THE ECONOMIC COMPLEXITY OF TECHNOLOGICAL CHANGE: INTERACTIONS, KNOWLEDGE AND PATH DEPENDENCE[1]

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1. INTRODUCTION

Complexity is emerging as a new unifying theory to understand endogenous change and transformation across a variety of disciplines, ranging from mathematics and physics to biology. Complexity thinking is primarily a systemic and dynamic approach according to which the outcome of the behavior of each agent and of the system into which each agent is embedded, is intrinsically dynamic and can only be understood as the result of multiple interactions among heterogeneous agents embedded in evolving structures and between the micro and macro levels.

Different attempts have been made to apply complexity to economics, ranging from computational complexity to econophysics, connectivity complexity and bounded rationality complexity. Too often these attempts have missed the basic feature of economics that consists in the analysis of the role of the intentional, rent-seeking conduct in the interpretation of the behavior of agents. Agents are portrayed as automata that are not able to implement the intentional pursuit of their interest (Rosser, 1999 and 2004).

This Handbook presents a systematic attempt to show how, building upon the achievements of complexity theory, a substantial contribute to the economics of innovation can be implemented. At the same time it shows that an economic approach to complexity can be elaborated and fruitfully implemented. This introductory chapter articulates the view that innovation is the emergent property of a system characterized by organized complexity. It implements an approach that enables to provide basic and simple economic foundations at the same time to analyzing the outcome of the intentional economic action of agents endowed with some levels of creativity, both at the micro and macro level, and to the notion of organized complexity.

According to the theory of complexity, emergence is a phenomenon whereby aggregate behaviors that arise from the organized interactions of localized individual behaviors, provide both the system and the agents with new

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capabilities and functionalities. Innovation and organized complexity can be seen as emerging properties of a system stemming from the combined result of the action of individual and heterogeneous agents with the structural characteristics of an organized system that is able to qualify and amplify the results of their action. The analysis of innovation as an emergent property of a system enables to combine the individualistic analysis of innovation as the result of intentional decision making of agents with the holistic understanding of the properties of the system into which such innovative action takes place and actually makes it possible. For the same token, the analysis of an organized complexity as an emerging property enables to appreciate how the structural and architectural characteristics of a system are themselves the product of the interactions within the system and provide the context into which the individual reaction of agents can yield the introduction of innovations.

Here complexity theory enables a major progress in the economic analysis of innovation, especially if the latter is defined as a productivity-enhancing event. It is difficult, in fact, to understand how and why economic agents would not push innovative activities to the point where their marginal costs match their marginal revenue. The appreciation of the special features of the system into which the individual action takes place and of the specific processes by means of which the features of the system lead to the mergence of innovations, marks an important analytical progress.

Economic of innovation may help the theory of complexity, and especially its applications to economic analysis, in two ways. First, complexity theory often misses an economic analysis of the incentives and motivations of individual action. Economic agents are and remain rent-seeking individuals and it is necessary to understand why they may want to change and move in the multidimensional spaces that characterize economic systems. Here the economics of innovation may contribute the analysis with the understanding of the out-of-equilibrium determinants of the attempt of agents to try and introduce innovations.

Second, in the complexity theory a major distinction is made between disorganized and organized complexity. In the former "the interactions of the local entities tend to smooth each other out" (Miller and Page, 2007:48). In the latter "interactions are not independent, feedback can enter the system. Feedback fundamentally alters the dynamics of a system. In a system with negative feedback, changes get quickly absorbed and the system gains stability. With positive feedback, changes get amplified leading to instability" (Miller and Page, 2007:50). Yet the theory of complexity does not provide an analysis of the endogenous determinants of the features of system. A basic question remains unresolved in much complexity thinking: how, when and why is a system characterized by organized or disorganized complexity? The basic distinction elaborated by Hayek between cosmos and taxis, e.g. spontaneous and designed order, provides basic guidance (Hayek, 1945 and 1973).

The notion of organized complexity as an emerging property of an economic system enables to grasp the endogenous dynamics of the system. The reaction of firms that happens to be creative because of the feedbacks available, affect the structure of the system and can either implement its organization or open a degenerative process. Clearly the characteristics that qualify the levels of organization of the systems complexity are endogenous to the system itself.

It seems clear that all the effort made in the identification of innovation as an emergent property of a system as a mean to try and articulate its endogeneity would be spoiled if it eventually leads to accept the view that the organized complexity of a system is an exogenous and unpredictable characterization. Here the economics of innovation can provide important elements with its analysis of the endogenous formation of economic structures as the result of the recursive process of path dependent change.

Our attempt to implement the merging of the theory of complexity with the economics of innovation provides a complementary path to recent attempts to apply the methodologies elaborated by complexity into economics, such as complex networks (see Cowan, Jonard, Zimmermann, 2006 and 2007), percolation (see Antonelli, 1997b; Silverberg and Verspagen, 2005), and NK-modeling (see Frenken, 2006 a and 2006b; Frenken and Nuvolari, 2004), for it focuses attention upon the scope of application of the basic tools of the economics of innovation to embrace the full range of analytical perspectives brought by the analysis of innovation as an emerging property stemming from the endogenous result of both the intentional, rent-seeking conduct of individual and heterogeneous agents and the endogenous characteristics of economic systems qualified by organized complexity.

This introductory chapter articulates an approach where agents are myopic: their rationality is bounded, as opposed to Olympian, because of the wide array of unexpected events, surprises and mistakes that characterize their decision making and the conduct of their business in a ever changing environment. Our agents retain the typical characteristics of economic actors, including intentional choice and strategic conduct, augmented by the attribution of potential creativity. In our approach, however, economic agents may change both their production and their utility functions. Our agents, in fact, are endowed with an extended procedural rationality that includes the capability to learn and to try and react to the changing conditions of their economic environment by means of the generation of new tastes as well as new technological knowledge and its exploitation by means of the introduction of technological innovations. In this approach agents do more than adjusting prices to quantities and vice versa: they can try and change their technologies and their preferences. Agents are intrinsically heterogeneous. Their basic characteristics differ in terms of original endowments such as learning capabilities, size, and location. Their variety is also endogenous as it keeps changing as a result of the dynamics of endogenous technological change (Albin, 1998).

The determinants and the effects of this potential creativity and the context into which it can be implemented, however, require careful investigation. The actual creativity of agents is not obvious, nor spontaneous, but induced and systemic.

To investigate the determinants of the actual creativity of agents three steps are necessary. First, the incentives to change must be identified and qualified. Agents are reluctant to change their production and utility functions and a specific motivation is necessary to induce them to try and change their routines. Second, the localized context of action and the web of knowledge interactions and externalities into which each agent is embedded are crucial to make their reaction actually creative, as opposed to adaptive, so as to shape the actual effects of their endogenous efforts to change their technologies and their preferences. Third, the sequential process of feedbacks that make the creative reaction a sustained process must be identified. The creative reaction of each agent in fact is not a punctual event that takes place isolated in time and space, but rather a historic process where the sequence of feedbacks plays a key role (Arthur, 1990).

The analysis of the effects must include, next to the introduction of innovations that increase the efficiency of the production process, the structural consequences upon the context of action. The successful introduction of new localized technologies, in fact, changes the structure of the system and hence the flows of knowledge externalities and interactions. This dynamic loop exhibits the characters of a recursive, non-ergodic and path dependent historic process. This approach enables to move away from the static, low-level complexity of general equilibrium that applies when both technologies and preferences are static, or the smooth and ubiquitous growth based upon learning processes and spontaneous spillover of the new growth theory. It makes it possible a significant progress also with respect to evolutionary thinking where the causal analysis of the determinants of the generation of innovations is reduced to the random walks of spontaneous variations.

This approach provides the tools to grasp the dynamics of technological change as an endogenous and recurrent process that combines rent-seeking intentionality at the agent levels with the appreciation of the knowledge externalities and interactions that stem from the structural characters of the system.

2. THE ECONOMICS OF INNOVATION AS AN EMERGING PROPERTY OF AN ORGANIZED COMPLEXITY

A definition

Economics of innovation studies the determinants and the effects of the generation of new technological and organizational knowledge, the introduction of innovations in product, process, organization, mix of inputs and markets, their selection and eventual diffusion. Innovation takes place when it consists in actions that are able to engender an increase in the value of the output, adjusted for its qualitative content, that exceed their costs (Griliches, 1961).

Technological and organizational changes are defined as innovations only if and when the two overlapping features of novelty and increased efficiency coincide. Changes are innovations if they consist at the same time in the introduction of a novelty that is also able to yield an increase in the relationship between outputs and inputs. Total factor productivity can be considered a reliable indicator of the relationship between outputs and inputs of the production processes: novelties that are actually able to increase the ratio of inputs to output are true innovations. Either characteristic is necessary to identify an innovation. Only if we retain such a strict definition of innovation, as a productivity-enhancing novelty can we grasp its out-of-equilibrium characteristics.

It is clear in fact, on the one hand, that indeed total factor productivity may increase for a variety of other factors, especially if and when markets are not in equilibrium. On the other however it is also clear that often novelties do not last and are selected out in the market selection process with no actual economic effect. On a similar ground we see that minor changes in products may feed monopolistic competition and do not increase the efficiency of the production process at large. It is not surprising that much theorizing upon the new theories of growth never tackles the issue and prefers a more comfortable definition of innovation as a form of increase in the variety of products.

Innovation is the result of a variety of activities. Learning processes of various kinds play a major role in the accumulation of the competence that is necessary to generate new technological knowledge and eventually to introduce innovations. The access to external knowledge is a crucial factor in the generation of new technological knowledge. The adoption of new capital and intermediary goods incorporating technological innovations is an essential component of the innovation process. Research and developments indicators are able to grasp only a fraction of such activities. Much R&D on the other hand is funded and performed to generate novelties that are not able to increase the efficiency of the production process. As it is well known only a fraction of the technological innovations being introduced is represented by patent statistics. Neither R&D nor patent statistics account for innovations in organization, input mix and markets. Innovation counts suffer the subjective character of the claims upon which they are based. Product innovations introduced by upstream producers are often considered process innovations by downstream users (Kleinknecht, van Montfort, Brouwer, 2002). The distinction between innovation, adoption and diffusion is more and more blurred by the increasing awareness of the amount of creative efforts that are necessary to adopt and imitate an innovation. Moreover, and most importantly, the economic analysis of innovation should take into account the time distribution of adoptions, rather than their punctual introduction. Total factor productivity indicators instead can grasp the full bundle of the economic effects of the introduction and diffusion of an innovation. Hence total factor productivity indicators are likely to provide an accurate measure of the actual amount and extent of the innovations being introduced (Crépon, Duguet, Mairesse, 1998).

In sum, new products, new processes, new organization methods, new inputs and new markets can be defined as innovations only if they yield an increase in total factor productivity. Hence the marginal product of innovation efforts exceeds its marginal costs. This is at the origin of a serious problem for textbook economics.

Departing from dead-ends

This new approach enables to overcome the limitations of two contending approaches: general equilibrium analysis and darwinistic evolutionary population thinking.

The merging of the theory of complexity and the economics of innovation provides a new way to integrate economic and complexity thinking and contributes to the building of an economic theory of complexity that puts the endogenous and systemic emergence of innovation at the core of the analysis. The continual introduction of new technologies and their selection is seen as the emerging and systemic property of an out-of-equilibrium dynamics characterized by path dependent non-ergodicity and interactions both among agents and between micro and macro levels. The organized complexity of the system that enables the emergence of innovations is itself the product of the recurrent and path dependent interaction of rent-seeking agents (Arthur, 1994 and 1999).

