"Reviewing Path Dependence Theory in Economics: Micro–Foundations of Endogenous Change Processes"

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Abstract

This paper proposes a critical review of some of the main applications of path-dependence in economic theory. In particular, it calls attention on those theories clarifying the micro-foundations of path-dependent processes in economics. In the field of innovation, path-dependence shows the endogenous character of technological change, revealing the complex interplay among firm's structural specificities, irreversibility, creativity, localized learning, externalities, feedbacks and contingent disturbing factors. In cognitive and institutional economics, the path-dependent character of learning processes, shown by cognitive and neurobiological studies, suggests interesting explanations for economic and institutional inefficiency persistence and, in general, for institutional genesis and evolution processes. Micro-foundations of economic path-dependence offer new opportunities for further extending theoretical and empirical economic research. For instance, they could contribute to extend economic self-organization approach, which has focused on the non-linear character of economic dynamic processes and has described economic systems as dissipative and entropic structures. In this sense, path-dependence represents a fertile tool for further clarifying economic and institutional dynamics and a precious opportunity of interdisciplinary research.

Keywords: path-dependence, endogenous change, non-ergodic process, knowledge production, innovation economics, cognitive economics, institutions, neural structures, self-organization, dissipative systems, entropy law

JEL classification: A12, B25, O31

1. Introduction

Originated in natural sciences, path-dependence concept appeared in economic theory since the mid of 1980s. It started to be applied in industrial and innovation economics, economic history and economic geography; later, studies on path-dependent processes bloomed in new institutional, cognitive and experimental economics and, even, in some analyses on tourism development (Dosi and Metcalfe, 1991; Krugman, 1991; Antonelli, 1995; Rizzello, 1995; Dosi, 1997; Egidi and Narduzzo, 1997; Magnusson and Ottosson, 1997; Rizzello, 1999; Garrouste and Ioannides, 2001; Redding, 2002; Rizzello, 2004; MacKinnon et al., 2009; Antonelli, 2011; Martin and Sunley, 2012; Carson and Carson, 2016; Madsen, 2016).

Path-dependence describes endogenous processes of change and development where specificities of economic agents and their mutual interrelation with reference context and historical events, also little and apparently irrelevant, push towards multiple directions. In this sense, path-dependent processes are non-linear processes which can be split in multiple steps: each of them follows a specific direction, according to non-ergodic and upsetting pressures. The strong interplay among the idiosyncratic nature of economic agents, individuals' bounded rationality and creativity, local externalities, as well as access to knowledge spillovers and feedbacks from external environment significantly affect knowledge production and decision making processes, molding agents' behavior and evolutionary mechanisms of systems. In the presence of these conditions, it is not possible to predict the final state of the process: multiple results are feasible, also including inefficiency or static efficiency states.

The extraordinary versatility of this analytical tool has made it possible not only its transposition in economic theory, but also in other research areas, like neurobiological, cognitive and, more recently, political studies (Madsen, 2016; Pierson, 2000).

In industrial and innovation economics, path-dependence has represented a general framework for explaining intrinsic features of dynamic efficiency and processes of growth and, in particular, the endogenous character of technological change (Dosi and Metcalfe, 1991; Antonelli, 1995; Dosi, 1997; Martin and Simmie, 2008; Antonelli, 2011; Antonelli et al., 2012; Isaksen and Trippl, 2016).

In new institutional economics, path-dependence (North, 1990; 1991; 1994; Rizzello, 1999; North, 2005) has played a crucial role in explaining the persistency of institutional and organizational inefficiency and has stimulated a more complex investigation on long-term economic and social effects, working as a useful tool to understand historical, economic and social regional backwardness. The more recent approach of Institutional Hysteresis (Setterfield, 1993; Madsen, 2016) represents another contribution in this sense, studying long-term institutional changes and

defining institutions as non-optimal path-dependent expressions, investigated through analytical categories like cumulative causation, lock-in, uncertainty and irrevocability.

In cognitive economics, some relevant studies showing the path-dependent nature of neural functioning and mental processes (Moscovici, 1984; Gazzaniga et al., 2002; Damasio, 1995; Arcuri and Castelli, 2000; O'Shea, 2005; Higgins, 2012) are applied in order to investigate knowledge production mechanisms and economic decision-making. Theories on knowledge production process - coming from cognitive and social psychology - and theories on cerebral mapping activity - derived from neuroscience – have been adopted for explaining the micro-foundations of genesis and evolution of economic and social decision processes and of institutional norms (Rizzello and Turvani, 2002; Mantzavinos at al., 2004; North, 2010; Ambrosino, 2012; Ambrosino et al., 2015).

This paper proposes a review of some of the most relevant results of path-dependence application in economic theory, starting from a brief historical framing. In particular, it calls attention on those theories clarifying the micro-foundations of path-dependent processes in economics. Micro-foundations are represented by those analytical elements able to explain path-dependent processes starting from the individual level (economic agent and the person) and that include, in this sense, not only economic, but also biological and cognitive categories. In this perspective, this contribution reviews the main findings in path-dependence research elaborated by innovation economics, cognitive and institutional economics. Moreover, it stresses the relevance of these studies in offering new opportunities for extending self-organization approach to economics, which has focused on the non-linear and path-dependent character of economic systems, described as dissipative structures.

