A complex evolutionary view of the origin and developments of organizational capabilities

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Abstract

Routines and organizational capabilities are central constructs in explanations of firms' heterogeneity and sustained competitive advantage in industries and markets. Building on the foundational contribution of Nelson and Winter, the routines and knowledge capabilities of firms have been a major focus of theorizing in many areas within innovation and management research. Despite this, numerous issues still remain unresolved, particularly regarding the specific mechanisms by which capabilities emerge and develop over time. In this paper, we contend that the evolutionary approach to the firm pioneered by Nelson and Winter can resolve existing contentious issues about the topic by adopting a complexity perspective. In particular, we argue that a view of the firm as a complex adaptive system enhances evolutionary explanations of the origin of organizational capabilities, and how these emerge and change via processes of organizational learning. In addition, we show that embedding this view within a general evolutionary framework emphasizes the role of knowledge capabilities as sources of developmental variety in the evolution of firms, and allows accounting for their creation via self-organizing processes as a fundamental dynamic force in economic evolution.

Introduction

Organizational capabilities and their role in understanding the nature and behavior of firms have been the focus of recent theoretical work in many domains within the innovation and management fields[2,3,4,5,6]. Despite this, as with any approach seeking to understand complex realworld phenomena, the capabilities research field is developing at a slow pace, and as an area of enquiry is still in its infancy remaining mostly conceptual and centered on foundational level questions[7]. Among the various issues highlighted in the literature, the need of better explanations of the origin of organizational capabilities, and how they develop over time is generally quoted as one of the most prominent limitations of the approach[8,9,10,11,12]. The objective of this paper is to add to the ongoing conceptual advancement of the field by contributing to the enhancement of explanations of how capabilities are originated and developed in firms.

Capabilities are organizational knowledge assets, and as such they cannot be 'acquired', they have to be built up over time via organizational learning. They are also key determinants of differential organizational performance and evolutionary long term survival. Adequate explanations of their origins and development should therefore first explicitly consider the element of time, and second be conceptually framed in the general context of the evolution of firms. This is why, as several authors have suggested, evolutionary theory constitutes the most appropriate framework to embed these explanations. According to Winter[11] "confronting the analytical obstacles posed by considering time in explanations of the origin of capabilities is inherent in the nature of the topic, and evolutionary theory is the way to organize the confrontation"[11]. Katkalo *et al*.[6] have also proposed that the integration of the study of capabilities within a general theory of economic evolution is one of the conceptual steps required for the approach to move forward[1]. We agree with these authors, and so Nelson and Winter's evolutionary approach to the firm [1,13], and their definition of organizational capabilities and routines constitute the starting point of our contribution.

Nelson and Winter[1] define the concept of routines as the organizational level counterpart of individual skills. In their analysis thus routines embody the collective knowledge capabilities of the firm, and organizational learning is essentially a process of routine modification. Their account of routines therefore provides the conceptual link between individual skills/behavior and collective capabilities/behavior in firms, and a way to 'move' from the level of the individuals to the level of the organization. This methodological approximation, while being analytically and conceptually adequate, leaves explanatory factors at the micro-level of individuals unexplored and implicit[14,15].

The evolutionary perspective of the firm provides the temporal dimension that is required to explain how routines and capabilities originate and develop in firms; it also explicitly places this explanation within the general context of the evolution of firms. However, a complete explanation of the origin and development of organizational capabilities requires that the evolutionary view descends one level of analysis, to the micro-level of the firm's constituents[11,16]. In our view, the evolutionary approach can do this by adopting a complexity perspective, and this is the central argument of this paper[2]. In particular, our main contention is that viewing Nelson and Winter's firms as complex adaptive systems can significantly enhance evolutionary explanations of the emergence and development of capabilities by explicitly incorporating the influence that individual 'micro-

level' factors have in these processes. We also argue that the adoption of a complexity perspective contributes to improve evolutionary explanations of the multidimensional nature of knowledge capabilities and their role as a source of heterogeneity and differential performance in firms. In addition, we contend that embedding this view within a general evolutionary framework emphasizes the role of capabilities as sources of developmental variety in the evolution of firms, and allows accounting for their creation via self-organization as a fundamental force in economic evolution.

The paper is structured as follows. In the next section, we present Nelson and Winter's[1] concepts of organizational capabilities and routines, and place their generation via organizational learning within a general evolutionary framework. In section three, drawing upon existing literature mainly within the organizational studies and management fields, we outline the main characteristics of the firm when viewed as a socio-economic complex adaptive system. In section four (which constitutes our contribution) we provide a discussion of the ways in which this view of the firm enhances evolutionary explanations of the origin and development of organizational capabilities. In the final section we present directions for future research on the topic and some concluding remarks.

Organizational capabilities and routines in the evolutionary firm

The starting point of the characterization of firms in Nelson and Winter's[1] is the recognition of the key role of knowledge in determining a firm's behavior and long term success. Knowledge in the evolutionary view is defined as a multi-dimensional and broader concept than information: it is partly tacit, it is incomplete and imperfect – firms and individuals are bounded rational[17,18], and it incorporates not only problem solving and other type of cognitive abilities but also a certain constructed representation of reality which includes a perception, a belief, and a judgment dimension[19]. A fundamental implication of these features is that the knowledge capabilities of firms and the ability to apply them to perform organizational operations are highly idiosyncratic, and therefore constitute essential sources of heterogeneity in organizational behavior and performance[3]. In an evolutionary context, capabilities are thus defined as firm specific sets of knowledge which are embedded in organizational routines[2].

