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WORKING PAPER SERIES

The persistence of innovation and path dependence

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The persistence of innovation and path dependence

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1. Introduction

The persistence of innovation has been the object of a recent body of literature. Most of the contributions consist of empirical analyses carried out with time series tools or transition matrixes. The theoretical underpinnings of this approach lie in the concepts of cumulativeness and technological learning. However this literature fails to grasp the systemic character of persistent processes.

In this chapter we develop an integrated framework able to graft the persistence of innovation within a complex dynamic framework. We therefore try to establish a link between persistence and path dependence by putting particular emphasis on the dynamics of local attractors. In particular we focus on innovation considered as a dynamic process characterised by persistence and path dependence. More precisely, we develop the kinds of local attractors that distinctively create persistent and path-dependent processes of technological change. The rationale behind our study is the understanding of innovation processes, organizational change, growth, and systemic dynamics.

In our approach, the generation of new knowledge and the introduction of innovation are the results of cumulative patterns and learning dynamics. This pattern of technological accumulation is at the base of the persistence of innovation. This means that current innovation is explained by past innovation and, thus, innovation has enduring effects as a result of knowledge cumulability and learning processes.

We also retain that innovation persistence is path dependent as opposed to past dependence. While past-dependent processes are fully determined by the initial conditions, path dependent processes are affected by contingent factors that intervene in modifying the rate and the direction of technological change. As such, path dependent processes are shaped by the localized context of action.

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Hence in our view, innovation is a collective process that takes place when systemic conditions are at work. Thus, following Antonelli (2008), “innovation is one of the key emergent properties of an economic system viewed as a dynamic complex system”.

Under the assumptions that the introduction of innovation is persistent, path dependent and has a systemic character, in this chapter we investigate the role and the different kinds of local attractors that may influence the dynamics of technological change. In our view, local attractors may foster technological accumulation and learning dynamics and, as a consequence, the persistence of innovation. They are the driving forces that influence the rate, the sequence and the direction of the path and, thus, introduce discontinuity in the process making it a path dependent process. Hence, local attractors engender the systemic conditions at the base of knowledge and social interactions and, thus, give rise to the introduction of technological innovations. In the very long term, the technologies and their local attractors develop reverse links, promoting complex dynamics. In our view, attractors result from localised increasing returns or at least through offsets to diminishing returns, particularly through the generation of what we refer to as ‘dynamic and interactive economies of scale and scope’. Some examples of contexts where such kinds of gains are significant and hence local attractors play a major role are technological districts, regional innovation systems and innovative milieux, but also knowledge platforms and networks.

Our work can contribute to the literature under three perspectives. First, we try to enclose the concepts of persistence and path dependence in a common framework. Second, we call the attention to the local attractors that may influence the dynamics of technological change. Finally, we analyse the dynamics at the base of local attractors’ generation not only in the geographical space but also in the knowledge space.

The chapter is organised as follows. The second section discusses the literature on the persistence of innovation. The third section provides an overview of the local attractor concept and develops an interpretative framework that links it to the notion of path dependence and persistence. Following our interpretative framework, sections four critically review the theoretical and empirical literature on technological change in order to capture the role of local attractors under different perspectives. In section five we outline our conclusions.

2. The persistence of innovation

The persistence of innovation activities has been largely analyzed from a theoretical viewpoint and empirically confirmed only to a limited extent. According to neo-Schumpeterians, knowledge accumulation and technological learning account for the main forces leading to innovation persistence. Schumpeter himself distinguished between two different patterns of innovations. In *The Theory of Economic Development* (1912), the 'creative destruction' process is conceptualised. In this model, knowledge is conceived as a free good and, thus, all the firms can fish in the same pool of accessible technologies. As a consequence, new innovators introduce new technology while old innovators rest stuck in old innovation. On the contrary, in *Capitalism, Socialism and Democracy* Schumpeter (1942) emphasises the cumulative nature of technological change. In this view, the innovation process is described as a process of 'creative accumulation'. Knowledge is created and accumulated within firms. This builds high barriers to entry and, as a consequence, established large firms become key actors in the process of technological change. Within this framework success breeds success, current innovation is explained by past innovation and, thus, innovation is persistent (Alfranca, Rama and von Tunzelmann, 2002).