Organization thinking, as distinct from population thinking, plays a crucial role to grasping the causes and the consequences of the changing structure, composition and organization of the system (Lane, 1993a and b; Lane et. alii 2009).

Technological and structural change are the result of a sequential process of systemic change where agents are never able to anticipate ex-ante the outcome of their reactions to emerging surprises. The changing characters of their localized context of action in fact engender out-of-equilibrium conditions to which they react. When knowledge externalities and interactions engender positive feedbacks their reaction is creative. Firms are able to change both their technologies and the structure of the system: a recursive, historic and path-dependent process of change takes place. When the context of action does not provide knowledge externalities and interactions sufficient to engender positive feedbacks, the reaction of firms is adaptive and a single static attractor consolidates: general equilibrium analysis applies.

In general equilibrium economics the preferences and the technologies, of the representative agent and hence her production and utility functions, are allowed to change only as the result of exogenous shocks. As soon as the notion of endogenous change is introduced and heterogeneous agents are credited with the capability to change their production and utility functions in response to economic stimulations, the general equilibrium analysis appears a simplistic approach. The assumption of the necessary gravitation and convergence towards a single equilibrium point cannot be retained because of the changing centers of attraction. As soon as we acknowledge that both preferences and technologies are the result of the intentional decision-making of heterogeneous actors that are part of a system of interdependencies, the foundations of general equilibrium economics collapse, yet its powerful systemic approach should be retained and implemented.

Kenneth Arrow has provided key contributions to reconcile the evidence about growth with general equilibrium analysis both with the articulated notion of learning by doing, eventually implemented with learning by using, and with the path breaking analysis of the limitation of knowledge as an economic good (Arrow, 1962a, 1962b, 1969, 1974). Building upon his legacy, the new growth theory shares the view that knowledge is characterized by an array of idiosyncratic features such non-appropriability, non-divisibility, non-excludability, non-exhaustibility that are the cause of knowledge externalities and contribute the continual and homogeneous introduction of innovations. The new growth theory however has not been able to appreciate the endogenous, idiosyncratic and dynamic character of knowledge spillovers. Assuming that knowledge spillovers are given and evenly distributed in time and space, the new growth theory claims that technological change takes place evenly through time and space without discontinuities and leads to smooth dynamic processes (Romer, 1994).

The main limitation of new growth theory is the underlying assumption of an automatic, spontaneous and ubiquitous trickle down of the new technological knowledge inputs into every other kind of activity in the economic system. In Aghion and Howitt's model, downstream sectors make no particular efforts to identify, understand or use the new knowledge embodied in new intermediary inputs. Technology adoption and transfer take place in the absence of effort, interaction or dedicated activity. Although perhaps not like manna from heaven, new technological knowledge rains from upstream and wets whatever is below – be it sectors or regions (Aghion and Howitt, 1992, 1998; Aghion and Tirole, 1994).

These assumptions contrast sharply the rich evidence about the punctuated and discontinuous rates and directions of technological change and are not able to explain the wide variety across countries, regions, industries and firms in terms of rates of introduction and diffusion of innovations (Mokyr, 1990a, 1990b, 2002).

The second attempt to elaborate an evolutionary economics based upon darwinistic population thinking, implemented by Nelson and Winter (1982) since the late seventies of XX century, has much contributed to place innovation at the center stage of economic analysis. Evolutionary economics has built an outstanding corpus of knowledge about the characteristics of innovation and of technological knowledge with the identification of important taxonomies and significant sequences. The grafting of biological metaphors has focused on population thinking, as distinct from organization thinking, stressing the role of the natality, mortality, entry, exit and mobility of agents, while little attention has been paid to the causes and effects of the organization of economic systems. Agents are not credited with the intentional capability to change their technologies and their preferences.

Consistently with the general evolutionary frame of analysis, innovation is regarded as the product of random variations and accidental mutations, rather then the result of the intentional action of agents. The radical criticism raised by Edith Penrose against the first wave of attempts to integrate Social Darwinism into mainstream economics, based upon the well-known article by Armen Alchian (Alchian, 1950), apply very much to second wave as well: "to abandon [the] development [of firms] to the laws of nature diverts attention from the importance of human decisions and motives, and from problems of ethics and public policy, and surrounds the whole question of the growth of the firm of with an aura of 'naturalness' and even inevitability" (Penrose, 1952, p. 809; Penrose, 1953).

Evolutionary economics has focused much more the analysis of the selective diffusion of new technologies rather then the analysis of the actual determinants of the generation of new technological knowledge and the introduction of innovations (Metcalfe, 1994).

The causal analysis of the determinants of technological change, however, has been left at the margin of the exploration. This seems quite paradoxical. Evolutionary economics is not able to explain the determinants of the central mechanism of economic change (Hodgson, Knudsen, 2006).

Standing on giants' shoulders: Marshall and Schumpeter

In our approach, innovation is not only the result of the intentional action of each individual agent, but it is the endogenous product of dynamics of the system. The individual action and the system conditions are crucial and complementary ingredients to explain the emergence of innovations (See Table 1).

Innovation cannot be considered but the intentional result of the economic action of agents: it does not fall from heaven. Neither is it the result of random variations. Dedicated resources to knowledge governance are necessary to implement the competence accumulated by means of learning and to manage its exploitation. Agents succeed in their creative reactions when a number of contingent external conditions apply at the system level. Innovation is made possible by key systemic conditions: "innovation is a path dependent, collective process that takes place in a localized context, if, when and where a sufficient number of creative reactions are made in a coherent, complementary and consistent way. As such innovation is one of the key emergent properties of an economic system viewed as a dynamic complex system" (Antonelli, 2008:I).

An innovation economics approach to complexity thinking makes it possible to overcome the limitations of both general equilibrium economics and evolutionary analysis into a complex dynamics approach. It builds upon the integration of Schumpeterian analysis of innovation as a form of reaction, to the changing conditions of product and factor markets, with the Marshallian partial equilibrium approach to localized increasing returns based upon circumscribed of externalities. This approach contrasts the general equilibrium analysis where economic agents are indeed embedded in a systemic analysis but are not supposed to be able to change purposely their technologies and their preferences. This effort can contribute a complex dynamics where technological change is the central engine of the evolving dynamics-viewed and it is the result of the creative response of intentional agents, embedded in the organized complexity of a system populated by interacting and reactive agents (Antonelli, 2007, 2008a and 2009a).

The Marshallian approach provides the basic frame for a systemic understanding of the behavior of heterogeneous agents that are interdependent within a dynamic context characterized by localized increasing returns and increasing levels of division of labor engendered by specialization. The Marshallian partial equilibrium analysis provides a rich analytical apparatus that emphasizes the idiosyncratic variety of agents and markets that interact in a systemic context characterized by endogenous structural change. The Marshallian partial equilibrium enables the use of the foundations of microeconomics as they provide the analytical context into which the maximizing conduct of individual agents can be interpreted and yet makes room for understanding the interactive process of structural and technological change. The integration of partial equilibria, however, does not lead to general equilibrium. As Young (1928) has shown, each change in a component of the system modifies its structural composition and organization and feeds in turn new ripples of technological change via new flows of externalities. Technological change and structural change are intertwined and necessary components of an aggregate and systemic dynamics (Foster, 2005; Metcalfe, Ramlogan, Foster, 2008).

For these reasons the Marshallian approach can be retained and integrated with the Schumpeterian and classical approaches that stress the role of the creative reaction of firms caught in out-of-equilibrium conditions into an economics of complexity that emphasizes the endogenous emergence of technological change and the continual transformation of the structure of the system (Schumpeter, 1941; Downie, 1958).

The aggregate dynamics of the system, in fact, is far from the assumptions of an even, smooth and homogenous pace. It is instead characterized by strong elements of contingent discontinuity as well as historic hysteresis (Anderson, Arrow, Pines, 1988). The understanding of the dynamics of the system requires the grasping of the causes and determinants of both individual action and the changing centers of gravitation of the system (Blume and Durlauf, 2005).

The appreciation of the systemic conditions that shape and make innovations possible, together with their individual causes lead to the identification of innovation as an emergent property of a system. This approach provides a solution to the conundrum of an intentional economic action whose rewards are large than its costs, only if the organized complexity that enables the mergence of innovations is explained as an endogenous and dynamic process engendered by the interactions of rent-seeking agents.

The reappraisal of a somewhat forgotten contribution by Joseph Schumpeter (1947b) provides basic support in this endeavur. The direct quote with added italics of a key portion of this text seems most appropriate here: "*What has not been adequately appreciated among theorists is the distinction between different kinds of reaction to changes in 'condition*'. Whenever an economy or a sector of an economy adapts itself to a change in its data in the way that traditional theory describes, *whenever, that is, an economy reacts to an increase in population by simply adding the new brains and hands to the working force in the existing employment, or an industry reacts to a protective duty by the expansion within its existing practice, we may speak of the development as an adaptive response. And whenever the economy or an industry or some firms in an industry do something else, something that is outside of the range of existing practice, we may speak of creative response.*

Creative response has at least three essential characteristics. "*First, from the standpoint of the observer who is in full possession of all relevant facts, it can always be understood ex post; but it can be practically never be understood ex ante; that is to say, it cannot be predicted by applying the ordinary rules of inference from the pre-existing facts."* This is why the 'how' in what has been called the 'mechanisms' must be investigated in each case. "*Secondly, creative response shapes the whole course of subsequent events and their 'long-run' outcome. It is not true that both types of responses dominate only what the economist loves to call 'transitions', leaving the ultimate outcome to be determined by the initial data. Creative response changes social and economic situations for good, or, to put it differently, it creates situations from which there is no bridge to those situations that might have emerged in the absence. This is why creative response is an essential element in the historical process; no deterministic credo avails against this.* Thirdly, *creative response –the frequency of its occurrence in a group, its intensity and success or failure- has obviously something, be that much or little, to do (a) with quality of the personnel available in a society, (b) with relative quality of personnel, that is, with quality available to a particular field of activity relative to the quality available, at the same time, to others, and (c) with individual decisions, actions, and patterns of behavior.*" (Schumpeter, 1947b: 149-150).

Innovation aand organized complexity as emergent properties of an economic system

In our approach, innovation is an emergent property that takes place when complexity is organized, i.e. when a number of complementary conditions enables the creative reaction of agents and makes it possible to introduce innovations that actually increase their efficiency. The dynamics of complex systems is based upon the combination of the reactivity of agents, caught in out-of-equilibrium conditions, with the features of the system into which each agent is embedded in terms of externalities, interactions, positive feedbacks that enable the generation of localized technological knowledge, the introduction of localized technological change and lead to endogenous structural change. The process is characterized by path dependent non-ergodicity.