As indicated in the introduction, Nelson and Winter define routines (or the knowledge capabilities that they embody)[4] as the organizational level counterpart of individual skills. Routines thus store the collective knowledge of the firm, which while being formed by the individual skills or 'knowledges' of its constituents it cannot be reduced to them. Since knowledge resides in the minds of the individuals of the firm, organizational knowledge is unevenly distributed: it cannot be fully grasped and/or controlled by any of them, and it has to be applied and brought together in the context of the performance of multi-person activities. This implies that, for its operational use within a firm, knowledge has to be coordinated, and organizational routines also serve this role. In this respect, routines work as knowledge coordination devices which emerge partly spontaneously in firms, i.e without a directed effort or the conscious design by top management, and tend to be self-sustaining or maintained without managerial effort[11].

More recent and general evolutionary accounts consider (although some of them only implicitly) that organizational capabilities are embodied in: routines defined as socio-economic *replicators*,[20] in a firm's *codex*, [21] in *generic rules*, [22] and in relevant organizational *instructions* (Pelikan, 2011). In the remainder of this work we will use the term 'routines' in a general sense to refer to any of these loci for the knowledge capabilities of a firm. Irrespective of the different concepts used to designate where organizational capabilities reside, the key point from an evolutionary viewpoint is that for the long term survival of a firm, these cannot remain static but have to be modified over time through learning. The modification of routines via organizational learning is generally explained in an evolutionary setting following Nelson and Winter's[1] concept of higher level 'learning' or 'search' routines by which firms look for ways to modify their lower level operational ones[23]. Firms undertake trial and error search processes in interaction with their environment by which successful routines are reinforced and embedded in their existing set, and less successful ones are abandoned. Operational routines maintain established search patterns, and search routines are higher level routines for exploration that extend the search in new directions generally in a 'guided' manner[24].

In light of the ideas presented above, and accepting the general view that economic evolution is essentially Darwinian[5][25,26] the evolution of a population of firms can be explained through the interaction of three basic mechanisms: a mechanism of *retention* or inheritance by which some relatively stable characteristics are preserved over time (and may be passed to other firms), a mechanism of change by which new *variations* are constantly generated, and a mechanism of *selection* by which the frequency of some variations relative to others is increased. The mechanism that allows the preservation and transmission of organizational characteristics is provided by the routines (codex, generic rules, or instructions) of the firm which guarantee that useful or valuable knowledge capabilities are stored and passed on over time. The mechanism of selection is provided by the market in which firms interact in a competitive manner, and explains why in given contexts some firms are more adapted or more successful than others, and some survive longer than others. The selection of those firm's behaviors that are relatively more successful modifies their distribution in the population (and that of their underlying knowledge capabilities/routines), so that the likelihood that firms display successful behaviors/capabilities in the future increases. Through selection, information is fed back from the market into firms so that valuable behaviors/capabilities are retained and used in the future[15].

The mechanism of variety generation continuously creates the diversity among individual firms necessary for selection to operate, and thus for evolution to proceed. Diversity is introduced in a population of firms in two ways: through *variational* changes in the composition of the population as the result of the selection process, and *transformational* or *developmental*

changes as a consequence of modification in the characteristics of the individual firms of the population[27]. Developmental changes in firms take place via the modification of their existing routines/capabilities through organizational learning, so it is this through developmental processes that evolving firms build up their knowledge capabilities over time. As previously indicated, the modification of routines by learning is generally explained in the evolutionary view[6] by the concept of higher level 'search' routines by which firms look for ways to modify their lower level operational ones. This account of organizational learning thus explains he modification of capabilities and routines in terms of other (higher order) routines, and it does not really include an explicit explanation of the actual mechanism by which new capabilities/routines are created. Neither does explicitly account for the influence of individual characteristics and other micro-level factors in the process. As Winter[12] has stated, an evolutionary first-order answer regarding the creation of a capability is 'it evolved from another capability'. Within an evolutionary setting, the study of the origin of capabilities and routines is essentially a study of transition (and transmission) mechanisms between ancestors and descendants, which merges into the study of incremental change of existing capabilities and routines[12]. The notion of routine, and the account of organizational learning based on higher order routines leave explanatory mechanisms and the influence of micro-level factors in the creation of capabilities unexplored and implicit. Our key argument is that these can be explored and explicitly incorporated in evolutionary explanations via the adoption of a complexity perspective.

Firms as complex adaptive systems (CAS)

CAS can be broadly defined as open dynamical systems that able to self-organize their structural configuration through the exchange of information, energy and other resources within their environment, and are able to transform these resources in order to support action[28].