The paper is structured as follows. Section 2 proposes a historical review of path-dependence application in economic theory, starting from the forerunners of this analysis - for instance, some contributions of J.Schumpeter or F.Momigliano – and proceeding with the famous contributions of P.David and B.Arthur. Section 3 analyzes the main interesting results of path-dependence application in industrial and innovation economics, focusing particularly on the main findings of C. Antonelli's research. Section 4 focuses on cognitive approach to economics, where the application of *cognitive path-dependence* has provided not only interesting interpretations of economic behavior, through the explanation of individual and social mechanisms intervening in learning processes, but it has also clarified some mechanisms of standardization and change of institutional norms. North's contributions (4.1) represent a milestone, in this sense, and a significant enrichment for standard institutional theory, through the integration of the cognitive level of inquiry. Sections 5 traces the main analytical foundations of economic self-organization, stressing the path-dependent character of evolutionary mechanisms characterizing dissipative structures and gives some hints for

further research in the field. Section 6 summarizes the analysis and offers a synoptic table showing the main theoretical references and analytical elements characterizing path-dependent processes described in economic theory.

2. Path-dependence in economic theory: a historical perspective

Officially, path-dependence starts to be applied in economics in 1985. Some previous contributions, however, pave the way to the application of path-dependence in economics. They deal with the issue of technological change and stress the role of some intrinsic features of economic organizations and their interplay with external environment in governing their current and future development path.

A part of economic literature (Antonelli, 1995; Rizzello, 1995; 1999; 2003; Madsen, 2016) has interpreted, in this sense, some works of J. Schumpeter (1942), F. Momigliano (1975; 1983), R. Nelson and S. Winter's book of 1982 and J. Keynes's *General Theory* (1936).

In *Capitalism, Socialism and Democracy* (1942), Schumpeter takes a step forward with respect to his previous work. This has led literature to distinguish between a "first" and a "second" Schumpeter. Both explain economic development as a dynamic process, but the former considers technological change as derived from the adoption of external innovations offered by inventors. On the contrary, starting from the contribution of 1942, technological change is explained as an endogenous process. Successful technological changes make it possible to exploit a quasi-monopolistic position, to invest profits in research and to generate innovations. In this sense, innovation is "internalized" in the productive process of each single firm and technological change is strongly tied to the intrinsic features of the firm and to its ability to preserve a competitive economic position.

In his analysis of technological change, in 1960s and 1970s, Momigliano explains how the enterprise is able to create new needs and, simultaneously, new products to answer them (particularly, he focuses on big enterprises controlling large portions of markets). Moreover, he observes that small firms can innovate easier, thanks to their specificity and flexibility. In this sense, technological change turns out to be particularly tied to the specificity of the firm, its economic role and the interaction with external environment (for instance, the possibility to exploit externalities derived from scientific research, economic policies, infrastructures projects, etc.). All these elements characterize path-dependence and occupy a relevant part in the author's analysis.

Also Nelson and Winter's work of 1982 can be considered a forerunner of path-dependence analysis in economics. Trying to define an evolutionary theory of economic change, they adopt A.

Alchian's perspective on economic evolution (1950), the Darwinian theory on natural selection (1859) and the Schumpeterian theory on technological innovation (1934). Though their contribution focuses mainly on exogenous change, a part of the analysis could be partly incorporated in a path-dependence perspective. The explanation of organizations in terms of *routines* goes in this direction. Adoption and implementation of specific routines as well as decisions concerning technological innovation are strongly affected by organization's specificities, reference market dynamics and the presence of externalities.

Finally, a part of literature (Fontana and Gerrard, 2004; Madsen, 2016) finds a relevant coherence with path-dependence approach in Keynes's *General Theory*: in particular, some aspects concerning the role of historical time, expectations and uncertainty which exert non-ergodic and disturbing forces in the economic process.

Path dependence has been definitely applied in economics through the seminal contributions of P.David and B.Arthur.

David (1985) defines path-dependence with these words: "a *path-dependent* sequence of economic changes is one of which important influences upon the eventual outcome can be exerted by temporally remote events, including happenings dominated by chance elements rather than systematic force. Stochastic processes like that do not converge automatically to a fixed-point distribution of outcomes, and are called *non-ergodic*. In such circumstances "historical accidents" can neither be ignored, nor neatly quarantined for the purpose of economic analysis; the dynamic process itself takes on an *essentially historical* character." (David, 1985, p. 332).

In this famous contribution, he explains - through the story of QWERTY keyboard - how little accidents interplay with expectations, exerting a more than proportional effect on economic dynamics. This happened to QWERTY keyboard's sales: while, at the beginning, the level of sales was limited, they significantly increased when positive expectations - that the new system would have triumphed on the others - spread, despite the higher efficiency of Dvorak keyboards. According to his interpretation, "each stochastic in favor of QWERTY would raise the probability (but not guarantee) that the next selector would favor QWERTY" (David, 1985, p. 335).

Three elements are at the basis of QWERTY economics: technical interrelatedness; economies of scale; quasi-irreversibility of the investment. Technical interrelatedness (the interrelation between the hardware - the keyboard - and the software - the typists' mind) makes it possible the decreasing of some costs included in QWERTY typewriting system and, in particular, those tied to typists' learning, as this kind of training starts to spread and standardize. In its turn, the spread of QWERTY system learning influences the decision to adopt QWERTY keyboard. This entails decreasing costs

and economies of scale that push towards the standardization of QWERTY keyboard production. This means, consequently, high costs to convert production as well as typewriters' training, entailing the quasi-irreversibility of investments.