In evolutionary theory, the persistence of innovation activities stems from competition and selection mechanisms. In this view, the accumulation of knowledge and learning dynamics lead to the formation of firm-specific routines that may generate a stable pattern of economic activities. Yet, the inertia stemming from routines can be counteracted by dynamic forces like technological competition and innovation that push the economic system towards evolution (Nelson and Winter's, 1982). As a consequence, firms that survive to the market competition are those that persistently implement new techniques and introduce new ideas, which, in turn, increase their profitability and market share. Thus, the selection mechanism that pushes firms to persistently rely on innovation is a function of their internal competencies, technological capability and profitability.

A recent strand of literature has tried to empirically analyse the persistence of innovation. It is possible to distinguish two main lines of research in this area. A first set of studies aims at analysing the persistence in the introduction of innovation trying to understand whether innovators have a stronger probability than non-innovators to keep innovating. In particular, these empirical works focus on the determinants and the features of the persistency by observing firms' patenting activity over time (Geroski, Van Reenen and Walters 1997, Malerba et al. 1997, Cefis and Orsenigo 2001, Cefis 2003, Alfranca, Rama and von Tunzelmann 2002) or the introduction of product and process innovation as revealed by innovation surveys repeated along time (Peters 2009, Raymond et al. 2006, Roper and Hewitt-Dundas 2008). These works, explicitly or implicitly, are based on the dynamic capabilities theory (Teece and Pisano 1994) and refer to the idea that technical change builds upon accumulated competencies and that new knowledge are generated by what has been learned in the past. A second set of studies examines persistency in the effects of innovation rather than the persistence of innovation *per se* (Cefis and Ciccarelli 2005, Latham and Le Bas 2006). These works build upon the idea that the stream of profits generated by past innovation gives firms the opportunity to keep on innovating and confirm that the impact of innovation on profits is cumulative and long lasting.

While the importance of internal technological capabilities and financial resources has been widely analysed by both the theoretical and empirical literature on the persistence of innovation, less attention has been paid to the environment in which firms operate. However, the role of the external context can not be neglected as technological change is the joint outcome of innovation and learning activities within organizations and interaction between these and their environments (Fagerberg, 1994). The external context is a fundamental condition to the introduction of innovation as it provides firms with access to complementary and indispensable inputs in terms of external knowledge. Without an appropriate context that enables the access to external knowledge, the reaction of firms fails to be creative and, hence, the generation of new knowledge cannot persist over time.

The literature on knowledge spillovers and knowledge externalities allows for appreciating the key role of the context into which firms innovate. Yet, this strand of the literature fails to account for the fundamental role of interactions among agents within the system in the process of technological change. Interactions are instead a fundamental ingredient of complex economic dynamics. For this reason we develop an integrated framework able to graft the persistence of innovation within a complex dynamic framework by putting particular emphasis on the dynamics of local attractors. In our view, the concept of local attractor accounts for interdependences and networks among agents in the system that engender positive feedbacks leading to the introduction of innovations. Local attractors promote knowledge externalities and interactions and, in turn, favor the persistence of the rates of introduction of innovations. Hence, firms are able to change both their technologies and the structure of the system following a recursive, historic and path-dependent process of change. In this view the introduction of innovation is the result of a persistent process endogenous to both the firm and the system.

3. The role of local attractors in complexity

Local attractors

The attractor concept has been first developed by Lorenz (1963) in a model of atmospheric convection and has remained a cornerstone in chaos theory (Prigogine and Stengers, 1984), first, and complexity theory (Kauffman, 1993, 1995) later on. In chaos theory the local attractor concept has been used for stressing the sensitivity to initial conditions in the evolution of a system. Following the Lorentz work on atmospheric forecasting, the attractor concept has also been explained by means of the well known 'butterfly effect' metaphor. It suggests that small events, like the flap of a butterfly's wings, can engender large effects in the trajectory of the system, like an hurricane in another continent. It is worth stressing that the local attractor, as it is conceptualized in chaos theory, describes deterministic processes which lead to unpredictable results. In other words, initial conditions are important and their effects can be magnified during the process, thus, leading to unpredictable outcomes.