In this context, self-organization involves that no system constituent (or anything outside the system) has a direct or an exclusive control over its collective patterns or how these patterns change. It also means that the interactions among the system's constituents are not centrally controlled, but local, this 'localness' being related to physical or cognitive dimensions. The collective ordered patterns that emerge via self-organization in CAS are usually known as 'emergent' properties, i.e. properties that arise or characterize a system at a certain level as the result of interactions taking place at a lower level. Since their emergence and the way they change over time are partially determined by local interactions at the level of the system's components, the system properties derive from individual properties but cannot be reduced to them. In addition, emergent properties can change because the system's constituents are partially, not fully, connected in their network of interactions. Partial connectivity is indeed an essential requisite for the structural development of CAS[18,29]. Structural developmental processes (which can be triggered by both internal and external environmental factors) involve the reconfiguration of a system's connective structure, and hence the creation of new emergent collective properties, allowing CAS to change and adapt their behavior over time.

All CAS whether they are physical, chemical, biological or socio-economic share the above general properties and mechanisms.[30,31] However, their specific dynamics and behavior are highly dependent upon the nature of the system under analysis. In this respect, Foster [28] provides an insightful taxonomy that allows distinguishing socioeconomic CAS (generally formed by people) from their counterpart in the physio-chemical and biological spheres in terms of their different orders of complexity. According to Foster's classification all socio-economics systems including firms are *third* and *fourth* order CAS[7] .Third order CAS are systems which interact with their environment not only via the exchange of information and other resources, but also through the formation of images of possible worlds that they store in their mental models, internal models[32] or schemata[33]. They are therefore able to form knowledge structures or sets by establishing connections between imagined elements and ideas, which do not necessarily exist in their observed reality. In these systems thus knowledge is not only the result of the accumulation of experiences but it also involves creativity. Fourth order CAS are systems that in addition to be able to create and imagine internal models of their own, they can imagine what the internal models of other systems with which they interact might be, and to interlink these to create interconnected knowledge sets. This means that in order four CAS knowledge involves does not only involve creativity but it is also interactive.

Viewing the firm as a system[8] inexorably requires defining it as a complex adaptive system of individuals of order four, which through its interaction with its environment transforms information and other resources into useful knowledge, and applies this knowledge to increase the value of what it produces. Any view of the firm as a system of individuals involves that what a firm knows (and does) is irrevocably linked to what its members know (and do). However, when the firm is defined as a CAS, the particular structure of interactions[9] that these individuals hold determine to a great extent its collective knowledge, and hence its overall behavior. In other words, organizational knowledge and behavior in a complexity framework are emergent properties of the firm that result from the self-organizing interactive behavior of its individual components. CAS in general organize within nested hierarchies, which implies that these constituents are also complex adaptive agents of order four, i.e. they are able to imagine and form mental representations about the beliefs, intentions and the knowledge of the individuals with which they interact within the firm. In doing so and through their self-organizing interactions, individuals coordinate their knowledge and behavior and form shared 'understandings' and knowledge structures that underpin the organizational behavior of the firm, and are critical for its functioning as a whole. As emergent properties, collective knowledge and behavior in firms are highly specific as they crucially depend on the particular properties of the interactive structure that underlies them.

The effect that the specific properties of the interactive structure of a firm have on its global knowledge and behavior are

generally illustrated through Kauffman **29** NK models[10]. These models show that the properties of the interactive structure of a firm (in terms of the number of connections, K, among its constituents, N) influence the rate at which information is transmitted in the firm, and hence the collective patterns that emerge via self-organization from these connections. Different connectivity levels have thus associated a different dominant mode of organizational knowledge and behavior. The properties of the connective structure of firms also influence their ability to modify their organizational patterns as a result of changes in their individual constituents. In firms with interactions structures with very low connectivity (with only a few connections among their members) information is easily transmitted, so the coordination of individual patterns via self-organization is easier than in firms with highly connected structures. These firms are also very stable (any change in one of their members will affect only a few others); however, they have limited ability to change as their interactions structure tend to get locked into configurations of connections that are extremely difficult to be 'broken' to give way to new emergent organizational patterns. Firms with very high connectivity, on the other hand, can easily change; however, they are extremely unstable since any change in one of their individuals propagates to all the other individuals it is connected to, changing each of them, and progressively propagating back, generating further escalations of change in the firm's organizational patterns. In this case, a new individual pattern may span the entire firm, and quickly lead to new self-organized collective knowledge and behavior, but it may then be too rapidly substituted by another pattern, and associated new collective properties, making it very difficult for the firm to lock into any of the emerged possibilities. Hence, connective structures closer to the two extremes of very low and very high connectivity are of relatively poor quality from a dynamic viewpoint: highly ordered not very connected structures are difficult to break down to allow change, and in very connected structures there is not enough stability for any good interactive arrangement to persist. In partially connected structures characteristic of firms as CAS in which no one of these two dynamical modes dominates, firms are stable enough to operate and flexible enough to change and develop over time.

As we have previously argued, the view of the firm presented above can significantly enhance evolutionary explanations of the origin and development of organizational capabilities. In the following section we justify this argument by presenting the specific conceptual aspects that we consider are enriched by the adoption of a complexity perspective.

The evolutionary view of organizational capabilities within a complexity perspective

A complexity perspective enhances evolutionary explanations of the multi-dimensional nature of knowledge in firms and adds micro-level sources of organizational heterogeneity.

As outlined in section two, in the evolutionary view the knowledge that firms hold in their organizational capabilities is defined as a multidimensional, broader concept than information. Knowledge in complex adaptive firms of order four is understood in this wider sense, and as in the evolutionary approach, has a fundamental role both for their proper functioning, and as a source of organizational heterogeneity and differential performance. Adopting a complexity perspective, however, adds several important aspects to these ideas.