This approach builds upon five basic points:

i. The distinction between ex-ante and ex-post is crucial. Bounded rationality limits the foresight of agents. Economic agents however are credited with the basic capability to react to unexpected changes in their economic environment by changing their technology. Agents try and change their technology when their performances are both below and above their expectations.

ii. The reaction of firms can be either adaptive or creative. Occasionally, when the context is favorable, their reaction becomes creative and they can innovate. When the organization and composition of the economic structure and the quality of the external conditions add to the characteristics of the individual firms to explain whether, when, how and why their reaction can be either adaptive or creative. The levels of knowledge externalities and the quality of the generative relations that take place in the context into which firms are localized, determine the actual chances that the reaction of firms leads to the actual introduction of innovations.

iii. Their reaction is localized by the irreversibility of their tangible and intangible inputs as well as by their competence based upon learning processes and rests upon the recombinant generation of knowledge that is both internal and external. Innovation emerges as the result of the fertile interaction between the knowledge characteristics of the context and the competence of the individuals.

iv. The introduction of innovations changes the structure of the economic system into which firms are embedded, including the availability of knowledge externalities and the quality of generative relations. These in turn affect the direction and the rate of the economic dynamics. Occasionally, loops of systemic positive feedbacks between structural and technological change lead to the emergence of organized complexity that feeds innovation cascades and Schumpeterian gales of innovations.

v. The interaction between technological and structural change engenders dynamic processes that are non-ergodic because history exerts a strong effect in shaping their dynamics. History matters in influencing the dynamics of economic processes but innovations, introduced along the path, can alter it. History matters, yet small events can change it.

In this approach, innovation is an emergent property of the system that, when framed as an organized complexity, qualifies and makes possible the creative response of agents.

Let us now turn our attention to analyze the building blocks of our approach. The following chapters show how the integration of complexity thinking with the basic tools of the Schumpeterian economics of innovation can implement a rigorous representation of the systemic dynamics of technological change.

TABLE 1. DEADS ENDS AND NEW PROSPECTS FOR THE ANALYSIS OF SYSTEMS WHERE INNOVATION IS AN ENDOGENOUS, TFP-ENHANCING EMERGENT PROPERTY

	MICRO	MESO	MACRO
GENERAL EQUILIBRIUM	THE REPRESENTATIVE AGENT CAN ADAPT BUT CANNOT INNOVATE	MARKET TRANSACTIONS	LOW-LEVEL STATIC COMPLEXITY
MARSHALLIAN PARTIAL EQUILIBRIUM	INTRINSIC HETEROGENEITY AND VARIETY OF AGENTS AND LOCATIONS	LOCALIZED INCREASING RETURNS BASED UPON EXTERNALITIES	UNEVEN GROWTH
ARROVIAN LEGACY	LEARNING; KNOWLEDGE AS AN IMPERFECT ECONOMIC GOOD	KNOWLEDGE SPILLOVER	SPONTANEOUS, EVEN AND STEADY DYNAMIC EQUILIBRIUM
DARWINIAN EVOLUTIONISM	RANDOM VARIATIONS AND OCCASIONAL MUTATIONS	SELECTION BASED UPON REPLICATOR DYNAMICS; EMERGENCE OF DOMINANT DESIGNS	GROWTH&CHANGE BASED UPON SELECTIVE DIFFUSION OF INNOVATIONS

COMPLEXITY CUM INNOVATION	INNOVATION AS AN EMERGENT PROPERTY WHEN INDIVIDUAL REACTIONS BASED ON GENERATIVE RELATIONS MATCH ORGANIZED COMPLEXITY	KNOWLEDGE GOVERNANCE; NON-ERGODIC CHANGES IN THE ORGANIZATION OF STRUCTURES AND NETWORKS	GROWTH AND PATH DEPENDENT CHANGE BASED UPON INNOVATION WITHIN ORGANIZED COMPLEXITY

3. THE DETERMINANTS OF THE CREATIVE RECTION

Consistently with the dominant view that technological change is exogenous or, at best, the automatic product of either spontaneous learning procedures within firms or uncontrolled leakage of knowledge externalities among firms, very little attention has been paid to the analysis of the determinants of innovation. This contrasts the size and the wealth of the large literature that has explored the effects of innovation on the increase of total factor productivity and hence on growth, profitability, performance, economic and industrial structures.

Even evolutionary economics assumes that innovation is the spontaneous outcome of random mutations: agents introduce innovations occasionally without any specific motivation. In evolutionary economics there is no attempt to identify the historic, regional and institutional determinants of the decisions that lead to the generation of innovations. Much effort is made, instead, to explore the features of the selection, adoption and diffusion mechanisms of the 'spontaneous' flow of innovations. Much evolutionary economics, so far, elaborates a theory of selective diffusion of innovations, rather than a theory of innovation.

As a result, the analysis of the determinants of the introduction of innovation, considered as the result of intentional decision-making, remains substantially under-investigated. This is not surprising as it is indeed difficult to provide a consistent and coherent explanation of decision-making procedures that lead to an increase of output that exceeds the increase of inputs and hence cannot be justified according to marginalistic procedures. Rational innovators in fact should stretch their innovative activities to the point where marginal costs match marginal revenues: no room for residuals should be left.

In the classical economics of technological change three different frames have been identified to try and explain the endogenous introduction of innovations: a) the inducement approach elaborated along the lines of the early contributions of Karl Marx, b) the demand pull approach elaborated by the Post-Keynesian school; c) the Schumpeterian legacies.

Our approach impinges upon the late contribution of Joseph Schumpeter and focuses the role of the relations between profitability and innovation. The analysis of the causal relations between levels of profitability, as distinct from competition, enables to elaborate a consistent and coherent frame of analysis and integrate these different and yet complementary strands of literature that share the view that technological change is endogenous and that the decision to innovate is an intentional and relevant component of economic decision-making.

The contribution of the behavioral theories of the firm provides substantial help in this effort. The decision to innovate, in fact, cannot be treated with the standard maximization procedures. The outcomes of innovations are hard to predict, and the actual chances of introduction of successful innovations are subject to radical uncertainty. The introduction of innovations is the result of a complex sequence of intentional decision-making that takes place when firms are found in out-of-equilibrium conditions. According to James March (March and Simon, 1958; Cyert and March, 1963), firms are not profit maximizers. Firms are able to rely upon procedural, as opposed to substantive, rationality: firms use satisfying procedures and identify satisfactory levels of performances. Firms are risk adverse and hence reluctant to change their routines, their production processes, their networks of suppliers, their products and their marketing activities. Firms can overcome their intrinsic inertia and resistance to change only when unexpected changes in their environment push them to take the risks associated with innovation (March and Shapira, 1987).

Nelson and Winter (1982) make an important contribution along these lines: " In the orthodox formulation, the decision rules are assumed to be profit-maximizing, over a sharply defined opportunity set that is taken as a datum, the firms in the industry and the industry as a whole are assumed to be at equilibrium size, and innovation (if it is treated at all) is absorbed into the traditional framework rather mechanically. In evolutionary theory, decision rules are viewed as a legacy from the past and hence appropriate, at best, to the range of circumstances in which the firm customarily finds itself, and are viewed as unresponsive, or inappropriate, to novel situations or situations encountered irregularly. Firms are regarded as expanding or contracting in response to disequilibria, with no presumption that the industry is 'near' equilibrium. Innovation is treated as stochastic and as variable across firms" (Nelson and Winter, 1982: 165-166).

The integration of these elements, into the single frame of the localized technological change approach, enables to overcome the limitations of the stochastic approach of evolutionary approaches and elaborate the hypothesis that firms try and innovate when they are found in out-of-equilibrium conditions, and more specifically when profits are either below or above the norm. When equilibrium conditions prevail and there are no extra-profits, firms are not induced to try and change their technologies, neither their organizations, markets and input mixes. According to this approach a non-linear relationship between profits and innovation is at work.

Let us first review the main hypothesis elaborated about the relations between out of equilibrium conditions and the inducement to innovate.

The Marxian legacies

Marx contributed the first elements of the theory of induced technological change. The introduction of new capital-intensive technologies is the result of the intentional process of augmented labour substitution. When wages increase, capitalists are induced to introduce new technologies that are embodied in capital goods. Hence technological change is introduced with the twin aim of substituting capital to labor so as to reduce the pressure of unions and increasing the total efficiency of the production process (Marx, 1867).

John Hicks (1932) and Fellner (1961) extracted from the analysis of Karl Marx the basic elements of the theory of the induced technological change: firms are induced to change their technology when wages increase. Technological change is considered an augmented form of substitution: technological change complements technical change. Binswanger and Ruttan (1978) eventually articulated a more general theory of induced technological change: firms introduce new technologies in order to save on the production factors that are relatively more expensive. Such production factors can be labor, as much as energy or even capital in specific circumstances. The induced technological change approach has been criticized by Salter (1966) according to whom firms should be equally eager to introduce any kind of technological change, either labour- or capital-intensive, provided it enables the reduction of production costs and the increase of efficiency.

An important facet of the Marxian analysis is missing in the induced technological change approach. The analysis of the Marxian contribution by Rosenberg (1976) highlights the limitations of the induced technological change approach and helps to understand the key role of profitability. Firms try and contrast the decline in their profitability, stemming from the increase in wages, with the introduction of technological innovations. Starting from a common reference to Marx, Hicks paved the way to a tradition of analysis that focuses the role of the changes in the prices of production factors in inducing technological innovations. Rosenberg, instead, stresses the role of the decline in profitability as the focusing mechanism that pushes firm to undertake innovative activities. According to Rosenberg, firms innovate in order to restore the levels of profitability (that have been undermined by the raise in wages). According to Hicks firms react to the increase in wages (and the related decline in profitability). As Nathan Rosenberg (1969) argues Marx provides elements to build much a broader inducement hypothesis, one where the levels of profitability are a cause of endogenous technological change. This line of analysis has received much less attention in the economics of innovation, and yet it provides a clear replay to Salter's arguments

The role of profitability in the demand pull hypothesis

The post-keynesian approach elaborated by Kaldor (1972 and 1981) stressed the key role of the demand in the explanation of the endogenous origin of technological change. To do so Kaldor had revisited the dynamic engine put in place by Adam Smith. According to Adam Smith the division of labour is determined by the extent of the market and is the cause of the increase of specialization. This leads to the accumulation of new technological knowledge, and eventually to the introduction of technological innovations. Technological innovations in turn lead to an increase in productivity. The increase in productivity leads to an increase in the demand and hence of the extent of the market. According to Adam Smith the relationship between division of labor, specialization, increase of competence, introduction of technological innovations, productivity growth, increase in demand and new division of labor consists in a recursive loop. Building on this interpretation Kaldor argued that an increase in the levels of the aggregate demand would engender an increase in the division of labor, hence of specialization, and eventually of the rate of introduction of technological innovations. The so-called 'demand-pull' hypothesis was borne. Schmookler (1966) provided empirical support to the hypothesis that demand growth pulls the increase of technological knowledge, hence of inventions and eventually technological innovations. Rosenberg and Mowery (1979) provide an outstanding account of the pervasive role of the demand-pull hypothesis within the post-Keynesian approach.

Less attention has received a previous contribution by Schmookler (1954) according to which the increase in the demand leads to the generation of additional technological knowledge and the eventual introduction of technological innovations via the increase in the profitability of both inventors and innovators. Firms are pulled to generate new technological knowledge and to introduce technological innovations by the high levels of prices for the products that are the object of an increasing demand and by the high levels of rewards that are attached. Young scholars specialize in the fields were wages increase because of the demand for their competence. New firms enter with innovative ideas in the industries where profits are growing because of the increase of the demand. Incumbent firms are induced to innovate by the growth in the demand and the extraprofits that are attached.