The literature on non-linear and complex systems offers a different perspective for understanding the local attractors concept. Here the term 'attractor' indicates a limitation in possibilities. Stuart Kauffman asserts that 'attractors "box" the behaviour of a system into small parts of its state space, or space of possibilities' (1993: 174). Every dynamical system has attractors that limit the possible states a system can reach.

Following the mathematical formalization, an attractor can be defined as a set of values in the phase space to which a system migrates over time. The phase space is an abstract space used to represent the behavior of a system which has as many dimensions as the variables of the system. Thus a point in the phase space defines a potential state of the system.

Each attractor has a basin of attraction, a region in the phase space which represents the set of all (initial) points that go to that attractor. In this way the literature on non-linear and complex systems introduces the idea of patterning. The emergence of patterning within a given system results from 'attractors'. As a consequence of local attractors a dynamic system does not move over time through all possible parts of a phase space but instead occupies a restricted part of it. Local attractors represent a set of possible states or phase space which a time series generated by a dynamical system tend to take over time. They represent the outcome that a dynamic system eventually can reach.

In this line of thought, the process is no more deterministic as it is influenced not only by initial condition but also by its iterative function. Hence, in complex theory the sensitivity to both initial condition and chance events make the dynamic process a stochastic process as opposed to a deterministic one. In this line of thoughts, Prigogine (1997) underlines how complexity theory allows mediating "between two alienating representations: that of a deterministic world and that of an arbitrary world subject to pure chance. Systems are thus seen as being 'on the edge of chaos'. Order and chaos are in a kind of balance where the components are neither fully locked into place but yet do not fully dissolve into anarchy. Time flows with minor changes in the past being able to produce potentially massive effects in the present or future. Such small events are not 'forgotten'".

Multiple attractors and path dependence

How an outcome (attractor) comes to be selected over time when there are several possible long-run outcomes?

History may decide the outcome. When many outcomes are possible, chance events become magnified by positive feedbacks and drive the system towards the actual outcome to be selected. Positive feedbacks magnify the effects of small shifts in the system. There is thus a self-reinforcing mechanism that makes the system move towards a new configuration. Small or chance events (*à la* David), perturbations or historical accidents (*à la* Arthur) at critical times influence which outcome is selected and the chosen outcome may have higher energy than other possible end states. Early perturbations become important in the selection of the structure.

Positive feedback is an essential concept in order to capture the role of local attractors in complexity. The trajectory of dynamical systems is attracted towards an attractor through positive feedback occurring over time. Positive feedbacks exacerbate initial stresses in the system, so rendering it unable to absorb shocks and re-establishing the original equilibrium. Very strong interactions occur between the parts of a system and there is an absence of a central hierarchical structure able to 'govern' outcomes. Positive feedbacks occur when a change tendency is reinforced rather than dampened down as occurs with the negative feedback and hence engender out of equilibrium conditions.

In economics, positive feedbacks engender increasing returns and are strictly related with the path dependence concept (Arthur, 1994). Increasing returns make for many possible outcomes. When the process leading to the selected outcome is a function of history, it is said to be a path dependent process. In order to define it, Paul David (2001) first draws on a negative definition opposing path dependent to path-independent dynamic processes. Path-independent processes possess the property of convergence to a unique, globally stable equilibrium configuration (single attractor) and, hence, history does not matter meaning that it cannot affect the processes' asymptotic distribution among the states. These processes are said to be ergodic as they are not influenced by their past states. On the contrary, 'processes that are non-ergodic, and thus unable to shake free of their history, are said to yield path dependent outcomes' (David 2001). Converting this last definition in a positive perspective, 'a path dependent stochastic process is one whose asymptotic distribution evolves as a consequence (function of) the process's own history' (David 2001). In path dependent processes the system does not converge to a single attractor. The evolution of the system may have multiple steady states. 'Once there are multiple stationary points of a dynamic process, path dependence follows automatically, since each stable stationary point has a basic of attraction' (Arrow, 2000: p. 178). Then the outcome to which the system eventually converges depends on its path. The selected steady state is determined not only by arbitrary initial conditions but also by chance events which occur during the process. These events that arise along the path are non-reversible. Path dependent processes are thus characterized by local irreversibilities.