First, a complexity perspective explicitly accounts for the actual factors that underlie the evolutionary multi-dimensional conception of knowledge. Organizational knowledge in the evolutionary view is considered to be partly tacit, limited, unevenly distributed, and involves highly subjective representations of reality. It is because of these features that firms create meaning out of information in a distinctive way to generate idiosyncratic and highly specific knowledge capabilities. Defining firms as CAS explicitly places the origin of these features in the cognitive and behavioral characteristics of their individual constituents. As fourth order complex adaptive agents, the individuals of a firm possess idiosyncratic and partly tacit sets of knowledge. They are also bounded rational, as they have limited cognitive skills, indeterminate and context dependent mental models, and specific perceptions or understandings of the environment in which they are embedded. Since organizational knowledge in a complex firm is an emergent property that arises from the individual knowledge of its interlinked constituents (even if it cannot be reduced to it) by nature it will reflect all these properties.

In addition, the definition of the firm's constituents as four order complex agents involves a notion of knowledge that incorporates *imagination* and *creativity*, aspects that are usually neglected or underplayed in the evolutionary approach. In the evolutionary view, knowledge includes internal models defined as constructed representations of reality that involve a perception, a belief and/or a judgment dimension. Constructed representations defined in this way however are different from imagination, creativity, and the forming of conceptions. Perception, belief, and judgement refer to given alternatives, even if these can be uncertain and difficult to assess, while imagination is the very act of mentally creating those alternatives[34]. The knowledge of individuals in firms as CAS includes not only the capacity to form mental models of their actual reality, but more importantly, the ability to create representations of an imaged reality, and in particular of the possible behaviors and mental models of the systems, and/or agents with which they interact. Furthermore, order four complexity incorporates the*interactive* aspect of knowledge, which means that the constituents of the firm are able to interlink these representations into interconnected mental models to form structured knowledge sets. Imagination and creativity are unique in individuals, and so are the specific ways in which individuals interlink their mental models within firms. This implies that these structured knowledge sets will be highly firm specific. The properties of knowledge incorporated by the complexity view thus add key sources of inter-firm heterogeneity at the micro-level that are not considered by the evolutionary approach.

Finally, the features of organizational knowledge as an emergent property of the firm do not just derive from the individual properties of its constituents, but crucially from the connections that are built between them. Individuals in complex firms create collective knowledge patterns via their interactive behavior, the nature and the content of which are shaped to a great extent by the particular way in which these individuals are interconnected. Different structures of connections have different properties and thus will have associated or 'support' different collective knowledge sets enabling different and specific capabilities and organizational behavior. The way in which individual idiosyncratic knowledge and behavior are interlinked within a firm therefore constitutes another source of organizational heterogeneity at the micro level that the complexity 38 perspective adds to the evolutionary view. This idea directly leads us to the following aspect of the evolutionary approach to the firm that we consider can be enhanced by adopting a complexity perspective.

A complexity perspective enhances evolutionary explanations of the origin of organizational capabilities

In the evolutionary approach knowledge capabilities underlie organizational behavior, and are considered to be embedded in the routines of a firm. Routines defined in this way, i.e., as underlying generative structures, do not only work as stores of knowledge but also as cognitive coordination devices in firms. Since knowledge is unevenly distributed among the individuals of the firm it must be coordinated to be applied in the performance of organizational activities, and routines effectively serve this coordinating role. As already indicated ascribing this role to the concept of routines leaves essential mechanisms regarding their origin unexplained. In particular, the use of routines as coordination devices 'black-boxes' the details of how the coordination process takes place within the firm since routines are defined as directly embodying the collective 'already coordinated' knowledge capabilities of a firm. Subsuming intra-firm cognitive interactions in the notion of routines thus avoids an explicit identification of the mechanism by which individual knowledge is coordinated in the firm, and hence an explanation of the actual dynamic process by which organizational capabilities are originated. By adopting a complexity perspective the evolutionary view can make this coordination process explicit.

In a complexity context, knowledge capabilities are created by the individuals of a firm via a dynamic process of self-organization. When firms are defined as CAS, organizational knowledge is an emergent property of the firm, and capabilities are essentially structured sets of knowledge that originate from the coordinating self-organizing interactions of its individual constituents. Self-organization is indeed the coordinating force that explains how, as Nelson and Winter have put forward, organizational capabilities embodied in routines emerge spontaneously in firms, i.e without a directed effort or the conscious design by top management.

Considering self-organization as the mechanism by which capabilities are originated in a firm allows the identification of two key micro-level sources of their idiosyncratic nature. One is (as indicated above) the specific cognitive characteristics of its individuals, i.e. their creativity, imagination, their limited abilities, an their subjective and incomplete mental models. The second one is the individuals' specific behavior, i.e. the particular way in which they apply their distinctive knowledge to behave and carry out activities in the firm. Since individuals are highly heterogeneous, have different cognitive abilities, and different understandings and perceptions of their reality, they will have a unique way of applying their knowledge to perform activities. Even in the unlikely case that two individuals within a firm had the same exact set of cognitive abilities, and the same mental models, they most probably would use them in a different manner to perform the same task, and would achieve a different outcome.