Arthur (1989) develops convergent reflections, focusing on increasing returns technologies. In this case, small random events can exert a strong influence on the success of a certain technology. This makes the process inflexible (when a technology dominates the others, it becomes little by little locked-in), non-ergodic (initial events exert a strong influence in determining the outcome of the process) and unpredictable. On the contrary, in the presence of constant and decreasing returns to scale, small events are not able to influence the outcome of the process: here, history appears to be merely "the deliverer of the inevitable" (Arthur, 1989, p. 127).

Taking into account the role of bounded rationality in decision processes, Arthur defines his idea of "chance" or "historical small events" as "those events or conditions that are outside the *ex-ante* knowledge of the observer, beyond the resolving power of his 'model' or abstraction of the situation" (Arthur, 1989, p. 118). In this case, many outcomes of the process are feasible. It is not possible to take for granted that the best technology among the others is the technology that will be actually adopted.

Economic path-dependence concept has not been spared by critics from the beginning (Liebowitz and Margolis, 1995; Rizzello, 2004; Madsen, 2016). Liebowitz and Margolis (1995), for instance, do not recognize many of the processes considered by literature as "path-dependent" and maintain that path-dependence has occurred few times in history.

They distinguish, in fact, among tree forms: the first-degree and second-degree path-dependence (weak forms) that are very common in economics; third degree path-dependence (the strongest form), significantly less common. First-degree path-dependence defines a development path strongly influenced by events, sometime insignificant, and costly to be left, whose outcome – however - turns out to be optimal (not necessarily the only one optimal). The definition of the second-degree path-dependence needs the assumption of imperfect information. In decision-making process, individuals are not immediately aware of all criticalities of their decisions, but only later they realize them. This does not entail inevitably an inefficient outcome, but different decisions would have led to better results. The third-degree path-dependence implies that the process leads to an inefficient outcome: this involves a market failure. The outcome of the process cannot be predicted and switching from one arrangement to the other is significantly costly.

More generally, main critics derive also from the capability of path-dependence to explain exogenous shocks and from the necessity to clarify their role in dynamic processes (Madsen, 2016).

3. Path-dependence in industrial and innovation economics

A fundamental contribution in the definition of path-dependent dynamics in industrial and innovation economics is represented by C. Antonelli's research (Antonelli, 1997; 2006; 2011; Antonelli et al., 2012).

Path-dependence concept overcomes the main limits of neoclassical theory in explaining dynamic efficiency and endogenous technological change (Antonelli, 2006). Neoclassical theory, in fact, explains conditions for static efficiency and describes development and growth in terms of exogenous change of technology, preferences, availability of natural resources and demography. Firms enter or exit the market, according to prices and costs' conditions they face. However, "they are not supposed to be able to change their technology and hence their production function. At best, these firms are able to influence the position and slop of supply curves as a consequence of their entry and exit" (Antonelli, 2006, p. 28).

This analysis defines ergodic processes, whose direction is not influenced by initial conditions. On the contrary, path-dependence is a non-ergodic process where initial conditions do not completely determine the end state, but their interplay with perturbations during the process may modify its direction (Antonelli, 2006; 2011).

In innovation economics, the adoption of path-dependence clarifies the endogenous nature of technological change (Antonelli, 1997; 2006; Antonelli et al., 2012). This is strictly influenced not only by the characteristics of the firm (like size, structure or organizational routines, etc.), but also by the connections with its reference context as well as by the capability to implement competences, to access to localized learning and by combination with accidental events. This affects knowledge generation and accumulation and the introduction of new technologies.

Technological change assumes, in this sense, a "localized" character: it is no more the mere result of the adoption of a certain external innovation; it derives from an endogenous and complex evolutionary process. In this perspective, specific aspects neglected by neoclassical theory play a relevant role: bounded rationality, transaction costs, imperfect information and structural specificity of firms and markets represent some examples (read also Rizzello, 1999).

The path-dependent character of technological change derives from the combination among the irreversibility (both static and dynamic), indivisibility (among production factors), structural behavior and creativity of the economic agent as well as access conditions to knowledge accumulation, local externalities, positive feedbacks and market dynamics. Firm is embedded in a complex network of information flows and connections with other agents in a context historically

and institutionally defined, where expectations and unexpected events play a decisive role (Antonelli, 1997; 2006).

Irreversibility can arise at each step of the process. Static irreversibility entails specific costs to change a given system of production factors, organization and preferences: in this sense, it strongly pushes the process along a certain direction and plays a relevant role in selecting rival technologies, according to their level of complementarity and compatibility with the productive system. Dynamic irreversibility depends on localized learning and concerns specific techniques and competencies that guide knowledge production and the adoption of technological innovations.

Indivisibility concerns production factors and is at the basis, for instance, of economies of scale, economies of scope and externalities. Great importance assume, in this sense, interdependencies and complementarities in production and consumption among industries.

Creativity describes agents' active role in modifying their preferences in time (structural behavior of the agent), inducing in this way a change in technology. "In this approach firms do more than adjust prices to quantities and vice versa; they are also able to manipulate interactively the basic structure of the system"(Antonelli, 1997, p. 645). Creativity, moreover, entails a decentralized decision-making organization, generating flexible choices and contributing to the accumulation of knowledge and the production of externalities and knowledge spillovers.

Local externalities and positive feedbacks originate both at production level, for instance through economies of scale and scope and through knowledge accumulation and spillovers. In this case, a relevant role in knowledge access is played by the institutional framework, including in particular property rights, labor and financial markets (Antonelli, 2006).