Multiple attractors and persistence

How long does the dynamic system occupy the same region in the phase space?

Once the outcome has been selected, a new structure of the system emerges. As the new structure is subject to long-term self-reinforcement mechanisms, it is difficult to change it. Each attractor has a basin of attraction which represents a region in phase space composed by the set of all points that pull the system towards the attractor. When the system enters into the orbit of one attractor the system may eventually lock into its new configuration.

Yet, the dynamic system's new configuration may be ever changing when the impulse to change comes from within the system and as such the process of change is endogenous. The system can adapt and evolve but only within a limited set of possibilities. As it moves around the attractor, the dynamic system may evolve toward a new configuration which is roughly the same but not exactly the same than the previous one.

In economics, this means that increasing returns are localised. The dynamic system can adapt and evolve following self-organizing and self-reinforcing mechanisms. If one product, a firm or even a nation in competitive marketplace gets ahead in the development process by chance it tends to stay ahead and even increase its lead (Arthur, 1994). Localised increasing returns thus allow for persistence in the process of change.

Movements toward a new attractor

When does the complex dynamic system move from an attractor to another?

When discontinuities and radical perturbations arise the actual configuration becomes unattractive. The system moves unpredictably and irreversibly away from the old local attractor when its development is constrained within a progressively narrower range of possibilities that lead to decline. In other words, when localised features built over time shift from be advantageous to become barriers to future development and change of a system, the latter is pushed away from the old attractor towards a new one.

It is worth stressing an important distinction between social and natural sciences on this point. What distinguishes social from natural phenomena is that change arises from intentional choices by agents. As a consequence, while in natural sciences radical perturbations occur exogenously, we maintain that when considering social phenomena the perturbations are endogenous.

4. The kinds of local attractors in the complex dynamics of technological change

We now mean to analyse technological change within a complex dynamic framework playing particular attention to the role and kinds of local attractors. Our unit of analysis is the economic system which is defined as follows:

- Our economic agents are heterogeneous agents that are interconnected and networked with other agents in the system in order to exploit complementarities and interdependence.
- The heterogeneous agents are firms and also public and private institutions and organisations.
- The introduction of innovation stems from intentional choices by economic agents.
- The structure of the system change endogenously.

Following the complexity theory the interactions between economic agents are as fundamental as the behavior of economic agents themselves. The system's properties emerge from the interactions between heterogeneous agents and are, thus, generated by system dynamics. These collective emergent properties are different from those of the agents composing the system. In this line of reasoning, innovation emerges from the systemic interactions among firms and the other agents and is different from each other alternative innovation which would arise from the individual agent alone. In complex theory, this concept is commonly explained by saying that ‘the sum is greater than the size of its parts’. This suggests that the innovation process is not only differentiated but it is also magnified by systemic dynamics.

The consequences of intentional interactions among agents are endogenous the generation of unexpected events and new configurations of the system structure. This generates path dependence and the persistence of innovation.

In order to discuss our approach, we analyse technological change in two phase spaces: geographical and knowledge space. Their structure matters in that they provide the context for actions of innovating agents. In each space attractors can have as many dimensions as the number of variables that influence its system.

As far as geographical space is concerned, the literature on agglomeration and dynamic processes leading to innovation is fertile (Boschma and Lambooy, 1999; Boschma and Frenken, 2006; Martin and Sunley, 2006; Martin, 2010). There is also a number of interesting applications of the complexity approach in urban and regional economics (Allen, 1997; Garnsey, 1998; Garnsey and McGlade, 2006). Yet, there is still space for exploring this stream of the literature.