In addition, self-organization underlines the fact that individuals do not apply knowledge to operate in firms in an isolated manner, they typically do it via their interactive behavior. The contribution of any firm constituent to the formation of the capabilities of a firm therefore will be determined by the way in which its knowledge is linked to the knowledge of others members when it is put to work through their mutual interactions in the firm. Indeed, for individual knowledge to be applied in an effective manner in a firm, the members carrying it must 'fit' within a particular connective structure. The involvement of a given

individual in the creation of capabilities thus greatly depends on whether (and to what extent) their knowledge can be applied within the structural 'constraints' provided by its particular structure of interactions. This is also the reason why, as the evolutionary view highlights, the knowledge capabilities that a firm holds in its routines (and the specific behavior they enable) cannot be inferred from the individual knowledge/behavior of its constituents since they also derive from the properties of the structure of interactions between them. What a firm knows (and does) is somewhat more than simply the adding up of what its members know (and do). As illustrated by Kauffman models, different firms' interactive structures give rise to different emergent knowledge capabilities depending on their number of constituents and their connections, and the properties inferred from them. As indicated above the particular way in which individuals are connected in a firm constitutes another micro-level source of heterogeneity in firms: as interactive structures vary significantly among firms, they will develop highly different collective understandings and knowledge capabilities about the same issues, and will therefore behave in a very distinct way.

The properties of the connective structure within which individual knowledge and behavior must be coordinated for organizational capabilities to emerge are also relevant to explain the different nature of the knowledge capabilities of a firm. For instance, dynamic capabilities [35] will be more likely to emerge in firms in which one or more of its members are very creative or innovative, and/or have a high ability to learn, but also, and even more importantly, in firms with a connective structure that provides these individuals with the specific interactions and the flexibility required for their new ideas and behaviors to arise and succeed. A firm can possess very creative and cognitively able individuals (i.e. with a high ability to solve problems and/or very reliable representations of the environment); however, if these individuals are not supported by an appropriate connective structure (e.g., it is a very constraining or rigid structure) or, in their local interactions, they are not connecting with the 'right' people or in the right way, the firm will most likely not generate dynamic capabilities since the interactions assuring the coordination of the knowledge required for their creation are not in place. In a similar way, absorptive capabilities[36] will almost certainly be supported or will emerge from interactions among individuals with an ability to recognize the value of external knowledge and how to apply it, and again within a structure of connections in the firm that is appropriate and flexible enough to accommodate this knowledge.

The emergence of knowledge capabilities through self-organization constitutes a co-ordination mechanism which allows firms to use their individuals' knowledge in an effective manner. However, for a firm's long term survival in an evolutionary environment its knowledge capabilities cannot remain static but have to be modified over time through processes of organizational learning. This leads us to the following point in our discussion.

A complexity perspective enhances evolutionary explanations of organizational learning

As outlined in previous sections, organizational learning in the evolutionary approach is generally explained as trial and error search processes through which effective and successful routines/knowledge capabilities are reinforced and ineffective ones are abandoned. This account of learning defines changes in routines in terms of other 'higher order' routines, and does not explicitly incorporates the role of individual learning and other factors at the micro level in the process of modification of routines and capabilities over time.

The complexity view explicitly places individual learning as the basis of organizational learning since it is through the learning and adaptation processes of its individual constituents that a complex adaptive firm 'learns'. First, it is individuals who equipped with new knowledge as a result of their individual learning modify their behavior and dislodge firm's structures to allow their modification and/or creation of new ones to support new knowledge capabilities; and second it is via the new interactions and self-organized behavior of individuals that these new capabilities emerge in the firm. Organizational learning in a complexity context thus generates new capabilities and behavioral patterns in firms through processes of structural re-configuration that result from the learning of their individual constituents.

Individual learning processes can be triggered by factors internal to the firm, such as its individuals' imagination, their creativity, the actions of 'rule breakers', and also changes in the individuals environment both within the firm (e.g. resulting from internal selection processes) and outside the firm (e.g. changes in their local interactions with external agents). Learning processes initiated in this way modify the individuals' knowledge and behavior, including their interactive behavior, and hence the way they are connected. This thus leads to a break-down of their pre-existing structure of interactions, and to the emergence of a new one which will support new self-organized organizational capabilities and behavior from the *bottom up*. Individual learning can also be triggered by changes in the environment of the firm. Within a nested hierarchy, a firm interacts as 'a whole' with other CAS in its environment (e.g. direct and indirect competitors, firms in a different sector producing a complementary good, suppliers, consumers, the government, financial organizations). As CAS these systems are also simultaneously learning, and changing their behavior, hence posing both new challenges (e.g. selection pressure from competitors with an improved new product) and opportunities (e.g. resulting from favorable changes in government regulations, or successful new knowledge interchanges with collaborators) for the firm. The effects of these environmental pressures and/or opportunities are 'passed on' or filtered in a *top down* manner to the members of the firm, initiating individual learning processes which again will modify their knowledge and interactive behavior leading to a 'rupture' of their existing structure of interactions, and ultimately via self-organization to the creation of a new one with a new associated emergent capabilities.

Organization learning in a complexity context is thus characterized by a dynamic synergetic feedback loop that connects the

individual and the organizational levels: changes at the micro — level (in the knowledge, behavior and interactions structure of individuals in the firm) lead in a bottom up manner to the emergence of new organizational self-organized knowledge and behavior, which in turn influence these individuals in a top down manner through their local environment.