The interaction among irreversibility, creativity, local externalities and feedbacks governs the direction of the process at each step: while irreversibility is a past-dependent (deterministic) force, the others can redirect the process (Antonelli, 2006). Past dependence, in fact, can be considered "an extreme form of non-ergodicity" (Antonelli, 2006, p. 5) because initial conditions explain completely the future development of the system, excluding changes during the process (Antonelli, 1997, 2006; Rizzello,1999).

From a methodological point of view, Markov chains can help to explain the difference between past and path-dependence (Antonelli, 1997). Simple Markov chains describe past-dependent processes: a particular state of the process completely derives from a specific previous state. In this perspective, it is difficult to provide appropriate explanations of dynamic evolution of industries and, generally, of economies of growth. On the other hand, in complex Markov chains, transition probabilities depend on each change and specific conditions characterizing the process till a certain state. This defines a path-dependent process which provides, for instance, interesting explanations

of the evolution of routines used by firms.

Antonelli (1997; 2006) distinguishes, moreover, between "internal" and "external" path-dependence. The first strictly depends on the irreversibility of production factors and on conditions favoring firm's creativity, reaction to unexpected events and localized learning mechanisms. External path-dependence depends on conditions external to the firm, in particular characteristics of products or factors' market, evolution in consumption or rival production as well as access to external knowledge.

Finally, path-dependence has turned out to be a useful tool also in innovation persistence analysis and in percolation theory (Antonelli et al., 2012).

In the first case, cumulated knowledge – both internal and external to the firm, but within a specific context of action - makes it possible an innovation persistence process thanks to knowledge spillovers and feedbacks. Persistence of innovation shows a clear path-dependent character: specificities of the firm vary according to the different level of accumulated knowledge and their interplay with context of action and fortuitous events play a determinant role in favoring or hindering exploitation of knowledge spillovers (Antonelli et al., 2012). "The access to the stock of knowledge external of each other firm and the actual amount of knowledge externalities that qualify the regional and industrial context of action of each firm are a necessary condition for the actual introduction of technological innovations. .. The process exhibits the character of path-dependence because of the effects of contingent factors that emerge through the process and yet are able to alter its dynamics" (Antonelli et al., 2012, p. 8 and p. 21).

Path-dependence character of innovation persistence has not only theoretically examined, but also empirically proved. Antonelli et al. (2012), for instance, propose a combination of multiple transition probability matrices and elaboration of panel data, that is briefly summarized as follows. Values in multiple transition probability matrices derive from non-homogeneous Markov chains computations that express variation between innovative and non-innovative states. Multiple transition probability matrices introduce time-variance. In this sense, they do not only prove persistence of innovation - calculated through total factor productivity – in the reference period, but also the effects of contingent factors in each sub-periods. In order to assess these effects, it is necessary to compare parameters of different Markov chains across a defined sub-period. This makes transition probability distribution no more time-invariant, but changing according to the "weight" of such factors. On the other hand, econometric analysis becomes fundamental in

computing the effect of each contingent internal and external factor (size of firms, wages, access to knowledge spillovers, etc.) on innovation persistence.[1]

First formulated in physics, percolation theory is applied in economics to study dynamic processes and assumes that, in the same reference context, mutual relationships among agents affect goods and information exchanges. For this reason, the theory exploits properties of stochastic Markov random fields: connectivity and receptivity coefficients. In percolation theory, the former expresses the amounts of information transferred among firms; the latter specifies the amount of information stored and used by each firm (Antonelli, 1997). This is the reason why percolation probability has been defined as "the probability that each firm *i* can effectively communicate with the other firms that are part of the same system that is the joint probability of transmitting and receiving" (Antonelli, 1997, p. 664).

Not only receptivity and connectivity, but also events and agents' concentration affect percolation probability. These elements are not exogenous: connectivity and receptivity, particularly, depend on idiosyncratic characteristics of agents, on consolidated connectivity and receptivity structures, on feedbacks from the local context.

4. Cognitive economics: path-dependence, knowledge and institutional norms

F.Hayek's model of the mind (Hayek, 1952; Rizzello, 1999) - one of the founding contributions of cognitive economics (Langlois, 1986; Rizzello, 1999; Egidi and Rizzello, 2003; 2004) - could be considered a relevant forerunner of studies showing the path-dependent nature of individual knowledge production that have been adopted by cognitive economics.

As explained in *The Sensory Order*, when a physical object or an event are perceived, they exert a set of stimuli to the nervous system. This system translates stimuli in impulses which are transmitted through networks of connections. In other words, the classification of stimuli takes place through the classification of impulses, by means of association mechanisms. The same class of stimuli can be directed to a unique class of impulses (simple classification) or to different classes (multiple classification). Every time new stimuli are transmitted, their association with classes of

[1] The empirical analysis described above suggests interesting possible applications in the institutional field, in order to examine the path-dependent character of institutional evolution in a country (or a region) and the effects on economic development.
Multiple transition probability matrices can be used in order to test persistence in institutional evolution, that could be measured through indicators like incentives to reduce transaction costs and uncertainty; efficiency of bureaucracy and judicial system; property rights system, etc. Values in multiple transition probability matrices, derived from Markov chains processes, could indicate the effects of contingent factors - like beliefs, small historical events, social norms, externalities, etc. – on institutional evolution. On the other hand, econometric analysis is relevant in order to evaluate how much each factor affects institutional evolution. This is only a small limited suggestion open to discussion and feasibility testing.

impulses (or classes of responses) will be conditioned by past connections between similar stimuli and impulses, according to a typical path-dependent process. This means that individuals do not perceive external objects in all their properties, but they perceive only those aspects related to our internal rules of classification. In other words, they classify stimuli, by adjusting them to the existing classes of impulses, created from past experience. Adjustments mechanism entails continuous reclassification processes. New classes are created by modifying or destroying the old ones every time the expectations deriving from a certain classification are disappointed by new experiences.

