up policy types, public policies derived from the innovation systems and cumulative causation groups aim to recognize the fact that the emergent structure may not be conducive to an economic development process. Therefore, intervention should not only take into account bottom-up aspects but also, and mainly, top-down policies that focused on both defining the specialization pattern and choosing the driver sectors for economic development. The latter leads to a discussion about how to identify such sectors and involves various perspectives ranging from finding windows of opportunity (Pérez, 2010; Dosi, 1982), choosing sectors with increasing returns (Dosi et al., 1990; Reinert, 2007), focusing on short cycle technologies (Lee, 2013), to prioritizing the manufacture and production of capital goods (Rosenberg, 1963; Pisano and Shih, 2009), among others.

In sum, those groups that are closer to the second historical tradition discuss the productive specialization profile (top-down policies), nevertheless they see room for evolutionary dynamics in structural change. Freeman has noticed "the policies promoted by List in his development of the concept of National System of Innovation advocated not only for protection of infant industries but a broad range of policies designed to accelerate, or to make possible, industrialization and economic growth." Therefore, he proposed that policies should be "concerned with learning about new technology and applying it." (Freeman, 1995: 5). Closer to new Latin American structuralism, Cimoli et al. (2010) have pointed out that

> structural change is, by definition, a process of qualitative change, which does not emerge spontaneously from the smooth accumulation of factors of production. In this sense the evidence confirms what the literature on comparative development has already pointed out, namely the key role played by the industrial and technological policies in picking up a dynamic growth path among the various alternative paths. (Cimoli et al., 2010: 406).

6. Conclusions

In this paper we have proposed that the umbrella of complexity is large enough to include different evolutionary neo-Schumpeterian groups because it takes on a set of ontological assumptions for complex systems that have been stressed differently by each evolutionary group. We have also proposed that a set of ideas linked to complexity theory can be read in different traditions within the history of economic thought. We have also stressed that different but complementary visions of public industrial and technological intervention can be derived from the ontological assumptions of complexity. Finally, we have shown a link between these issues: each group exhibits a different link with each tradition within the history of economic

thought, and therefore, different ways of conceiving public intervention.

In this context, there is a contrast between the two forms of conceiving public intervention, which are aligned with historical precedents and with the dimensions of complexity that they emphasize. At one extreme, the groups that have focused on understanding the problem of change as dependent on the issue of coordination have centered their work on solving systematic problems that make the system less self-organized, which goes hand-in-hand with self-transformation through the creative functions of markets. In this case, policy recommendations seek to generate conditions of pre-emergence, according to which the role of the state is to bring about conditions that favor learning processes, interactions between agents, selection mechanisms, the generation of public or quasi-public goods, etc. That is, they seek to resolve the systematic problems that block the development process. In this context, policies tend to be of the bottom-up, horizontal or diffusion-oriented type, as there is trust that the system will function – once the initial conditions have been set – in such a way as to achieve structural change processes and economic development. It is significant that for these groups innovation and development are the emergent properties par excellence for an economic complex systems.

At the other extreme, the groups that sought to understand the transformation process as the result of a cumulative process have emphasized the question of the divergence between complex economic systems caused by positive feedbacks between innovation, structural change, and demand growth. The sectoral differences with regard to learning, the spread of technological progress and increasing returns, and the recognition of divergent paths associated with structural characteristics all lead to policy interventions focusing not only on generating the conditions for structural change but also on promoting it directly in order to avoid system lock-in positions such as low-income or low-development traps. In this case, public policies focused on top-down, vertical or mission-oriented interventions promote sector selection with the goal of creating a specialization profile that fomented economic development. This is coherent with those policies promoted by the development school who favor top-down and vertical policies that promote structural change processes.

Regardless of the economic dynamic that has arisen from the complexity perspective, it reveals emergent properties that are the consequence of simultaneous bottom-up and top-down processes. In other words, the evolutionary dynamic is built through individual actions, but they are also affected by macro and meso structural conditions, including institutions, which limit their behaviors, choices, and possibilities for learning. In this sense, the complexity approach is coherent with regulatory recommendations in which both types of intervention are justified. For example, intervention is necessary to change specialization trade profile in order to avoid lock-in situations while simultaneously developing capacities to increase the generation of variety, which in turn improves the innovative capacity of the system.

In this context, the different dimensions of the complexity approach reveal not only the differences in each group of contributions' policy recommendations but also the need to articulate them. In this way, bottom-up and top-down approaches are not mutually exclusive options but rather complementary ones. Even more, industrial and technological policies often combine both types of intervention instead of choose one or the other type. As such, the structural change policy promoted by the different contributions would be enriched because it would not only focus on improving the competitive process in firm populations – as has been suggested by the *self-organization/self-transformation and habits and routines* groups – but would also, through the selection of technologically progressive sectors, provide more space for the application of bottom-up policies for improving productive, technological, commercial, and organizational capacities.

Complexity is a plural framework that allows integrating different industrial and technological policies designs and avoiding a false antinomy between top-down vs. bottom-up, vertical vs. horizontal, and mission- vs. diffusion-oriented policies. In this paper we show that complexity can be useful to mix effectively the policies recommendations of the five groups of evolutionary neo-Schumpeterian authors. The contribution of this paper is that the policy integration has a theoretical root and it is not merely instrumental one.

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