Following this line of analysis we can claim that excess demand engenders out-of-equilibrium conditions that lead to an increase in prices and in profitability. Out-of-equilibrium conditions here are determined by the un-expected increase in the demand: had the firm anticipated the high levels of the demand, current supply would have already accommodated it with no increase in prices and hence in profits. When the demand fetches un-expected levels, instead, prices increase and consequently profits. Then firms are pulled to accommodate the increased levels of the demand with an increase in supply. The increase in supply however can be obtained both via investments with a given technology and an increase in productivity of the given resources, via the introduction of technological innovations. The accumulation of competence and expertise based upon learning processes enables the generation of new technological knowledge. Extraprofits provide the opportunity to fund the generation of new technological knowledge and the introduction of technological innovations. Hence the increase in demand feeds the introduction of innovations by means of an increase of profits above the norm. In other words we can easily reconcile the demand-pull hypothesis with the argument that extra profits favor the introduction of additional innovations.

The chain-loop elaborated by Kaldor after Smith can be integrated with a an additional ring: increase in demand, extraprofits, new division of labor, specialization, increase of competence, introduction of technological innovations, productivity growth (Scherer, 1982).

The increase in demand engenders an increase in profits that in turn provides both the incentives and the opportunities for the introduction of innovations. The incentives are the determined by the perspective to take advantage of the excess demand via the increase in supply by means of new productivity-enhancing technologies. The opportunities stem from the resources made available by extraprofits.

The Schumpeterian legacies

The third basic starting point to elaborate a theory of the endogenous decision-making of innovation is provided by the Neo-Schumpeterian literature that has debated and implemented the so-called Schumpeterian Hypothesis on the relations between forms of competition and incentives to innovate. The consensus was reached about the argument that the rate of innovation is higher when forms of oligopolistic rivalry characterize the market structure. When perfect competition prevails, firms cannot bear the burden of research activities. When the number of competitors is too small, close to monopolistic conditions, incentives to innovate are missing. Cutthroat competition risks to reduce the incentives to introduce technologies for the intrinsic non-appropriability of knowledge and the high risks of imitation and entry of new competitors that can take advantage of opportunistic behavior. Some intermediary levels of workable competition, comprised between the extremes of monopoly and perfect competition, among large firms might favor the rate of introduction of innovations. Oligopolistic market structures and the large size of firms are viewed as positive factors able to sustain the rates of introduction of innovations (Scherer, 1967 and 1970; Dasgupta and Stiglitz, 1980; Fisher and Temin, 1973; Link, 1980).

The Neo-Schumpeterian school has been very selective in implementing the Schumpeterian legacy and has neglected two crucial contributions of the late Schumpeter. As a matter of fact the scope of the analysis elaborated by Schumpeter in 1947 with two path-breaking and yet almost forgotten articles published by the *Journal of Economic History* provides ammunitions to elaborate much a more radical departure from equilibrium analysis.

With the analysis of the role of creative reaction, Schumpeter (1947b) fully elaborates the view that firms and agents at large are not passive adapters but can react to the changing conditions of both product and factor markets in a creative way, with the introduction of innovations, both in technologies and organizations and changing their products and processes. If firms are credited with the capability to innovate as a part of their business conduct, the notion of creative reaction becomes relevant. The conditions that qualify it warrant systematic investigation.

Schumpeter makes a sharp distinction between adaptive and creative responses. Adaptive responses consist in standard price/quantity adjustments that are comprised within the range of existing practices. Creative responses are triggered by strategic interactions. The rivalry among firms able to introduce –purposely- new technologies is a major factor in fostering the rate of technological change (Scherer, 1967). Here, interactions take place in the market: the extent to which firms innovate is stirred by the change in behavior of other competing agents, namely the introduction of innovations, by neighbors in the product and output markets.

Creative responses consist in innovative changes that can be rarely understood *ex ante*, shape the whole course of subsequent events and their ‘long-run’ outcome: their frequency, intensity and success is influenced by a variety of conditional factors that are both internal to each firm and external. For a given shock, firms can switch from an adaptive response to a creative response according to the quality of their internal learning processes, and the context into which they are embedded. Learning in fact is a necessary but not sufficient condition for the generation of new knowledge. The notion of creative response elaborated by Schumpeter can be considered the synthesis of a long process of elaboration.

One extreme can be identified in *Business Cycles* (1939). Here the appreciation of the role of creative reaction in economic history is fully consistent with the Rosenberg-Marx line of analysis. Here Schumpeter suggests that the gales of innovations peak in the periods of decline of the rates of profitability and growth. After a sustained phase of expansion, the decline in the opportunities for further growth of output and profits induces firms to innovate. Hence the business cycle and the innovation cycle are specular. In periods of expansion the rates of introduction of innovations decline. When profitability and growth are high, firms exploit and refine the technological innovations introduced in the periods of crisis. Technological change is characterized by the introduction of minor and incremental innovations. On the opposite, major breakthroughs take place when the search for new technologies acquires a strong collective character. When the rates of growth are lower, and the profitability declines, in fact, many firms try and react by means of the systematic search for new ideas.

Following Schumpeter, Nelson and Winter elaborate the hypothesis of a relationship between negative profitability and innovation performances and implement formally the analysis of the relationship with a simulation model. According to Nelson and Winter when the profitability levels fall below average levels and enter into negative figures firms realize that business as usual is no longer viable and take into account the need for a change in routines and start the search for new technologies: "…we assume that if firms are sufficiently profitable they do no 'searching' at all. They simply attempt to preserve their existing routines, and are driven to consider alternatives only under the pressure of adversity………In the simulations run here, only those firms that make a gross return on their capital less than the target level of 16 percent engage in search" (Nelson and Winter, 1982: 211). The formalization of the relationship between negative profitability and innovation articulated in *Business Cycles* by Schumpeter, establishes the notion of failure-induced innovation, well rooted in the Schumpeterian tradition (Antonelli, 1989).

In *Business Cycles* Schumpeter implements also the basic notion of the complementarity between innovators in the introduction of the new gales of innovations. The new gales of innovation are in fact but the result of the convergent and complementary search activity of a variety of agents who search for new technologies that enable them to contrast the decline in profitability. The new gales can emerge only when a myriad of agents characterized by the variety of competences and localized knowledge is able to engage in a myriad of complementary actions of exploration and search.

The generalized decline in profitability and the complementarity among individual search activities stemming from the intrinsic indivisibility of knowledge and favors the emergence of collective knowledge pools and hence the chances of introduction of radical innovations. The causal relationship between profitability and innovation acquires in *Business Cycle* an aggregate dimension.

In *Capitalism socialism and democracy* (1942), Schumpeter identifies the large corporation as the driving institution for the introduction of innovations. The corporation is itself an institutional innovation that favors the introduction of technological innovations for many reasons. As a large literature has stressed, the corporation can use the barriers to entry as a barrier to imitation. The risks of uncontrolled leakage of proprietary knowledge in fact are reduced when the innovator enjoys the benefits of economies of scale and absolute cost advantages so that new competitors might imitate but cannot actually enter the market place.

Schumpeter is very clear in stressing the role of the corporation as a superior allocation and selection mechanism that reduces the inefficiency of financial markets in the provision of funds to innovative undertakings and increase the matching between competence and resources available to develop new technologies. Schumpeter regards the corporation as a hierarchical system that makes it possible the coordinated working of internal markets where financial resources matched with competence can be fueled towards risky but innovative undertakings.

Within the corporation the resources extracted by the extra-profits match the competences of skilled managers and the vision of potential entrepreneurs. The Schumpeterian corporation can reduce the intrinsic failure of competitive markets in the allocation of resources to research, in the identification of the proper level of rewards and hence incentives to the introduction of innovations. The corporation is an effective institution able to substitute the financial markets in the provision and allocation of funds to innovative activities because it combines financial resources and learning with entrepreneurial vision within competent hierarchies, provided that extra-profits can be earned and a consistent share is directed towards the generation and introduction of innovations (Penrose 1959).

It seems clear that the careful reading of the full range of contributions of Schumpeter suggests that the two articles published in 1947 do synthetize and frame the results of the long-term evolution of his thinking from the onset elaborated in *The theory of economic development* (1934). Building upon this Schumpeterian legacy we can try and articulate the hypothesis that firms try and innovate both when their profits fall below satisfying levels and when profitability provide the resources to use systematically innovation as a competitive tool. Here it is clear that the higher are the profits and the larger the opportunities to use a share to fund research activities and hence to increase the rates of introduction of new technologies.

The appreciation of the Schumpeterian notion of creative response and the identification of out-of-equilibrium conditions in: a) the reappraisal of the Marxian analysis of the role of the decline in profitability in pushing firms to innovate as a key component of the augmented induced technological change approach, b) the failure-induced approach elaborated by Schumpeter in Business Cycles, c) the reconsideration of the Schumpeterian analysis of the extra-profits associated with the corporation as an institutional engine for continual introduction of innovations, d) the appreciation of the role of extra-profits in providing incentives and opportunities to firms to innovate in the demand pull hypothesis; provides the basic tools to articulate the hypothesis of a causal relationship between profits above and below the norm, interpreted as indicators of out-of-equilibrium conditions, and innovation.

The focus on the relationship between profitability and innovation provides key elements to integrate into a single frame the different hypotheses articulated in the literature about the endogenous determinants of innovations. Table 2 summarizes the main results and shows that the hypothesis of a non-linear relationship can be considered the integrative device.

TABLE 2. PROFITABILITY AND INNOVATION: AN INTEGRATIVE FRAMEWORK

	PROFITABILITY BELOW THE AVERAGE	PROFITABILITY ABOVE THE AVERAGE
CLASSICAL INDUCEMENT	The increase in factor costs engenders the fall in profitability that induces the introduction of innovations	
DEMAND PULL		The increase in demand engenders the increase in profitability that pulls the introduction of innovations
SCHUMPETER: 'BUSINESS CYCLES'	Recession engenders the generalized fall of profitability that induces the collective search for new technologies	
SCHUMPETER: 'CAPITALISM SOCIALISM AND DEMOCRACY'		Barriers to entry and to imitation favor the duration of extraprofits and provide large corporations with the opportunity to fund R&D activities

Localized technological change
The localized technological change approach enables to integrate into a single framework the appreciation of the Schumpeterian notion of creative response and the identification of the role of out-of-equilibrium conditions as causal factors of the decision to innovate. The causal relationship between the levels of performances and the decision to innovate has been outlined in: a) the reappraisal of the Marxian analysis on the role of the decline in profitability in pushing firms to innovate as a key component of the augmented induced technological change approach, b) the failure-induced approach elaborated by Schumpeter in Business Cycles, c) the reconsideration of the Schumpeterian analysis of the extra-profits associated with the corporation as an institutional engine for the continual introduction of innovations, d) the appreciation of the role of extra-profits in providing incentives and opportunities to firms to innovate in the demand pull

hypothesis. These legacies provide the basic tools to articulate the localized technological change hypothesis of a causal relationship between performances above and below the norm, interpreted as indicators of out-of-equilibrium conditions, and innovation. In this approach innovation and competition are two intertwined aspects of a localized discovery process that enables firms to identify local and transient solutions in ever changing contexts (Hayek, 1968).