On the contrary, the application of complexity theory to the knowledge space is less diffused. Moreover, in this literature the unit of analysis is knowledge itself and the complex system is composed by networked pieces of knowledge that recombine in complex ways. In our framework, knowledge space represents a context of action for heterogeneous agents. In our view, knowledge space gives a new perspective for understanding the role of local attractors in making technological change a persistent and path dependent process. We think this is a new avenue to be exploited by the literature.

Movement in geographical space

What does make a possible outcome a base of attraction in geographical space?

The literature on agglomerations is an important reference on this point. This literature emphasizes that firms locating first in a place create an attraction for new firms to move there, and these in turn make an even stronger attraction for more firms to move there (Arthur, 1994). Initial conditions, historical accidents and self-reinforcing mechanisms play a crucial role in the process. In our view, this means that the process of agglomeration is a path dependent and persistent one.

A number of emergent properties or conditions of the local system can make a place in geographical space more attractive than others. This attractiveness in turn influences the process of technological change as spatial proximity supports the introduction of innovations and the dissemination of technological knowledge (Breschi and Lissoni, 2003; Boschma, 2005). Different mechanisms of attraction and agglomeration in a bounded geographical space have been highlighted by the literature like the access to a market for specialised labour (Marshall, 1890; Krugman, 1991) and to localised and dynamic capabilities (Maskell and Malmberg, 1999; Von Tunzelmann and Wang, 2003), the reduced costs for shared infrastructures and other collective resources and the reduced transaction costs for co-located trading partners (Arthur, 1994). Knowledge spillovers, knowledge and pecuniary externalities are other mechanisms behind the agglomeration of firms in the geographical space. These mechanisms give firms the access to external knowledge at costs that are lower than equilibrium levels. This in turn affects firms knowledge production function (Antonelli, 1999, 2008). The institutional endowment also has an impact on the emergence of local attractors. As the movement in the geographical space is governed by institutional rules, routines and practices (Arthur, 1994; Lundvall, 1992; Nelson and Winter, 1982) the institutional set-up (North, 1990) or institutional thickness (Amin and Thrift, 1994) can favour agglomeration phenomena. Finally, proximity to scientific institutions and universities and an attractive social environment (Aydalot, 1986; Camagni, 1991; Maillat, 1995; Etzkowitz and Leydesdorff, 1997, 2000; Cassia et al., 2009) engender collective learning processes which in turn foster the agglomeration of firms.

It is now clear how the structure of the system and the mechanisms operating within it can act as an attractor. The interaction and networks of local actors that allow for the exploitation of complementarities and interdependences, reinforced by the technological and industrial specialization of the area, the institutional endowment and by a common local culture of trust, based on shared practices and rules, are centripetal forces that make a base of attraction of the local system.

However, it is not only the local attributes or conditions but rather the sequence of cumulative interactions between them and positive feedbacks that give rise to a local complex system. Both geographic attractiveness and accidental historical order of choice generate agglomerations (Arthur 1989, 1994).

Thus the agglomeration process is a path dependent process. This means that the rate, the direction and the sequence of the economic agent actions can be intentionally changed. Path dependence is, thus, opposed to past dependence. The latter gives a deterministic interpretation to the patterns followed by economic agents. On the contrary, the path dependence concept allows taking into account history. This means that the technological process is influenced by arbitrary initial decisions taken by the economic agent under uncertain conditions but it is also determined by chance events arising during the process and by the local context of action. In this sense the past narrows but not univocally determines the final outcome and the space of action of economic agents. The creative response of heterogeneous agents to changes in the local context of action can modify unpredictably the rate and the direction of the innovation process.

If we apply our interpretative framework to the literature in the area of economic geography, evolutionary and institutional economics, it is possible to identify some concepts that fit with the local attractor one. These are the following:

- agglomeration and cluster (Arthur, 1994; Porter, 1990)
- innovation systems (Lundvall, 1992; Freeman, 1987)
- innovative milieu (Aydalot, 1986 ; Maillat, 1995).