Hayek's model has represented one of the first contributions adopted by cognitive economics in order to provide micro-founded explanations of economic behavior. Later, interesting theories showing the strong path-dependent nature of learning process have been integrated. These theories derive from cognitive studies - *cognitive path-dependence* category is one of the most representative contributions in this sense - and from neuroscience, that has clarified some mechanisms regulating neural circuits and brain functioning (Gazzaniga et al., 2002; Gazzaniga, 2004; Damasio, 1995; Rizzello, 1999; Arcuri and Castelli, 2000; Rizzello, 2004; O'Shea, 2005).

Cognitive path-dependence (Rizzello, 1999; 2004) stresses the role of the following elements in governing individual knowledge production process: genetic codes, characterized by a stochastic nature; individual past and present experiences, that are extremely idiosyncratic; historical events, often little and unpredictable; feedbacks from environment. This theoretical framework has been enriched through the integration of two categories derived from biogenetics and evolutionary biology: *neurognosis* and e*xaptation* (Rizzello, 1999; 2004; Ambrosino, 2012). They contribute to explain the neural foundations of cognitive path-dependence dynamics.

Neurognostic structures (Laughlin, 1996; Rizzello, 2003; Ambrosino, 2012) are individual innate neural systems regulating interpretation of sensorial data. As they depend on genotype and are strictly molded by idiosyncratic experiences, they could be considered as the source of mental resistance to change. Non-flexible learning paths can originate, in this sense, through self-reinforcing mechanisms: "every 'successful' perception reinforces the perception mechanisms in its direction, by creating neurobiological paths towards which similar external data will be conveyed, and the individual will change such paths only when a problematic novel situation arises" (Rizzello, 2004, p. 261).

However, neurognostic structures are not completely rigid: they can modify through experiences and feedbacks, producing new neural structures. This form of flexibility is well described by *exaptation* category, which defines the capability of evolutionary systems to use old structures for new functions (Ambrosino, 2012; Gould, 1991). Exaptation has been interpreted as the founding

mechanisms of mental propensity to change: previous nervous circuits partly modify or new ones are built up when new information - not fully compatible with old interpretative schemas – is elaborated and when elaboration process receive negative feedbacks from outside. This process of adaptation is significantly limited by the non-ergodic and path-dependent forces exerted by old experiences and genetic characteristics. "In other words, previous neural structures built and developed to solve problems of the interpretations of the external world effectively, reveal their capacity to co-op new configurations and functions when the individual faces new problems. After this process, these new modified neuronal configurations, in turn, are ready to co-op new unfamiliar external data, and so on." (Rizzello, 1993, p. 9).

Briefly summarizing, if - on the one side - knowledge production process is governed by static and quasi-rigid neural structures working as resistance forces to change, on the other side, a certain form of innovation of the process is made possible by neural capability to adjust and modify, according to new interpretative needs.

Cognitive path-dependence finds another relevant support in the *social cognitive theory* of A. Bandura (Bandura, 1986; 1989; Rizzello and Turvani, 2002; Ambrosino, 2012). This theory provides a relevant explanation of social interaction mechanisms intervening in personal knowledge production, by describing *vicarious* or *observational learning*. Vicarious learning defines a complex process of personal elaboration of observed experiences which makes it possible to produce "new behavior patterns, judgmental standards, cognitive competencies, and generative rules for creating new forms of behavior." (Bandura, 1989, p. 23). This is possible through "reflective self-consciousness", the individual capability to elaborate observed behavioral patterns through personal cognitive structures, strongly molded by genetic characteristics, experiences and feedbacks from external environment. Individual elaboration process, however, is strictly conditioned by social mental models which inhibit incoherent new behavioral patterns.

This micro-founded analysis of knowledge production process adopted by cognitive economics and showing the path-dependent character of learning process has provided interesting explanations of institutional genesis and evolution mechanisms and, in this sense, it has represented an extremely relevant foundation for *institutional cognitive economics* (Rizzello, 1999; Ambrosino, 2012; Ambrosino et al., 2015).

Cognitive economics adopts the Hayekian concept of institutional norms. Such norms derive from successful behavioral patterns which – generated at individual level, through elaboration of sensorial data and knowledge generation – are adopted by the social group as formal or informal norms, regulating individual and social conduct (Hayek, 1952; Rizzello, 1999; Ambrosino, 2012; Ambrosino et al., 2015). This kind of enactive process reveals strong path-dependent dynamics: the

emergence of a behavioral paradigm is particularly affected by individual knowledge production; selection and formalization of such paradigms seems to be more conditioned by historical and cultural features of the social group (Rizzello, 1999).

Cognitive economics explains also the implications of Bandura's social cognitive theory at institutional level: on the one side, vicarious learning assures continuity and solidity to institutions, as it contributes to the standardization of rules; on the other side, self-evaluation makes it possible the activation of evolutionary mechanisms, favoring institutional change in time (Rizzello and Turvani, 2002; Ambrosino, 2006; Ambrosino, 2102).