In the localized technological change approach agents are characterized by bounded and procedural rationality. Bounded rationality limits their global search in knowledge space. Procedural rationality constraints their search for new technologies in the proximity of the techniques already in use. Moreover firms are reluctant to change their routines, their production processes, the networks of suppliers and their marketing activities as much as their goals. Each of these changes, in fact, entail come costs, requires additional knowledge and engenders substantial risks. In equilibrium conditions, firms are reluctant to innovate.

Myopic firms try and innovate only when are faced with changes in the expected state of the world as generated by changes in both product and factor markets. Innovation is induced by the mismatch between unexpected events that myopic agents cannot fully anticipate and the irreversible decisions that need to be taken at any point in time. Substantial irreversibility qualifies their stocks of tangible and intangible capital. Out-of-equilibrium conditions and the mismatch between belief and related plans and actual product and factor market conditions push firms to try and modify the decisions that had been taken and the related irreversibilities. Switching costs are necessary in order to cope with the strong and weak irreversibilities that characterize the fixed capital and the reputation of the firm, its location in geographical, technical, and knowledge space, the relations with customers and providers of inputs, the skills of employees and the competence acquired. Switching costs engender opportunity costs. Firms try and innovate in order to save on switching costs. In order to innovate, however, firms need to mobilize their competence and extract new technological knowledge from structured interactions with other creative agents (Antonelli, 1995).

In order to face the switching costs stemming from the mismatch between beliefs and expectations on the one hand and actual performances on the other, firms rely on their competence. Competence is based upon learning processes. Agents in fact are able to learn by doing and by using: their competence is rooted in their historic context of action. Hence agents are localized and rooted in a limited portion of the geographic, technological, knowledge and competence space. Firms induced to innovate by irreversibility and disequilibrium in both products and factor markets search locally for new technologies.

Profitability levels stir the Schumpeterian creative response of firms. Firms are pushed to try and innovate and hence to search for new products and processes by the combined effects of incentives and opportunities that emerge when out-of-equilibrium conditions prevail. The levels of profitability are a clear and non-ambiguous indicator of the proximity to equilibrium conditions. While normal profits signal that the system is in equilibrium, both profits below and above the norm signal that the firm is away from equilibrium conditions. The larger is the variance of the levels of profitability and the stronger the conditions of out-of-equilibrium at the system level. The larger is the difference between the specific profit levels of each firm and the normal profitability and farther away are the local conditions from equilibrium.

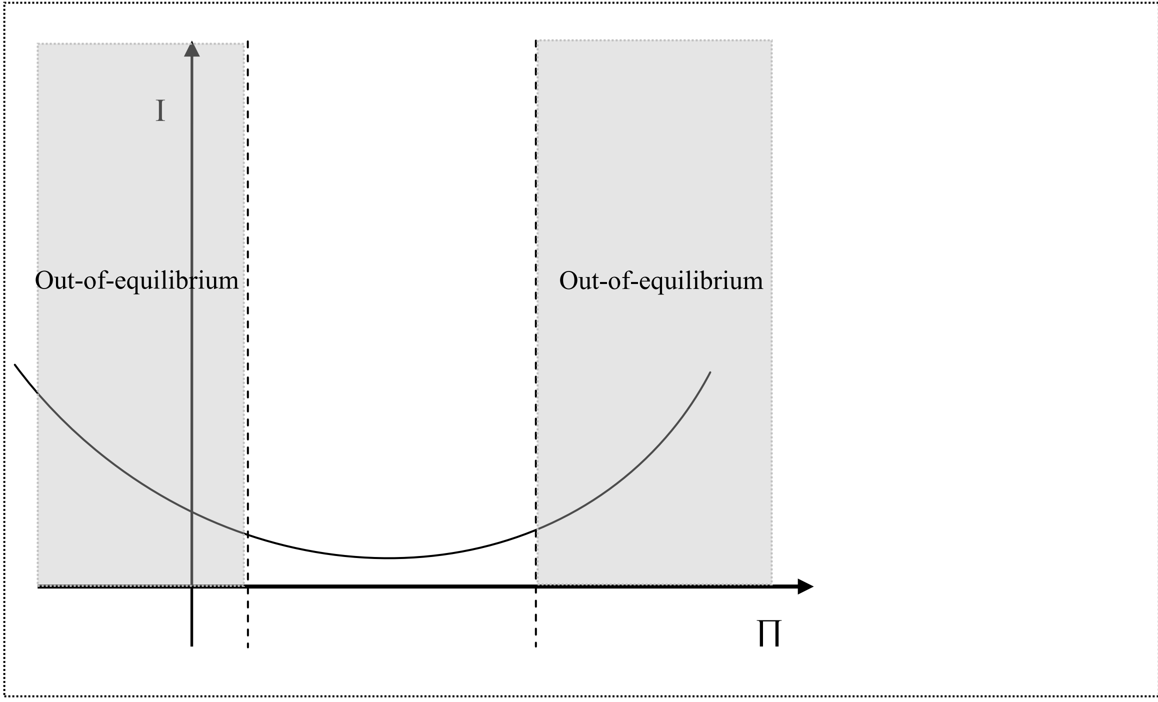
When the profits are below the norm and actually fetch negative values in absolute terms, firms understand that their survival is at stake. The low levels of profitability engender risks of survival that push firms to try and innovate. The intentional and explicit generation of new technological and organizational knowledge becomes necessary. To do so firms are induced towards an array of new routines such as the funding of research and development activities, the valorization of the tacit knowledge acquired by means of learning processes, the exploitation of external sources of new technological knowledge, the adoption and creative adaptations of new production processes and new products.

At the other extreme it is clear that the increase in demand engenders high levels of profits that provide firms with the incentives and the opportunity to introduce innovations. The resistance to change is much lower when organizations are performing and the abundance of resources makes it possible to identify the perspectives for new profitable ventures. Here change is intrinsically intertwined with growth and development, hence with new opportunities of upgrading for the members of the organization and for decision-makers. In product markets where workable competition prevails, and monopoly can be excluded, high profits signal conditions out-of-equilibrium associated with unexpected changes in either product or factor markets that enable firms to gain extra-profits, at least in the short term. Firms with high levels of profits are often characterized by dynamic capabilities and flexible organizations that have already being able to generate new technological knowledge and to introduce technological innovations (March and Simon, 1958; Penrose, 1959).

When profits are in the norm, firms have neither the incentives nor the opportunity to try and innovate. Internal resources to finance research and development and the eventual introduction of new prototypes are missing. At the same time inertia and resistance to change are not questioned, as managers do not feel the need to change the current state of their activities. The opportunity costs of risky undertakings whose failure might compromise the equilibrium of the company are very high. Product and factor markets should be close to condition of perfect competition: hence firms have little opportunities to exploit their innovations. Knowledge can hardly be appropriated and imitators can benefit of the knowledge generated by third parties. Credit rationing limits the access to financial resources that are necessary to generate new technological knowledge and to introduce technological innovations (Fazzari and Petersen, 1993; Bloch, 2005).

Assuming that workable competition characterizes the market place, and no monopolistic conditions can be identified, the causal relationship between profitability and innovation can be specified by a quadratic function: with low profits, below the average, including losses, firms have a strong incentive to innovate; with high profits above the norm, firms have important opportunities to fund research activities and hence innovate; firms with normal profits miss both incentives and opportunities. The basic argument is that combination of incentives and opportunities provides the basic mix of determinants to innovate. In the first case a failure inducement mechanism is at work: firms are induced to try and change their technologies and their organization when profits fall below a minimum threshold and their survival is put at risk. In the second case, incentives are lower but the opportunities for firms that enjoy extra-profits are strong. Firms can fund risky activities with a share of extra-profits and hence overcome the severe rationing of financial markets in the provision of resources for undertaking innovative activities. Firms with extra-profits moreover can guide internal markets by means of competent hierarchies so as to match financial resources, competence and innovative ideas. Firms with normal profits have both lesser incentives and opportunities to innovate.

FIGURE 1. THE QUADRATIC RELATIONSHIP BETWEEN PROFITS AND INNOVATION



The relationship between profit and innovation is shaped in Figure 1 where on the vertical axis I indicates the levels of innovation activity and on the horizontal axis ∏ stands for the levels of profitability. Figure 1 represents the basic argument according to which the rates of innovation are likely to be higher the farther away are the profitability levels of firms from equilibrium conditions. The grey regions identify the conditions of out-of-equibrium, as measured by the levels of profitability with respect to average values, where profitability is below and above the average.

With low profitability levels, fetching negative values, firms have a strong failure-induced incentive to innovate. Their survival is at risk. All the resources need to be mobilized in order to change the current state of activities, stop losses and introduce technological and organizational innovations that make it possible to increase their total factor productivity and hence to restore their competitivity.

Firms with profitability in the average have no incentives and no opportunities to innovate. Rational decision-making inhibits the assumption of actions in domains that are characterized by radical uncertainty such as innovative undertakings, for the well-known problems of unpredictability both in their generation and exploitation.

Finally, when firms enjoy extra-profits, at levels that are above the normal profitability, managers have the opportunity to fund research and innovative activities with their own internal funds. After payments of hefty dividends, managers can retain sufficient funds to undertake innovative projects designed to stretch the duration of market power. Extra-profits provide the opportunity to fund innovative activities and signal the existence of barriers to entry that increase de-facto the chances of appropriability of the stream of benefits stemming from the introduction of successful innovations.

In out-of-equilibrium the rent-seeking intentionality of agents overcomes their inertia and reluctance to try and innovate. Clearly our hypothesis is complementary to the so-called Schumpeterian Hypothesis about the relations between competition and innovation. It is clear in fact that when high profitability is associated with monopolistic conditions, firms have no incentives to try and innovate; when low profits are associated with cutthroat competition firms have not the possibility to try and innovate[2]. At the same time, however, our argument actually extends and qualify the Schumpeterian Hypothesis because oligopolistic rivalry and workable competition are indeed likely to stir the creative response of firms, and hence to push firms to try and innovate, but only when profits are either below or above the norm.

Antonelli and Scellato (2011) have tested the hypothesis of a U-relationship between levels of profitability and innovative activity, as measured by the rates of increase of total factor productivity, on the evidence of a large sample of 7000 Italian firms in the years 1996-2005. The results are robust to different approaches to evaluate productivity growth rates and confirm that a strong causal relation holds between the quadratic specification of profitability and the growth rates of total factor productivity.

Firms can introduce productivity enhancing innovations, however, only if they can rely upon the web of knowledge interactions and externalities that qualify their localized space to activate the recombinant generation of new technological knowledge: much of their actual innovative capability is shaped by their context of action. The quality of the context plays a key role

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[2] The so-called Schumpeterian hypothesis recently received new attention in the context of the new growth theory. This new literature has investigated the relationship between competition and innovation with contrasting results. Aghion and Howitt (1992) at first confirmed the Schumpeterian hypothesis according to which there is a negative correlation between competition and innovation, as measured by the intensity of R&D efforts. Subsequently Aghion and Howitt (1999), however, changed their mind and elaborated the view that competition should push firms to innovate. Finally Aghion et al. (2004) elaborated a compromise, suggesting that an inverted U shaped relation between competition and R&D expenditures might apply. The original findings of Scherer (1967) and Dasgupta and Stiglitz (1980) were confirmed after a long debate.

in assessing the actual possibility that the reaction of firms is creative, rather than adaptive.