Once the local attractor has emerged following a path dependent process, heterogeneous agents within it are subject to self-reinforcing mechanisms of the innovation process. The process of increasing returns is self-reinforcing since the benefits of remaining into the current path are higher than the cost of switching to an alternative path. Localized increasing returns operate as a selection mechanism and favor the survival and growth of firms that are well established in the local system and take part in the local dynamics of technological change. Thus, if one firm gets ahead by chance in the innovation process it tends to stay ahead and even increases its lead (Arthur, 1994). Innovation has enduring effects and the introduction of innovation is thus a persistent process.

As discussed in section two on the persistence of innovation, the successful introduction of innovation takes place when the internal capabilities accumulated by means of learning processes lead to the generation and exploitation of new knowledge. Another fundamental condition to the introduction of innovation is when the external context provides the access to complementary and indispensable inputs in terms of external knowledge. The generation of new knowledge requires both internal learning and the acquisition of external tacit and codified knowledge. Hence, knowledge accumulation and technological learning account for the main forces leading to innovation persistence. In this view, the introduction of innovation is a process of 'creative accumulation'. Knowledge is created and accumulated within firms and, thus, established firms become key actors in the process of technological change.

Similar arguments have been applied at the macro level in the works trying to answer the question why growth differs across countries (see Fagerberg, 1994). Starting with the neoclassical growth model proposed by Solow (1956, 1957), technological progress was included as an additional - exogenous - variable to account for long-run growth in GDP per capita. In this interpretation, technology is accessible for everybody free of charge. On this assumption the neoclassical model of economic growth predicts that, in the long run, GDP per capita in all countries will grow at the same, exogenously determined rate of technological progress. Subsequent contributions belonging to the technology-gap approach to economic growth and to the 'new growth theories' conceive technology in a different way. While in works based on traditional neoclassical theory of economic growth technology is assumed to be a public good and, as such, can not be the source of cross-country differences in GDP per capita, in the technology gap approach technological differences are the prime cause for differences in GDP per capita across countries (Ames and Rosenberg, 1963). This stream of the literature recognises the tacit nature of knowledge. As a result technological knowledge is difficult and costly to transfer. Knowledge is generated and exploited mainly within organizations and is at the base of internal capabilities formation. The process of technological change is the outcome of knowledge accumulation and learning activities and is influenced by country-specific factors (Nelson and Wright 1992). In this line of reasoning, the country leading in technology can be overtaken only if the 'national system of innovation' of some country, through the creation of a new 'national technology' succeeds in embarking on a new, superior path of technological change. New growth theories lead to similar conclusions. According to this stream of the literature, technological progress is not exogenous but it is the result of intentional activities by firms. Cross-country differences affect differences in cross-country rates of growth. Lock in situations may occur and, thus, rich country stay rich and poor countries stay poor.

Comparing the two debates in the literature, the first on innovation persistence and the second on the growth theory, is possible to notice many similarities. As a result of knowledge cumulability and learning processes innovation has enduring effects. Thus, new innovators are old innovators and the leader firm or country remains at the technology frontier. Increasing returns thus lead to the localised, persistent and path dependent process of technological change.

Why and how local attractors become unattractive?

When the leadership of the innovating firm is set adaptive behaviours can emerge and consequently lock in situation arises. The dynamic system moves around the attractor and evolve toward a new configuration which is roughly the same than the previous one. Congestion, over-specialisation and limited appropriability within the local attractor lead firms to exploit incremental innovation and rely mainly on internal knowledge and capabilities. As a consequence, localised capabilities deteriorates, routines become obsolete and the region lose market share and innovation capacity.