Moreover, if on the one hand knowledge production is the result of continuous adjustments of personal cognitive structures to social mental models and feedbacks, and - on the other hand – it plays a relevant role in reinforcing or modify such models, Bandura's theory provides a significant confirmation of cognitive path-dependence.

4.1. The contribution of Douglass North

A relevant contribution to the analysis of path-dependence in economics is offered by the new institutional economist D.North (North, 1990; 1991; 1994; 2003; 2005; 2010; Denzau and North, 1993; Mantzavinos et al., 2004; North, et al., 2006; Rizzello, 1999; 2004).

By trying to explain persistence of inefficient economic systems, for instance in many social organizations of North Africa or Middle East, North analyzes peculiarities of the related institutional and social settings. He describes these systems as characterized by "high measurement costs", "continuous effort at clientization" and "intensive bargaining at every margin". These elements prevent efficient economic processes, keeping high transaction costs, reinforcing uncertainty and producing relevant unproductivity levels.

According to the author, due to the path-dependent character of institutional change, persistence of inefficient economic dynamics self-reinforces significantly in time.

In particular, institutional change relies upon patterns of behavior and thought that – at each step – can modify the institutional setting (which includes both formal and informal norms), by affecting the interrelated system of institutional norms and organizations (political, economic organizations, etc.). Their interplay produces a continuous tension and takes place through path-dependent dynamics. The result of this tension cannot be predicted and evolutionary dynamics are non-linear.

North is extremely aware of crucial role played by learning in this process and of its the path-dependent character: learning it is the result of all experiences, past and present, that "have passed the slow test of time and are embodied in our language, institutions, technology, and ways of doing

things" (North, 1994, p. 364). In this sense, learning is "an incremental process filtered by the culture of a society which determines the perceived payoffs, but there is no guarantee that the cumulative past experience of a society will necessarily fit them to solve new problems" (North, 1994, p. 364). The interplay between individual and social learning, feedbacks and events can overturn development process and produce relevant low returns. In this case, society could get entrapped in an inefficient and static institutional setting.

This line of inquiry – affirming the strong link between institutional norms and learning processes - has been further developed by the author (see also Denzau and North, 1993; North, 2003, 2005; 2010; Mantzavinos et al., 2004; North et al., 2006) and offers interesting explanations of institutional genesis and change mechanisms, where the role of culture and learning becomes crucial. The path-dependent nature of institutional change is described, in particular, as deriving from the strong link between institutions and shared mental models, molded by cultural and historical factors.

In particular, individual and social learning process - thanks to imitation and social interaction mechanisms – activate processes of institutional genesis, through the replication of behavioral regularities recognized as fair and binding by the social group and which are, in time, formalized or fixed as informal norms. Institutional change, on the other hand, derives from changes in cultural and mental beliefs that push towards the modification - at least in part - of the organizational structures and, consequently, of the institutional setting.

In this sense, the path-dependent nature of institutional change finds its roots at cognitive level and is transposed to the institutional and the social one. Social mental models consolidate through positive feedbacks from external context, guiding individual behavior and institutional processes of genesis and standardization. On the contrary, institutional change reflects changes in shared mental models, whose renovation is activated when critical social and cultural factors or historical events emerge.

Definitely, North's institutional theories show the crucial role of culture, individual and social mental models, choices and feedbacks which exert multiple and often opposite forces on institutional genesis and evolution, leading to unpredictable social and institutional end states.

5. Path-dependence and Self-Organization approach to Economics

The key role of irreversibility, uncertainty, unpredictability of results, self-reinforcing mechanisms and non-linear change - characterizing path-dependence of processes described in the previous paragraphs - finds a further relevant theoretical foundation in the Self-Organization approach to

economics. This approach is grounded on the precious contributions of Georgescu-Roegen (1971; 1976) on the dissipative nature and entropic aspects of economic systems.

In the explanation of dynamic processes, self-organization approach[2] - affirmed in the second postwar through Prigogine's theory[3] - refers to non-equilibrium dissipative systems and their boundary conditions. Self-organization systems are evolutionary structures characterized by continuous exchanges with external environment, which take place by means of energy flows (Witt, 1997). These systems have reached a certain level of self-organization (*autopoiesis*), according to which they import energy and export entropy. Entropy law (the second law of thermodynamics) - which constitutes the analytical foundation of this approach - entails time-irreversibility and, consequently, the evolutionary character of change (Foster, 1993; 1997). "Although all processes can be reversed if sufficient free energy is used, the rise in energy cost necessary to arrest entropy growth is highly nonlinear and the resultant entropy barrier is such that irreversibility must prevail." (Foster, 1997, p. 439).

Self-organization approach to economics (Foster, 1993; 1997; Witt, 1997; Foster and Metcalfe, 2001) developed in order to call attention on the non-linear and irreversible character of economic processes. Economic systems acquire free energy in order to activate development and to prevent entropy increasing. The high cost of reversing processes and the further degradation of energy and matter (entropy rise) involved make these processes non-linear and time irreversible: in this sense, irreversibility has been interpreted as a clear tool of economic systems to offset entropy rise (Georgescu-Rogen, 1971; 1976; Foster, 1993; Witt, 1997).