While a complexity view explicitly defines learning in a firm as the result of the learning of its individuals, organizational learning cannot merely be reduced to individual learning, since as we have previously explained, the properties of the connective structure linking these individuals will determine to a great extent the nature and the content of newly created knowledge capabilities. Furthermore, as also illustrated by Kaufman models, these properties also influence the ability of firms to change, and therefore their ability to learn. The emergence of new capabilities in a complex firm crucially depends on the degree of localness and connectivity of its structure of interactions. Individuals as imaginative, creative and 'cognitive able' as they might be, will only be able to learn, modify their behavior, and take effective action if they manage to overcome the inertia and the structural constraints given by their pre-existing structure of interactions in the firm.

This is possible in firms as CAS because their members are partially connected in their network of local interactions. This means that the interactive structure in which these individuals are embedded, and within which they operate, is tight enough to support existing capabilities (and the behavioral patterns they yield), and flexible enough to allow them to learn and create new interactive structures so that new capabilities (and behaviors) can emerge. Put differently, organizational learning can effectively take place in firms whose connective structures are located in what Kauffman[29] has called the complexity regime. In this regime coordinating forces maintaining structural order and stability, and destabilizing forces pushing the firm towards disorder, coexist.

As explained before, highly ordered and stable organizational connective structures (i.e. those with very few connections) allow a high degree of centralization in a firm, which facilitates the coordination of the knowledge and behaviors of its individuals, and hence the effective *exploitation* of its existing capabilities. On the other hand, in this case, knowledge is locked tightly into the connective structure of the firm, and cannot be easily changed. This degree of rigidity makes organizational learning through processes of experimentation and decentralization extremely difficult. By contrast, interaction structures with a very high level of connectivity allow a high degree of differentiation and diversity, and so a greater level of experimentation,*exploration*, and capabilities creation in firms. However, these are quite unstable, new capabilities might be easily created, but they may then be too rapidly substituted by new ones, making it very difficult for the firm to exploit the capabilities created through these processes of decentralized experimentation[11].

In a complexity context, resilient firms will be those that throughout their histories have developed connective structures which allow a balance between the exploitation and exploration of their knowledge capabilities; or as indicated, those whose interactive structures are partially connected and located in the complexity regime. It is in this regime that the emergence of new capabilities through organizational learning is possible, and firms can develop over time.

A complexity perspective emphasizes the role of organizational capabilities as sources of developmental variety in the evolution of firms

As pointed out in section two, when economic evolution is explained in Darwinian terms, variety generation is one of the fundamental mechanisms by which firms evolve over time. New variety is introduced in a population of firms in two ways: through variational changes in the composition of the population as the result of selection processes, and through transformational changes in the characteristics of the individual firms as a result of developmental processes. As in the evolutionary view, the sources of variational change in a complexity setting lie in the interactions that firms as 'wholes' keep amongst them, and with other CAS in their environment.

Selection acts via competitive inter-firm interactions which determine which firms survive and/or grow, and which ones fail and eventually cease to exist. This process generates diversity in the pool of organizational capabilities and behavioral patterns in the population by adding or subtracting competing firms.[12] Although selection is contingent on heterogeneity in the characteristics of the firms forming the population, explanations of evolutionary change do not necessarily require accounting for the origin of this variety, or even considering that firms change over time. In fact, a canonical model of evolution would allow the individual characteristics of firms to remain fixed[24]. This has given the selection mechanism a predominant role in explanations of economic evolution, often overshadowing the influence of developmental processes in firms[13].

A proper and complete theoretical account of the evolution of firms however cannot ignore their internal dynamic behavior, and the developmental process by which this behavior and the knowledge capabilities that underpin it are modified to generate diversity over time[27,37]. Adopting a complexity view emphasizes and enhances explanations of how developmental variety (in capabilities and behavior) is created in a population of evolving firms. A definition of firms as CAS within a nested hierarchy focuses both on the interactions that firms as wholes maintain within their environment, and on their internal interactions and dynamics, and the ways in which these influence performance and survival in the long term. As we have shown throughout our discussion, complex adaptive firms generate diversity in their knowledge capabilities 'from within' as they undergo developmental processes of internal structural reconfiguration through organizational learning[14]. Although essentially an endogenous process, the creation of capabilities in firms is prompted by both internal and external environmental factors.

Therefore, the variety resulting from developmental processes is generated 'from within' in combination with 'disruptions' from the environment. However, from a complexity perspective, the constituents of the firm acquire a fundamental role in the development of firms. First, as indicated before, it is their learning and adaptive behavior that allow firms to change and learn. In addition, they constitute a continuous internal source of diversity in populations of firms: as complex adaptive agents of order four, they are creative, they possess imagination and they are also in permanent change in relation to what others adaptive individuals in their local environment are doing, which results in the constant generation of new possibilities, ideas and behaviors. Selection via inter-firm competition reduces variety, as variety is reduced, the pace of selection declines, and when only a single firm or group of firms account for all the knowledge capabilities and behavioral patterns in the population, evolution stops. Without developmental changes, diversity is more and more eroded over time, the fuel of evolution gets exhausted, and evolution ceases[27].