In this case the negative effects of agglomerations are higher than the positive ones. As shown in Antonelli, Patrucco and Quatraro (2010), there is an inverted U-shaped relationship between the agglomeration of innovation activities and regional productivity growth. Authors refer to the concept of pecuniary knowledge externalities for appreciating both positive and negative effects of agglomeration. The gains of regional concentration of knowledge generating activities are related with the reduction in the prices of knowledge as an input while the losses are related to the reduction in the prices of knowledge as an output. As a consequence agglomerations yield positive net knowledge externalities only until a given threshold. The main argument is that the advantages in term of knowledge externalities are dissipated by the losses engendered by reduced appropriability.

Firms within the local attractor understand that the benefits of remaining into the current technological path, that in turn has engendered the current local attractor, are lower than the cost of shifting to an alternative path and, thus, to an alternative attractor. Firms are induced to react creatively to changing local conditions. The collective process of search for new technology may finally engender radical changes in the technological paradigm and leads to Schumpeterian gales of creative destruction. Only the creation of a new and radical knowledge with a wide scope of application allows the disruption of the established innovators leadership and lets new innovators to be new leaders in the technological frontier.

The emerged radical innovation generates a perturbation in the system. The creation of a new technology and radical changes in the technological paradigm make the system moves unpredictably and irreversibly away from the old local attractor. Positive feedbacks and network externalities sustain this process of technological change and define the basin of attraction of the new attractor.

It is worth noting that in this interpretative framework the process of technological change is endogenous. Previous contributions in economic geography and evolutionary economics on path dependence assert that once the system has been locked into one attractor, the break of the current path and the switch to another attractor can be caused only by external shocks (David, 2005; Nelson, 1993). In this line of reasoning, the process of technological change is exogenous. On the contrary, in our interpretative framework we claim that the process is endogenous. Firms within the old attractor are induced by negative feedbacks to react creatively to changing condition. Their intentional search for a new path-breaking technology promotes the process of technological change and leads to innovation cascades. A new structure of the system emerges and, as a consequence, firms can move in geographical space towards the new base of attraction.

Movement in the knowledge space

What does make a possible outcome a base of attraction in the knowledge space?

The economics of knowledge literature offers the main concepts for explaining the behaviour of firms moving in the knowledge space. In particular, our framework on complex dynamics refers to both the localised technological knowledge and the recombinant knowledge approaches. The former assert that the stock of knowledge and competence internal to a firm are localised and constrained in a limited area in the knowledge space. In the latter the generation of new knowledge stems from the recombination of a variety of knowledge bits. Following a cumulative and interacting process, existing ideas are recombined in order to generate new ideas (Weitzman, 1996).

Different mechanisms make a restricted area in the knowledge space a base of attraction. First, the stock of knowledge and competence of firms is the result of a process of learning by doing, using and interacting. In this way firms accumulate knowledge that constrain their ray of action in the knowledge space and limit their possibilities to exploit alternative and unrelated knowledge. Secondly, the search for complementarities as conceived in the recombinant approach attracts firms toward bounded area in the knowledge space. In order to complement their internal knowledge and generate new technology, firms can move in the knowledge space and search for external knowledge. As a consequence firms are attracted towards a restricted area in the knowledge space which is composed by complementary knowledge to the internal ones. The search for external knowledge is thus local.

A number of emergent properties or conditions of the local system can make a place in knowledge space more attractive than others. In our view, the properties defining the structure of the knowledge space are knowledge proximity, knowledge coherence and knowledge variety, related or unrelated (Saviotti, 1996, 2004, 2007; Nesta and Saviotti, 2005; Frenken et al., 2007). Local attractors are thus areas characterised by high levels of knowledge proximity, knowledge coherence and knowledge related variety that allows the generation and exploitation of new technological knowledge. As suggested by Antonelli, Krafft and Quatraro (2010) in a study on the emergence of the new technological system based upon information and communication technologies, the recombination process has been more effective in areas characterized by higher levels of coherence and specialization of their knowledge space.