Self-organization approach has been proposed as a new paradigm explaining dynamic and dissipative features of natural and social systems. Relevant compatibilities, in economics, can be found in different scientific strands, from Neo-Austrians to Post-Keynesians and Neo-Schumpeterians, for the role that these strands recognized to uncertainty, non-linear dynamic processes and time-irreversibility. "The advantage of the self-organization approach is that it

[2] This approach overcomes the intrinsic limits in the use of biological analogy (Foster, 1993;1997; Witt, 1997). Evolutionary biology, tied to Neo-Darwinian tradition, reduces change to competition among genes: genetic competition makes it possible the final mutation, through the process of natural selection. Neoclassical economics which is based on this approach explains how "at each instant, competition ensures utility maximization, cost minimization and equilibrium" (Foster, 1997, p. 431). Neoclassical economics and Neo-Darwinian biology describe Newtonian systems, which are timeless and ahistorical, so time-reversible. These are closed systems answering the first law of thermodynamic (the principle of conservation) and their dynamics are affected by their initial conditions.
Lamarkian tradition considers changes of behavioral characteristics derived from experiences in specific environment. In economics, this entails the use of routines, which are defined as solving-problem procedures used in a specific context or situation. Still, Lamarkian tradition is based only on competition among genes and is characterized by timeless and ahistorical features. Also nonlinear "punctuated equilibria" theory - considering natural selection in a context of changes of environmental conditions and including historic contingencies – reveals some relevant criticalities.

[3] In contrast with Newton/Boltzmann mechanical approach and the thermodynamic theory of maximum disorder's equilibrium.

encompasses time irreversibility, structural change and fundamental uncertainty in an analytical framework which can be used in empirical settings." (Foster, 1997, p. 427).

The entropic and cybernetic character of economic systems has been easily explained considering the role of knowledge: in this sense, energy and entropy can be respectively converted in knowledge and complexity. For instance, many firms' strategies are elaborated to export obsolete knowledge (entropy), such as the abandon of specific product lines, techniques or organizational structures; in other cases, firms are not able to adapt and can collapse (Foster, 1993; 1997). In other words, the rise of entropy can be explained as the dissemination of new knowledge in the system - for instance the adoption of an innovation by a firm and the following alignment of the others - which makes the incorporated knowledge obsolete and increases entropy, meaning system's disorder. New successful organizational structures, efficient institutional frameworks regulating knowledge systems and the adoption of innovations play a fundamental role in preventing the rise of disorder and keep entropy low.

Dynamic change processes described by self-organization approach show evident path-dependent features. After all, relevant contributions on irreversibility, historical dimension of path change and non-linear dynamics offered, for instance, by David (1988) and Arthur (1988) have represented part of the theoretical basis of economic self-organization (Foster, 1994): "..firstly, self-organizational development is a process of cumulative, nonlinear structural change. Secondly, as such, it is a process which contains a degree of irreversibility. Thirdly, this implies that systems will experience discontinuous nonlinear structural change in its history; therefore, fundamental uncertainty is present. Fourthly, economic self-organization involves acquired energy and acquired knowledge which, in combination, yield creativity in economic evolution" (Foster, 1997, p. 444).

On the other hand, the main applications of path-dependence in economics, described in the previous paragraphs, offer to economic self-organization approach an interesting opportunity to better clarify the path-dependent character of agent's behavior and economic processes, regulated by entropy processes.

The crucial role of learning mechanisms as well as of uncertainty and expectations, at the basis of economic agents' behavior, can represent a fertile frontier for future research in the field.

Innovation economics has contributed, in this sense, by describing technological change process. Antonelli (2006) has defined in terms of entropy of the system the discrepancy level between agents' expectations and actual conditions of markets, both of products and factors. When the discrepancy level is significantly high, entropy increases, while the level of creativity decreases. Firms, in fact, find more difficult to absorb (or convert) entropy though simple adjustments prices-quantities: in this case, they could not be able to cope with the problem by innovating and could

collapse. Entropy levels and firms' reaction capability play a relevant role in technological change process by exerting a propulsive or, on the contrary, an obstructing force that could respectively result in the adoption of technological innovation or in a condition of static efficiency.

Also the cognitive and institutional analysis of path-dependent processes seem to contribute in a convergent way.

Rizzello (2003), for instance, has discussed the opportunity of integrating self-organization and cognitive approach to economics and the relevance of neuro-biological categories like *neurognosis* and *exaptation* (see par. 4) in explaining evolutionary processes at neural and cognitive level and clarifying the cybernetic nature of brain functioning, clearly able to self-regulate and change by evolving.

As discussed in par. 4, path-dependence characterizing neural and cognitive processes at the basis of individual learning reveals a relevant tension between mental resistance and propensity to change. Resistance to change is instructed by non-ergodic forces exerted by innate *neurognostic* structures, genetic rules, past experiences, consolidated behavioral routines and positive feedbacks. At the same time, the mutual interplay of these elements and the unpredictability of events can generate diverting pushes able to modify *neurognostic* structures - characterized by a plastic nature - and traditional learning paths. Social interaction and imitation mechanisms consolidate shared mental models, which reflect at social level the path-dependent nature of learning process, as North's analysis has revealed (par. 4.1).

This continuous friction at the basis of individual learning between conservative and innovative forces as well as the capability to coopt old structures for new purposes described by *exaptation* category suggest the energy economizing nature of these processes that could provide further explanation of dissipative systems' mechanisms to offset entropy level.