4. FROM KNOWLEDGE SPILLOVERS AND INTERACTIONS TO KNOWLEDGE EXTERNALITIES

The knowledge external to the firm, at each point in time, is a necessary and relevant complement to knowledge internal to the firm, in order to generate new knowledge. The access conditions to external knowledge are a key conditional factor in assessing the chances of generation of new knowledge. The generation of new knowledge is the specific outcome of an intentional conduct and requires four distinct and specific activities: internal learning, formal research and development activities, and the acquisition of external tacit and codified knowledge. Each of them is indispensable. Firms that have no access to external knowledge and cannot take advantage of essential complementary knowledge inputs can generate very little, if no new knowledge at all, even if internal learning combined with research and development activities, provides major contributions. Also the opposite is true. Firms that do not perform any knowledge generating activity but have access to rich knowledge commons can generate no new knowledge.

The context into which firm try and innovate plays a key role to make the actual introduction of productivity enhancing innovations possible. Without an appropriate context that enables the access to external knowledge, the reaction of firms fails to be creative and remains merely adaptive (Antonelli, 2007).

The appreciation of the key role of the context into which firms try and innovate is the result of an articulated process initiated with the identification of knowledge spillovers, eventually implemented by the notion of knowledge interactions and finally articulated in the notion of knowledge externalities. Let us consider them in turn.

Knowledge spillovers

The notion of knowledge spillovers has been introduced by Zvi Griliches (1979) to provide an analytical context into which the wide gap between the private and social returns of R&D expenditures could be explained. Because of low appropriability of knowledge, firms fund R&D activities but can appropriate only a fraction of the total benefits. Other firms however can take advantage of the knowledge spilling in the atmosphere. Griliches was able to appreciate the reverse side of the non-appropriability coin and to highlight its positive effects.

As a matter of fact knowledge spillovers are a direct application of the notion of technological externalities to the economics of knowledge and enable to grasp the effects of the spontaneous availability of production factors at no costs within a given production function (Meade, 1952). Knowledge spillovers do not require any transaction between the producers and the recipients of the external effects: they can be considered a characteristic of the 'atmosphere' of the districts into which firms are based. Knowledge spillovers affect the knowledge production function as they enable to account for a unpaid production factor consisting in the availability of external knowledge (Antonelli, 1999).

It seems more and more evident that the new growth theory impinges upon and elaborates the notion of knowledge spillovers initiated by Griliches. The new growth theory in fact has enriched and articulated the hypothesis that knowledge is a production factor spilling in the atmosphere of industrial districts. In this perspective the distinction between specific and generic knowledge is crucial. While specific knowledge is embedded in organizations and can be successfully appropriated by 'inventors'; generic knowledge is expected to spill freely in the atmosphere, with no costs for perspective users neither to acquire nor to use it. Generic knowledge spills in the atmosphere like manna: it can be accessed with no, search, transaction, interaction and communication costs (Romer, 1989 and 1994).

Substantial empirical investigations upon knowledge spillovers have made it possible to appreciate important qualifications about the characteristics of the localized context into which spillovers are found.

The application of the distinction between inter-industrial and intra-industrial externalities has been most useful. Intra-industrial spillovers, derived from MAR externalities, stress the horizontal complementarity of firms active within the same industry. When knowledge complementarity matters, firms participate to implementing a common knowledge base and each can profit from the advances of the other members of the same industry. Jacobs spillovers (Jacobs, 1969) identify the complementarity of firms across industries. Inter-industrial flows of knowledge are most relevant when vertical flows of knowledge across many industrial filieres are relevant for the knowledge generation in a single downstream industry. The reverse also applies and takes place when the knowledge spillovers of a single industry upstream have a wide scope of application across a wide variety of industrial activities such as in the case of general purpose technologies. It is clear that the industrial structure of an economic system here plays a key role in assessing the actual flows of knowledge spillovers: holes and weaknesses in the vertical and horizontal mix of industries can play a critical role in the provision of knowledge spillovers (Audretsch, Feldman, 1996).

Spillovers are mainly local because their effects are circumscribed within a limited ray of action: proximity matters. Proximity however has several dimensions. Indeed proximity in geographical space favors the dissemination of knowledge spillovers. Proximity in knowledge space however also matters as it favors the sharing of knowledge codes. In general distance in multidimensional space has strong negative effects upon the density, reliability, symmetry, recurrence and quality of knowledge spillovers (Feldman, 1999).

The rich empirical evidence gathered, however, has progressively made clear that knowledge spillovers do not take place freely in the atmosphere: interactions are necessary and crucial for the dissemination of knowledge to take place (Cohen and Levinthal, 1990).

From social interaction to knowledge interactions

The study of interactions is a growing field of economics and more specifically of the economics of complexity. The relations among agents in the economic system do not take place only in the markets and do not coincide only with market transactions. Transactions occur in the market place and are impersonal, punctual as opposed to recurrent, and individual. The notion of transaction does not apply within organizations where relations are recurrent and personal and take place in an organized context characterized by hierarchical relations. When interactions matter, prices are no longer the single vectors of all the relevant information for decision-makers. The notion of transaction is not sufficient to exhaust the variety of relations that take place within markets including organized transactions i.e. transactions that are made possible by complementary interactions and the exchanges of goods are mediated by personal and recurrent contacts and contracts.

When agents are credited with no capability to change endogenously their production and utility functions, transactions are the most important, if not the single form of interaction that economics study. When instead agents are credited with the capability to learn and to innovate, and hence to change their production and utility functions, other forms of relations, beyond transactions, become relevant.

Interactions have important effects on the behavior of agents, especially when we assume that the structure of the preferences of agents on the demand side and the structure of technological knowledge of producers is endogenous and exposed to mutual influence. Interactions are a specific form of interdependence whereby the changes in the behavior of other agents directly and explicitly affect the structure of the utility functions for households and of the production functions for producers (Durlauf, 2005). As Glaeser and Scheinkman state:" Each person's actions change not only because of the direct change in fundamentals, but also because of the change in behavior of their neighbors" (Glaeser and Scheinkman, 2000:1).

Interactions are a fundamental ingredient of complex dynamics. According to David Lane, complex economic dynamics takes place when the propensity to undertake specific actions of a set of heterogeneous agents changes because of their interactions with one another within structured networks.

Models of interactions have been used to analyze a variety of empirical contexts ranging from unemployment, from stock market crashes to crime, from the endogenous change of preferences to the generation of new technological knowledge. The correlated actions among interacting agents induce amplified responses to shocks. Interaction multipliers are the result of positive feedbacks (Arthur, 1990).

As a matter of fact social interaction had been widely used in the economics of innovation. The epidemic tradition of analysis of the diffusion of innovations, initiated by Zvi Griliches (1957) is based upon the notion of social interactions defined as contagion. In the epidemic tradition contagion takes place by means of interactions and it is considered as a mechanism of dissemination of information. Potential users become aware of new goods and of their superior characteristics, with respect to existing goods, by means of social interactions. Social interactions spread information about the new goods and convince reluctant adopters about the advantages. The reputation of lead users may add on the informational effects and provide incremental incentives to potential users to actually adopt the new goods. Late adopters can be considered as rational users that save on information and search costs (Lane, Arthur, 1993; Lane, Vescovini, 1996).

Recent advances in the analysis of diffusion processes have stressed the role of the structure of interactions. When the probability of interaction in the population of potential users, one of the key parameters of the logistic equation that is at the heart of by the epidemic approach, is assumed to have a Pareto distribution, as opposed to a normal one, it is sufficient that a few lead adopters have a large number of social interactions to spread the epidemic contagion to a large number of potential users so as to accelerate the speed of the process that is no loner bound to follow a S-shaped process. The analysis of the working of Internet networks has in fact provided large evidence about the key role of hubs within scale-free networks that support very large number of connections and enable information to reach instantaneously a wide range of connected users. The analysis of scale-free networks shows how important is the structure of social interaction to grasp their role in the dissemination of information (Barabàsi and Albert, 1999).

The application of interaction models seems most appropriate to explore the role of external tacit knowledge in the generation of new knowledge. Tacit knowledge in fact can be accessed only by means of personal communications and direct interactions that cannot be analyzed with the exclusive notion of transaction[3].

The results of the empirical analyses of Lundvall (1985) and Von Hippel (1976 and 1998) on the key role of user-producers interactions as basic engines for the generation of new technological knowledge and the eventual introduction of new technologies confirm the relevance of the vertical interactions, both upstream with providers and downstream with customers, that complement market transactions among heterogeneous agents in the generation of knowledge.

The literature on interactions suffers from two limitations: a) it does not consider the active and selective role of interacting agents; b) it does not consider the effects on costs and revenues of interactions.

As a matter of fact interactions, in general, and specifically knowledge interactions, are not free and do not fall like manna from heaven. Perspective users of knowledge interactions are not just passive recipients. Perspective recipients must act in order to benefit from knowledge interactions. The pursuit of knowledge interactions may be at the origin of mobility in space or of the creation of communication channels.

A cost of knowledge interactions should be identified. It consists of the networking efforts and resources that are necessary to activate and profit form them. Knowledge interaction costs are clearly influenced by the

[3] Systematic empirical investigations have explored the role of social interactions in the generation of technological knowledge (Griffith, Redding,Van Reenen, 2003; Lokshin, Belderbos, Carree, 2008). Antonelli and Scellato (2008) have applied the methodology of social interaction to test the role of knowledge spillovers at the territorial level and show how external knowledge made available by intra-industrial and inter-industrial interactions have a direct effect on total factor productivity levels of firms. They present an empirical analysis of firm level total factor productivity (TFP) for a sample of 7020 Italian manufacturing companies observed during years 1996-2005 and show that changes in firm level TFP are significantly affected by localised knowledge interactions. Such evidence is robust to the introduction of appropriate regional and sectoral controls, as well as to econometric specifications accounting for potential endogeneity problems. Moreover, they find strong empirical evidence suggesting that changes in competitive pressure, namely the creative reaction channel, significantly affect firm level TFP with and additive effect with respect to localised social interactions deriving from knowledge spillovers.

location of each firm with respect to other. Knowledge interactions provide firms with an essential and indispensable input into the generation of new technological knowledge, at costs that are influenced by the network structure of relations among firms. The structure of interactions plays a key role in assessing their effects upon the system. Hence the analysis of knowledge interactions should consider both their costs and their actual effects, as shaped by their structure. Once again the issue of intentionality matters: agents that decide to interact are aware of the outcomes in terms of opportunity costs and possible revenues: interactions are an economic matter. Interactions are discretionary and selective: agents select those with whom they enjoy to interact and those with whom they prefer not to interact.

An important step forward can be made when we appreciate the complementarity between knowledge interactions and knowledge transactions. Knowledge transactions are possible only because of the fabric of knowledge interactions that reduce the intrinsic information asymmetry that characterizes agents with respect to the generation and exploitation of knowledge. As a matter of fact interactions make transactions possible. With no interactions, knowledge transactions are quite difficult and actually impossible: markets for knowledge require interactions to become possible.

When attention is focused upon the knowledge generation process and the role of knowledge externalities in the provision of knowledge is appreciated as a key factor combined with the intentional participation of the recipients, the notion of pecuniary knowledge externalities overlaps significantly with the notion of knowledge interaction. Pecuniary knowledge externalities provide an effective tool to analyze the costs and the effects of interactions.