It is now clear that local attractors are areas in the knowledge space where fertile knowledge are accessible and make possible the generation of new knowledge through learning, accumulation and recombinant processes. Yet, at a given time, firms can select among multiple outcomes. Their location choice can be directed towards different places and is influenced by both their internal characteristics that include the preceding path and external characteristics that depend on the location strategies of other agents carried out in the past. Hence the concentration of innovating firms in the knowledge space and the consequent introduction of innovation stemming from the knowledge base available in the local attractor is a path dependence process.

With reference to the economics of knowledge literature, the kinds of knowledge attractors we identify are:

- Dominant design (Utterback and Abernathy, 1975)
- Core technologies
- Knowledge platforms

Firms are attracted towards the knowledge attractor until the profits stemming from their innovation activities are above the equilibrium one. The selection mechanism depends on the profits realized by each firm. Extra-profits and increasing returns of the innovation activities engender positive feedbacks and self-reinforcing mechanisms that sustain firms' creative behaviours and the persistence of innovation activities. The attractiveness of a place persists as long as the returns of knowledge recombination processes are positive.

Once an innovating agent have approached a local attractor in the knowledge space it is likely to introduce new technologies with a high degree of relativeness, similarity and coherence with the technologies already in place. As a consequence, the features of new technology change slowly and profits reach the equilibrium level. In this case, adaptive responses are likely to occur while knowledge externalities and interactions decrease. Inertial forces keep the economic system in equilibrium conditions and hence firms are not induced to change their technologies and innovate.

As soon as the level of profits falls below the equilibrium level, negative feedbacks arise and the local attractor becomes unattractive. The mismatch between expected and real returns on knowledge production activities pushes firms to react creatively to out of equilibrium conditions. Firms try to innovate and search for complementary knowledge to recombine with their internal one. New core technologies and drastic innovation emerge from a collective process of knowledge recombination. General purpose technologies represent an example of such a drastic innovation. According to Helpman (1998, p. 13), ‘a drastic innovation qualifies as a “general purpose technology” if it has the potential for pervasive use in a wide range of sectors in ways that drastically change their modes of operation’ and thus can provoke a perturbation in the system. The addition of a radically new technology decreases coherence and proximity in the local attractor and increase unrelated variety. These dynamics will disadvantage the firms within the local attractor where knowledge externalities and interactions are deteriorated. As a consequence the creation of such new drastic innovations makes the system move unpredictably and irreversibly away from the old local attractor in search of a new one. A new structure of the system emerges endogenously from the new architecture of externalities, interactions and networks set by innovating firms.

5. Discussion

In this chapter we developed an interpretative framework able to link the persistence and path dependence concepts and to graft them within a complex dynamic framework by putting particular emphasis on the dynamics of local attractors.

Complex theory allows for the appreciation of system dynamics of technological change as it investigates emergent, dynamic and self-organising systems that evolve and adapt in ways that deeply influence the probabilities of later events (Prigogine, 1997; Urry, 2006). This means that the dynamics of systems arise endogenously through a persistent and path dependent process.

We can highlight the theoretical foundations of our approach as follows. Economic agents are heterogeneous individuals. The introduction of innovation stems from intentional choices that are shaped by learning dynamics and the cumulativeness of knowledge. In this line of reasoning, innovation has enduring effects and the introduction of innovation is thus a persistent process.

The rate, direction and sequence of technological change can be intentionally changed by the heterogeneous agents that are able to select among multiple outcomes. This makes the introduction of innovation a path dependent process.

Positive feedbacks arising by knowledge externalities and interactions in the system influence the innovation process that consequently is a persistent, path dependent and systemic process.

As the system evolves and self-organises through time following the reactions of heterogeneous agents to changing conditions, the introduction of innovation is an endogenous process.

Local attractors fuel the mechanism at the base of these dynamics. A number of emergent properties of the local system, positive feedbacks and the interactions and networks of local actors that allow for the exploitation of complementarities and interdependences are centripetal forces that make a place in both the geographical and knowledge space more attractive than others.

Attractors stem from localised increasing returns and maintain their basis of attraction as long as positive feedbacks and self-reinforcing mechanisms sustain firms' creative behaviours and the returns of the innovation process are positive.

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