Complex adaptive firms are always unfolding since continual processes of individual adaptation and learning involve that new knowledge and diversity are always being created. There are essentially limitless possibilities for variability in the minds and the behavior of the individuals of a firm, and hence neither its interactive structure nor its behavior are fixed in time. In complex firms it is the individuals that make possible developmental and self-transformational changes, as they have the capacity to displace obsolete patterns, by breaking down the interactions structure that support them and giving way to novelty; indeed all economic evolution stems from this *micro-level* based process of 'creative destruction'.

The emphasis given to the micro-level basis of development in firms by a complexity perspective also enhances explanations of the three stage nature of economic evolution. In the economic sphere evolution follows three steps[27]: initial variation, selection and revised variation as a consequence of development induced both by internal forces and by the pressures and opportunities arising out of the selection process. As previously indicated, in the Darwinian evolutionary logic, selection provides the feedback loop on information about functionality of different firms' behaviors (and hence of their underlying routines/capabilities) so that those which worked in the past can be retained and used in future interactions within their environment. The buildup of knowledge capabilities through organizational learning and development thus depends to a great extent on the accumulation of experience that firms and their members gain in the selection process. The kinds of variations that matter in economic evolution are those that enhance performance, and the third stage of evolution, that of feedback from selection to development, reflects the trial and error nature of experience based learning.[24] This is an important particularity of evolution in socio-economic systems that distinguishes it from evolution in the biological world: when firms learn they are able to modify their routines/capabilities (the repositories of knowledge and information in the socio-economic sphere) while organisms cannot generally manipulate their genes (the repositories of information in the biological sphere)[15].

The link between selection and development is provided in a complexity context by the synergetic feedback loop that characterizes organizational learning in complex adaptive firms: changes at the micro-level of the individuals of a firm lead in a bottom up manner to the emergence of new collective self-organized capabilities and behaviors, the latter are tested/subject to selection, and the results of this process in turn influences the individuals of the firm in a top down manner through their local environment. As Arthur [38] has put it, this dynamic logic is the basis of one of the most fundamental insights in the economic world: 'aggregate patterns form from individual behavior, and individual behavior in turn responds to these aggregate patterns: there is a recursive loop. It is this recursive loop that connects with complexity […] Complexity is about how the interacting elements in a system change and adapt to create new overall patterns, and how these overall patterns in turn cause the interacting elements to change or adapt'[38].

The complexity perspective allows the incorporation of self-organization as a fundamental dynamic force in economic evolution

As indicated in the preceding point, explanations of economic evolution have tended to give selection a predominant role as the main mechanism accounting for the variety of organizational capabilities, structures and behaviors in populations of firms. Adopting a complexity perspective involves acknowledging self-organization as the dynamic force driving the development of firms, and hence the recognition that some of the sources of the organizational patterns displayed in a population may lie outside selection. In fact, within a complexity view both selection and self-organization are considered inseparable and essential forces in the evolution of firms.

Although some authors have suggested that self-organization could constitute an evolutionary force alternative to selection,[37] currently it is widely accepted that both selection and self-organizing developmental processes have a fundamental role in the evolution of all complex systems, including firms. The degree of contribution of selection and self-organization will depend on the particular nature and characteristics of the firms, and on the specific features of their environment. Thus an assessment of their relative evolutionary importance is to some extent an empirical question. However, particular empirical results would not make any of both forces inessential in theoretical explanations of the evolution of firms[39]. Both self-organization and selection are required: any explanation that disregards self-organization ignores its crucial role as a coordinating mechanism in processes of knowledge capabilities creation. As seen in preceding sections, the generation of organizational capabilities does not only constitute an evolutionary source of developmental variety (a key source of inter-firm heterogeneity) but also the means by which firms improve their performance and their likelihood of survival over time. On the other hand, any explanation overlooking

the evolutionary role of competitive selection forces, would not be able to account for the survival value of firms, and would leave the process by which populations of self-organized firms adapt to their environment inadequately explained.

Recognizing the fundamental role of both self-organization and selection in economic evolution is therefore an important theoretical issue. The adoption of a complexity perspective allows accounting for the influence of both mechanisms, and how they dynamically interrelate in the evolution of firms. As shown throughout our discussion, in a complexity framework, the knowledge capabilities and coherent behavior that firms present over time are the result of the combination of self-organizing forces acting internally as cognitive and organizational coordination devices, and destabilizing internal and external selection forces in the firms' environment that open the way for learning and the changes necessary for their long term success.

The local and partially connected structures of interactions that characterize firms as CAS provide the support and stability they require to operate, and at the same time the flexibility to change within a dynamic environment. This degree of connectivity also imposes structural constraints which 'guide' their developmental reconfiguration processes: the intra-firm connections that are formed as developmental changes proceed over time make the dynamics of firms structurally irreversible. This means that as time goes by selection forces operate upon variety which has been previously self-organized, and can be even in some cases conflicting with the direction of change 'dictated' by the environment. On the other hand, processes of self-organization may themselves depend on selection since, as previously stated, they are not only influenced by internal forces. They are also affected by pressures and opportunities arising out of the selection process, the effects of which are fed-back (in the third stage of economic evolution) in top down manner from selection to development.