Pecuniary knowledge externalities

The analysis of knowledge as both an input and an output and the appreciation of the costs and benefits of knowledge interactions call the attention on the notion of pecuniary knowledge externalities (Antonelli, 2008a).

In the Marshallian tradition the notion of externalities has been rooted on the supply side for quite a long time and provides an interesting device to accommodate the evidence of increasing returns without destroying the basic foundations of standard microeconomics at the firm level. Since the early Marshallian identification, externalities have received considerable attention. As a consequence many different kinds of externalities have been identified according to the specific characteristics of the external effects and the processes by means of which they take place.

Externalities owe their name to the Marshallian analysis of the causal role of factors external –as opposite to internal factors- to the firm, in the explanation of increasing returns. Externalities indeed account for factors that are external to the each firm, but by no means external to the system. On the opposite they are the result of the emergence and possibly decline of the idiosyncratic characteristics of the system into which firms are embedded and that the action of firms consisting both in market strategies and in the introduction of innovations has generated. The analysis of knowledge externalities provides a clue to grasping their endogenous and dynamic character (David, Foray, Dalle, 1995).

Recently, a new attention has been paid, in the economics of knowledge, to the distinction introduced by Meade (1952) and Scitovsky (1954) upon two quite different types of 'Marshallian externalities: a) technological externalities and b) pecuniary externalities. Technological externalities consist of direct interdependences among producers. Pecuniary externalities qualify the effects of external conditions upon the full range of prices of both inputs and outputs. According to Scitovsky, pecuniary externalities consist of the indirect interdependences among actors that take place via the price system. Pecuniary externalities apply when firms acquire inputs (and sell output) at costs (prices) that are lower (higher) than equilibrium levels because of specific structural factors (Antonelli, 2008a and b).

Pecuniary externalities consist of indirect interdependence, mediated by the market mechanisms, via the effects on the price system. Pecuniary externalities exert an effect both on the cost of production factors and the price of products. Positive pecuniary externalities are found when the latter are below the equilibrium levels. More precisely, while technological externalities take place when unpaid production factors enter the production function of users, pecuniary externalities apply when the cost and prices of both products and factors differ from equilibrium levels and reflect the effects of external forces. Pecuniary externalities affect the knowledge production function as well as the knowledge cost and the revenue functions and consequently have a clear effect on knowledge profit functions.

Pecuniary knowledge externalities enable to analyze the dynamics of external knowledge in its acquisition, use for the generation of new knowledge and exploitation. Let us analyze these aspects in turn.

The acquisition of external knowledge is the result of a long exploration process that includes such activities as search, screening and identification of other knowledge items. External knowledge can be accessed and eventually used in the generation of new knowledge only after dedicated resources have been invested in such activities. Knowledge interactions are not free. On the other hand, although external knowledge can be purchased the acquisition of external knowledge cannot take place without the building of dedicated knowledge governance mechanisms whereby transactions are possible only if implemented and complemented by significant interactions.

As far as knowledge generation is concerned we see that the analysis of knowledge externalities enables the appreciation of the effects of the external context on the actual costs of external knowledge including both interaction, transaction and purchasing costs and on the intentional decision-making of firms in the combination of internal and external knowledge inputs in the production of new knowledge. When knowledge externalities are important firms have a clear incentive to rely more on external rather than internal knowledge inputs in the generation of new knowledge.

Finally knowledge exploitation is affected by external effects insofar the price of knowledge as an output, as well as the opportunities for exclusive exploitation in the downstream application of new technological knowledge to introduce technological innovations, is considered.

Pecuniary knowledge externalities make it possible to appreciate the effects of transactions-cum-interactions that characterize the full range of aspcctes that qualify external knowledge including leakage, access, use and exploitation. Neither aspect involves either pure transactions or pure interactions. Hence neither analysis based upon sheer knowledge transactions, nor analyses based upon sheer knowledge interactions are sufficient to grasp the complex dynamics of intentional actions that characterize the use of knowledge as an external and yet indispensable input in the production of new knowledge.

Pecuniary knowledge externalities enable to grasp the combined effect, upon the intentional decision-making of creative agents, of the full range of differences between actual and equilibrium levels both in the access, use and purchasing costs and selling prices and actual exploitation conditions of the different forms of knowledge respectively as inputs and outputs.

Firms located within a geographical and knowledge region where a concentration of knowledge intensive activities is found, benefit from the reduction in the cost of exploration of external knowledge. Proximity favors the creation of communication channels and networks where knowledge interactions are easier. Pecuniary knowledge externalities account for the reduction in the actual cost for external knowledge: proximity, both in regional and knowledge space, improves the working of organized markets for knowledge and reduces transaction costs. As far as knowledge exploitation is concerned, we see that pecuniary knowledge externalities make it possible to grasp the effects of the external context on the prices of knowledge outputs. These effects may be negative when knowledge appropriability is considered. Agglomeration and proximity may reduce knowledge appropriability and exclusive exploitation. Such circumstances vary across the specific context of action of firms and do not hold everywhere and at all time, but only in highly idiosyncratic conditions (Antonelli, 2005).

A knowledge profit function with knowledge externalities enables to grasp not only the full range of factors affecting the access to external knowledge, but also both positive and negative effects of the external context into which such activities take place. Pecuniary knowledge externalities make it possible to appreciate both the positive and negative effects of the external context and their interplay as they apply not only to knowledge generation but also to knowledge exploitation and hence not only to knowledge production functions as well as to knowledge cost and revenue functions. Hence a knowledge profit function that integrates the working of pecuniary knowledge externalities, provides the tools to consider both the positive effects of knowledge externalities in terms of lower interaction, access, transaction and purchasing costs of some knowledge inputs and their negative ones in terms of reduced appropriability of knowledge as an output and exclusive exploitation hence reduction of the prices for the downstream products that embody new proprietary knowledge (Antonelli, 2010c).

The new appreciation of the dynamic effects of knowledge externalities, in terms of determinants of the actual capability to introduce new technologies, has pushed more recently much effort to understanding their structural determinants, such as the size distribution of the agents, the size of the agglomeration, the network structure of the relations, the distribution of the agents in the space, that qualify the context into which the external effects take place. The notion of threshold becomes central: below (above) some thresholds external effects may be positive (negative). Minimum and maximum levels can be identified with important consequences for understanding how the changing structure of innovation systems has a direct bearing on the rate and direction of technological change (Antonelli, Patrucco and Quatraro, 2008 and 2010).

The analysis of the role of the non-divisibility of knowledge in its generation has made it possible to identify three distinct characteristics of knowledge: knowledge cumulability, knowledge compositeness and knowledge fungibility. Knowledge cumulability takes place when new knowledge is the result of the diachronic complementarity of different vintages of knowledge. When knowledge is composite, new knowledge is generated by the recombination of bits of knowledge that belong to a variety of different fields. Finally, fungibility defines the downstream complementarity of any bit of knowledge. The same core of technological knowledge and competence can be applied to the production of a wide range of new fields.

This variety of knowledge generation processes has important implications for the analysis of knowledge externalities: each of them in fact highlights and stresses a facet of the complex architecture of relations, ranging from transactions to interactions, that matters. The study of externalities and specifically of knowledge externalities enables to grasp the relevance of the structural architecture of the system.

Knowledge externalities are essential to identify the conditions of organized complexity for which the system can attain the dynamic efficiency. Knowledge externalities in fact define the context into which effective generative relations can take place so that the reaction of firms can become creative.

In this context, the notion of the generative relationship introduced by David Lane and Robert Maxfield (1997) is crucial. Generative relationships are constructive positive feedbacks that lead to the introduction of innovations, and innovations feed structural change in agent/artifact space. The process takes place through a ‘bootstrap’ dynamics where new generative relationships induce attributional shifts that lead to actions that in turn generate possibilities for new generative relationships. The structural characteristics of the system in terms of the distribution of agents in multidimensional spaces, of their networks of communication, relationship and interactions qualified by aligned directedness, heterogeneity, mutual directedness, permissions and action opportunities, are key elements for the sustainability of the process.

The actual conditions of knowledge externalities define the context into which complex economic dynamics takes place. Only when knowledge externalities are available, in fact, the propensity of a set of heterogeneous agents to undertake specific actions, as a form of reaction to unexpected events, can lead to the actual introduction of innovations, because of their interactions with one another within structured networks.

5. LOCALIZED TECHNOLOGICAL KNOWLEDGE AND THE EMERGENCE OF INNOVATION AS A SYSTEM PROPERTY

The appreciation of the role of intentional decision-making in the generation of new knowledge and of the central role of learning processes and external knowledge qualifies the localized approach. Firms induced to innovate by irreversibility and disequilibrium in both product and factor markets search locally for new technologies. Procedural rationality, as opposed to Olympian rationality, and localized competence based upon learning processes, limit the global search of firms and constraint their search for new technologies in the proximity of the techniques already in use, upon which learning by doing and learning by using have increased the stock of competence and tacit knowledge. Both the rate and the direction of technological change are influenced by the search for new technologies that are complementary to existing ones. The quality of the context plays a key role in assessing the actual possibility that the reaction of firms is creative, rather than adaptive. In this approach the introduction of innovations and new technologies is the result of a local search, constrained by the limitations of firms to explore a wider range of technological options. This dynamics leads firms to remain in a region of techniques that are close to the original one and to continue to improve the technology in use.

The generation of new technological knowledge is the result of an intentional activity based upon four distinct and complementary inputs such as learning, research and development, and the access to both tacit and codified external knowledge. Each of them can be substituted only to a limited extent. In order to generate new technological knowledge firms must rely upon each of them and act as a system integrator (Antonelli, 1999).

In the localized technological knowledge framework of analysis, learning is the primary and indispensable source of competence and tacit knowledge. As a consequence firms are rooted in a limited portion of the knowledge space defined by the context into which their learning processes have been taking place, both in doing, in using and in interacting. Consequently no firm can command the full range of knowledge items that are necessary to generate new knowledge. Consequently no firm can innovate in isolation (Antonelli, 2001).

External knowledge is an essential input into the generation of new knowledge. External knowledge can be substituted to internal sources of knowledge only to a limited extent: full-fledged substitutability between internal and external knowledge cannot apply. With proper access to external knowledge firms can complement their localized, internal competence and actually introduce new technologies. Only when a complementary set of knowledge fragments is brought together within a context of consistent interactions, successful innovations can be introduced and adopted: technological knowledge is the product of a collective activity. The access conditions to external knowledge are a key conditional factor in assessing the actual chances of generation of new knowledge. Firms that have no access to external knowledge and cannot take advantage of essential complementary knowledge inputs can generate very little, if no new knowledge at all, even if internal learning and research activities provide major contributions (Antonelli, 2003).

The reaction of firms localized in a poor context, unable to provide appropriate flows of pecuniary knowledge externalities will not be able to generate new productivity enhancing technologies and will just adaptive: firms will move in the existing map of isoquants or introduce small changes that enable the introduction of technical change based upon substitution. Innovation will emerge as a system property when the reaction of firms, supported by the access to collective knowledge, will become actually creative and consist of the introduction of productivity enhancing technological changes that reshape the map of isoquants when their internal knowledge matches the availability of appropriate sources of external knowledge and is the result of a process of knowledge recombination.