6. Final remarks

This paper has offered a review of some of the main applications of path-dependence category in economics and, in particular, of those theories focusing on the micro-foundations of path-dependent processes concerning, as discussed, economic agent's specificities, creativity and structural behavior, irreversibility and indivisibility, localized learning; individual knowledge production process, neurognostic structures, vicarious learning, cognitive sources of institutional genesis and evolution; entropy processes.

Table 1 provides a synthetic scheme of theories and analytical key elements - discussed in this contribution - adopted by economics in order to show the path-dependent character of dynamic processes.

Tab 1 - Path-dependence in economic theory

	INNOVATION ECONOMICS	**COGNITIVE & INSTITUTIONAL ECONOMICS**	**ECONOMIC SELF-ORGANIZATION**
PATH-DEPENDENCE Theories and analytical key elements	Antonelli's theories (1997; 2006; 2011) on technological change: ▪ *Firm's specificities* ▪ *Localized learning* ▪ *Creativity* ▪ *Knowledge accumulation and spillovers as local externalities* ▪ *Increasing returns to production (economies of scale, scope, density, ..) as local externalities* ▪ *Action context (feedbacks)* ▪ *Irreversibility and indivisibility* ▪ *Historical and unexpected events* ▪ *Technological lock-in* ▪ *Innovation introduction, persistence and diffusion* ▪ *Rival technologies* ▪ *Evolution in consumption* ▪ *Market dynamics* ▪ *Technological and regional clusters* ▪ *Institutional setting* ▪ *Information networks* ▪ *Markov chains and transition probability matrices as methodological tools of analysis*	Neuro-biological tools: ▪ *Neurognostic structures* ▪ *Neural circuits* Cognitive theories in cognitive and institutional economics: ▪ *Hayek's model of the mind (1952)* ▪ *Cognitive path-dependence (Rizzello, 2004)* ▪ *Bandura's theory on vicarious learning (1986;1989)* ▪ *North's theories (1990; 2005) on learning process, shared mental models and institutional norms*	▪ *Georgescu-Roegen's theories (1971; 1976) on:* ○ *Economic dissipative structures* ○ *Entropy law* ○ *Time-irreversibility* ○ *Non-linear change* ▪ *entropy as obsolete knowledge (including processes, techniques and organizational routines)* ▪ *entropy as discrepancy among agents' expectations and actual conditions of markets* ▪ *creativity, knowledge and innovation to export entropy* ▪ *entropy levels exert diverting forces in endogenous change process (for instance, in technological change)*

In the field of innovation economics, some decisive contributions of Antonelli's research have further clarified technological change process: the application of path-dependence theory has revealed the endogenous character of its dynamics and has contributed to overturn the neoclassical theory affirming the exogenous nature of innovation mechanisms. Technological change is the result of the complex interplay among non-ergodic and path-dependent forces. Irreversibility and indivisibility among production factors, idiosyncratic features of the economic agent, creativity,

access to localized learning, externalities and knowledge spillovers, feedbacks as well as market conditions and accidental events exert multiple forces that can divert change process, at each step, and define a multiplicity of possible outcomes, excluding the unavoidability of Walrasian equilibrium end state. Markov chains have been proposed as a relevant methodological tool in order to implement path-dependent analysis as they make it possible to observe historical economic evolution both at micro - the single agent - and at macro level - the system (Antonelli, 1997).

Cognitive and institutional economics have adopted the concept of *cognitive path-dependence* in order to explain economic behavior and institutional standardization and change processes. The category shows the path-dependent character of knowledge production process – partly, already grasped by Hayek's theories on elaboration of sensorial data - clarifying the role of a set of elements – genetic code, experiences, events, feedbacks – that mold learning and decision-making process. Moreover, relevant neuro-biological studies – in particular, those concerning *neurognostic* structures - have contributed to explain the path-dependent nature of neural functioning. Bandura's *social cognitive theory* has, finally, contributed to further clarify personal knowledge production, by explaining - through the *vicarious learning* theory - how social interaction affects this process. All these contributions not only have clarified the path-dependent nature of knowledge production, but - taking into account the main assumption of institutional cognitive economics, concerning the cognitive nature of institutional norms - they have provided relevant explanations for institutional standardization and evolutionary processes. North's contributions (par. 4.1) fully embrace this line of enquiry, by stressing the role of learning, culture and shared mental models in molding institutional setting and its evolution in time.

Finally, first studies on economic path-dependence have contributed to the development of Self-Organization approach (par. 5) to economics. Starting from Georgescu-Roegen's famous contributions, this approach has described economic dynamic processes and defined economic systems as dissipative structures regulated by the second law of thermodynamics and strongly characterized by time-irreversibility and non-linear change. This paper has shown how innovation and cognitive economics have tried to integrate such approach to their analysis. The interpretation of entropy as a mismatch between agents' expectations and actual markets' conditions in innovation economics as well as the proposal to integrate cognitive economics and self-organization, in order to enrich the set of analytical categories able to explain the entropic and cybernetic nature of brain's and mental activities, could contribute to significantly enlarge this economic paradigm - further clarifying path-dependence in dissipative structures - and to favor cross-fertilization among economic and non-economic research strands.

The path-dependent character of technological change and knowledge production process not only enriches explanations on economic agents' behavior and dynamic processes: it also evidences the necessity to further extend theoretical and empirical economic research in an interdisciplinary sense, in order to provide more appropriate clarifications about the complex mechanisms underlying endogenous change, innovative processes, efficiency problems and main hindrances to development.

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