Conclusions

In this paper we have argued that the evolutionary approach to the firm pioneered by Nelson and Winter can provide suitable explanations of the origin and development of organizational capabilities by adopting a complexity perspective. The evolutionary view provides the temporal dimension required for an appropriate account of the creation and modification of capabilities and routines over time, and conceptually places these processes within a general framework of the evolution of firms. However, evolutionary explanations based in the concept of routines as cognitive coordination devices in firms leave key explanatory mechanisms and factors at the micro-level unexplored and implicit. Complete explanations of the origin and development of capabilities requires that the evolutionary view descends one level of analysis, to the micro-level of the firm's constituents to account for the influence of both their individual characteristics, and their interactions. We have discussed how the evolutionary perspective can take this conceptual step by adopting a complexity perspective. In particular, we have shown that viewing firms as complex adaptive systems, and embedding this view within a general Darwinian evolutionary framework, enhance explanations of the emergence and development of capabilities by explicitly incorporating the influence that individual micro-level factors have in these processes.

After presenting the core principles of the evolutionary approach to the firm, we have outlined the main characteristics and mechanisms of complex adaptive systems with a focus on those that are specific to systems in the socio-economic realm. This has established the theoretical framework for a view of the firm as a complex adaptive system. Based on this we have provided a discussion of the ways in which this view enhances evolutionary explanations of the origin and development of firms' capabilities. Our discussion is in need of further theoretical and (crucially) empirical elaboration, however we think that it constitutes a valuable and necessary theoretical first step. We have centered on the following theoretical improvements. Defining firms as complex systems provides a micro-founded evolutionary (hence time respectful) explanation of: i) the multi-dimensional nature of knowledge capabilities, and their role as a source of differential performance in firms, ii) the origin of routines and capabilities, and how these change over time via organizational learning, iii) the role of knowledge capabilities as sources of developmental variety in the evolution of firms, and finally iv) the interaction of selection and self-organization as essential forces in economic evolution.

Footnotes

[1] In fact, according to Katkalo *et al*.[6], Nelson and Winter's foundational work arguably remains the only serious effort on this front[6].

[2] The view that the complexity perspective can significantly contribute to improve evolutionary explanations of socio-economic phenomena in general is shared by an increasing number of scholars who over the past two decades have explicitly recognized the need of embedding evolutionary economic analysis in complex systems theory, suitable adapted to be used in economic contexts[40,38].

[3] The idea that knowledge constitutes a source of heterogeneity as well as a key resource for firms has its origin in Penrose,[41] and directly relates the evolutionary theory to the capabilities approach to the firm[35,42] . A fundamental point of this approach shared with the evolutionary view is that the firm is a socio-economic entity, the main characteristic of which is to 'know (well) how to do' certain things.

[4] In their foundational work, Nelson and Winter define routines as involving both capabilities (i.e. knowledge underpinning or

yielding organizational behavior), and behavioral decision rules (i.e. organizational behavior resulting from the application of knowledge). Currently, however, the prevailing view is that routines are mainly underlying generative structures, that is, they embody collective predispositions or knowledge that underlie (and become expressed in) the organizational behavior of firms[44,2,20].

[5] We consider that the evolution of firms can be explained in Darwinian terms applying the general meta-theoretical framework provided by Generalized Darwinism[26,25,21,45]. The legitimacy of this idea, as well as the specific form that such meta-theory should present, have been subjected to a great deal of controversy. We do not enter in any of these debates here. We agree with the main principles of Generalized Darwinism, and share the most recent view that its currently existing forms or versions are fully compatible and indeed complementary[26,46].

[6] See however [43,47,19] for more general computational ways of accounting for organizational learning in an evolutionary context.

[7] Physical, chemical and biological systems are first and second order CAS in Foster's[28] taxonomy.

[8] Definitions of the firm as a system of interacting elements, in which a relationship between the system's constituents and the system as a whole exist, are not new. See Montressor and Rogmanoli[48] for a detailed account of existing contributions to a systemic view of the firm.

[9] This interactive structure is closely related to both the formal designed organizational configuration of the firm and the social network of relationships of its constituents.

[10] NK models were originally devised by Kauffman[29] about abstract relationships among the components of a dynamical system so they are in themselves neither biological, nor physical, or economic but essentially mathematical. Consequently, although caution must be exercised in applying them too literally in socio-economic contexts,[28] they provide robust explanations to intuitions, and are highly useful for illustrative purposes[49].

[11] These two cases represent respectively the two extreme cases of over-exploitation and over-exploration of knowledge, both of which are detrimental for effective organizational learning in firms[50].

[12] New firms are typically created in the population via the transmission or differential copying (by collaboration or imitation) of 'successful' capabilities/routines.

[13] This has also been the case in evolutionary theorizing in other disciplines. Currently, however, the importance of development in evolution has been increasingly acknowledged, and many disciplines (such as the evo-devo perspective in biology) recognize its role and the need to incorporate developmental issues in their explanations of evolutionary change.

[14] In a complexity context, firms are not only self-organizing forms of order and organization but also 'self-transforming' forms of organization since, as Schumpeter put forward many years ago, they develop from within[51].

[15] It has to be noted that this does not involve that economic evolution is Lamarckian instead of Darwinian. The three stages characteristic of the evolution of firms is only one of the many distinctive features that differentiate Darwinian evolution in the economic field from its counterpart in the biological realm. In any case, accepting that socio-economic evolution is Darwinian does not mean that a Lamarckian possibility is necessarily excluded[52,39].

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