The recombinant generation of technological knowledge

Technological knowledge internal to each firm is localized in a limited portion of the knowledge space by the learning processes that are at the origin of its accumulation: the key role of learning and tacit knowledge roots and limits the span of command of the firm in the knowledge space. In order to generate new knowledge the firm must identify other bits of complementary knowledge and recombine them with the internal one. The notion of recombinant knowledge qualifies the nature of the knowledge production activity (Antonelli, 2008; Antonelli, Krafft, Quatraro, 2010).

The recombinant knowledge approach complements and integrates the analysis of external knowledge and localized technological knowledge. As Weitzman (1996: 209) recalls: "when research is applied, new ideas arise out of existing ideas in some kind of cumulative interactive process that intuitively has a different feel from prospecting for petroleum". As Arthur (2009:21) notes: " novel technologies arise by combination of existing technologies and …therefore existing technologies beget further technologies….". This insight leads to the recombinant growth approach which views new ideas as being generated through the recombination of existing ideas, under the constraint of diminishing returns to scale in the performance of the research and development (R&D) activities necessary to apply new ideas to economic activities (Weitzman, 1998).

A large literature on biological grafting has applied the so-called NK model in the economics of knowledge. According to Kauffman (1993) the success of a search process depends on the topography of a given knowledge landscape shaped by the complementary relations (K) among the different elements (N) of a given unit of knowledge. In the NK model, the features of the topological space within which the economic action that leads to the generation of new technological knowledge takes place, are not characterized from an economic viewpoint. Rather, the number of complementary relations and their distribution are given, as are the number of elements belonging to each unit of knowledge. As frequently occurs when biological metaphors are grafted onto economics, this is compounded by the fact that the number of components and their relations are exogenous and there is little economic analysis of their associated costs and revenues.

This approach can be implemented as soon as the characteristics of the knowledge space into which eventual recombination may take place are appreciated: some regions of the knowledge space are more fertile than others. Recombinations are seen as the products of a combinatorial engine where the location in knowledge space of each agent possessing the bits of complementary knowledge plays a key role in shaping the recombinatory process. In this view, recombination does not take place as if it were the product of a random process. On the opposite, recombination is guided by the intentional action of perspective agents seeking to solve the specific problem they are facing and is shaped by their distribution in knowledge space. Proximity in knowledge space matters as much as the actual intentionality of agents to try and change their own technologies and to participate into the recombination. Passive agents are not likely to join the recombinatory process. New technologies are the result of a recursive process of recombination of the bits of knowledge possessed by intentional agents distributed in a map that evolves together with the technology itself.

The new economics of knowledge suggests that the knowledge is a system that can be represented by means of a map where a variety of interrelated components or modules are connected by links of varying strength according to their cognitive distance. The map of the knowledge system shows that the knowledge space is rugged and is characterized by different levels of complementarity and interdependence among a variety of components. The relations among such components may be qualified in terms of fungibility, cumulability and compositeness according to the contribution that each body of knowledge is able to make in the recombinant generation of new technological knowledge. Radical technological change takes place when a variety of complementary bodies of knowledge come together to form a hub that provides knowledge externalities to the "peripheries", which in their turn provide new inputs and help the pursuit of further recombination stretching its core (Antonelli, 1999 and 2008a).

The generation of new knowledge by means of the recombination of pre-existing knowledge items does not yield the same results in all possible directions. Some recombination processes are likely to be more fertile than others. Some knowledge items happen to be central in the generation of new knowledge (Olsson, 2000; Olsson and Frey, 2002).

The empirical evidence provided by the new economics of knowledge suggests that the knowledge space is rugged and is characterized by a variety of landscapes. In some regions knowledge cores emerge and contribute to form a hub that provides knowledge externalities to the "peripheries", which in their turn are reliant on this knowledge from the core. In other regions however such dynamics does not take place. Some regions are potentially fertile and others are not able to support the reaction of firms. The generation of new technological knowledge and the eventual introduction of productivity enhancing new technologies depend upon the quality of the context into which firms are localized, as well as on their capability to accumulate competence and implement appropriate recombination processes: organized complexity matters in the recombinant generation of knowledge.

New technological knowledge can be generated whenever, wherever and if previous and parallel knowledge is available and accessible. Moreover, at each point in time, no agent possesses all the knowledge inputs required. External knowledge is an essential input into the recombinant generation of new knowledge. Knowledge communication, both internal and external to firms, among learning agents plays a central role in the generation of new knowledge. Agents search in the knowledge space for other knowledge item, create communication channels and activate knowledge flows. Moreover firms can move within the knowledge space and select their location so as to access the new knowledge that will be most usefully recombined with their existing competences. Agents identify other agents with whom cognitive interactions and transactions are most likely to yield positive outcomes so as to benefit from localized pecuniary knowledge externalities.

In this context knowledge, external to firms, is an essential input into the generation of new knowledge. Access to external knowledge generally requires investment to enable search, screening, interaction and understanding, all of which are necessary before the external units of knowledge can be recombined with firms' internal knowledge. In certain areas of the knowledge space, fertile knowledge is available and can be accessed at a cost. Recombination will only occur if it is expected to yield net revenues in terms of the flows of knowledge outputs that it will generate.

Knowledge recombination is the process by means of which new technological systems based upon webs of complementary technologies emerge. The process is characterized by clear sequences based on highly selective exploration. The emergence of a core of complementary technologies is the first aggregating step. This initial core of technologies is very productive and is characterized by low recombination costs and high revenues from the additional knowledge generated. This engenders a process of technological convergence. The emergence of new knowledge cores pushes firms already active in existing knowledge space to explore seemingly less complementary knowledge regions in an effort to take advantage of new, marginal opportunities for knowledge recombination. Eventually, the increasing variety of these recombinations will prove less and less effective and the diminishing returns to recombination will become apparent.

In sum, according to our analysis, the generation of technological knowledge and the introduction of technological change are characterized by four assumptions: a) firms are rooted in a limited portion of the space of technology, knowledge and geography both by the irreversibility of their stock of tangible and intangible inputs and by the competence based upon learning processes; b) firms are characterized by bounded rationality, but their procedural rationality includes the possibility to react to un-expected events and generate intentionally new technological knowledge and introduce new technologies react; c) because external knowledge is an indispensable input into the generation of new knowledge and no firm or agent can command all available knowledge, the quality of the reaction of each firm, whether adaptive or creative, depends upon the amount of knowledge available in the proximity within the technological, regional and knowledge space into which each innovator is embedded.

Knowledge positive feedbacks and the emergence of innovation

Our analysis enables to put in context the notion of knowledge positive feedback. Knowledge positive feedbacks take place in well specific circumstances when and where the interplay between the recombinant generation of technological knowledge and the changing characteristics of the knowledge and regional space feed each other so as to support the reaction of firms and make it creative.

The notion of positive knowledge feedback has two important implications. First, recombinant knowledge and localized technological change do not provide unlimited opportunities, which are fertile at any time, and in any place. Knowledge recombination may occasionally yield positive returns in well-defined and circumscribed circumstances that take place in historic time, regional space and knowledge space, when a number of key conditions apply. In some cases, however, the returns from recombination may be less productive.

When the structure of the system is such that knowledge externalities are not available and the access to external knowledge is burdened by heavy transaction, search and communication costs, high levels of congestion and strong appropriability, and the architecture of interactions limits knowledge interactions, single innovations may occasionally take place, but remain isolated acts of a minority of individual firms with little systemic effects. When the competitive threat to established market position is weak and hence creative social reactions are not solicited, inferior technologies are likely to be resilient. Adaptive responses, as opposed to creative ex-adaptive ones, are likely to occur when firms have not access to knowledge social interactions and the generation of knowledge should rely only upon internal sources. Firms are not able to introduce new localized, productivity enhancing technologies and may prefer to switch, i.e. just to change their techniques within the existing maps of isoquants. When the access of firms to external knowledge is costly if not inhibited, and adaptive responses, as opposed to creative ones, prevail, no technological change takes place and hence the structures of the system do not change.

The conditions for the emergence of innovations are set when the mismatch between expectation and real market conditions stirs the reaction of myopic but reactive agents and the flows of pecuniary knowledge externalities are large and consistent with their knowledge base. When both conditions apply, agents discover that their reaction is actually creative and activates a process of centred recombination that may occasionally generate new radical technologies. The actual emergence of innovations in fact takes place when active users of pre-existing technologies access the knowledge spilling over from the innovative activities of other actors co-localized in the knowledge space and combine it with their core knowledge. The larger the number of reactive agents, able to mobilize their competence and tacit knowledge and intentionally searching for new technologies and the larger the actual chances that a chain reaction leading to the generation of new technological knowledge and the eventual introduction of new technologies is set forth.

When positive feedbacks qualify the individual reaction of a firm into a creative process, innovations emerge from a collective process of generation of new technological knowledge and can lead to actual innovation cascades. It is clear in fact that the larger is the number of innovations and the larger the mismatch between the plans of individual myopic firms and the actual conditions of product and factor markets, hence the number of firms that are induced to react creatively and the larger is the amount of technological knowledge that is generated in the system. In such conditions not only a larger number of firms is induced to try and change its technology, but also a larger amount of knowledge is being generated. The chances that the reaction of firms becomes actually creative and can actually lead to the introduction of successful technological innovations that increase the levels of total factor productivity in turn increase (Antonelli, 2007 and 2008a).

The organization, composition and distribution of the knowledge base, i.e. the complementarity between the competence of reacting firms, the variety and coherence of their individual research efforts, play a key role in supporting the reaction of firms and helping the emergence of innovation. (Antonelli Krafft Quatraro, 2010).

In special circumstances the dynamics of positive feedbacks can activate self sustained chain-reactions that lead to broader innovation cascades or Schumpeterian gales of creative destruction. New technological systems emerge and articulate around core technologies that act as general purpose technologies, i.e. hubs in the collective process of knowledge generation in which all the parties involved act intentionally, within a well-identified rent-seeking perspective. Such exceptional outcomes of individual interactions are clearly influenced both by the population dynamics of the entries of more or less compatible agents with whom recombination can be practised, and the organization and composition of the knowledge base. New gales emerge from a sequential process of selective aggregation in the knowledge space of heterogeneous agents yet encompassing specific knowledge components with high levels of potential complementarity and coherence.

Schumpeterian gales of innovation can be better understood as a historical process of emergence of new technological systems based upon a selective and sequential overlapping among complementary technologies that takes place in well defined circumstances (Antonelli, 2001).

Much progress can be done by merging the literature on localized technological change and recombinant knowledge with the General Purpose Technology (GPT) literature. The notion of GPT implements and elaborates the Schumpeterian notion of the gales of technological innovations.

According to Schumpeter the gales of technological innovations occur when a radically new technology with a wide scope of applicability is introduced in the system. There is today a large body of empirical and theoretical work investigating the hypothesis that when a core body of new, radical knowledge with a wide scope of application emerges out of a generalized and collective process of search and exploration and may promote a wave of ripple effects that invest all the system (Bresnahan and Trajtenberg, 1995; Lypsey et al., 1998, 2005).

It becomes now clear that externalities are but endogenous. As it is well known, the notion of externalities has been first introduced by Alfred Marshall to identify the external causes of increasing returns at the firm level. Its meaning has been eventually stretched so as to consider more generally the effects that an array of factors, including knowledge spillovers, external to each firm, but internal to a regional system, have on their performances. The notion of externalities has progressively acquired dynamic implications so as to include the consequences on the individuals of the changing features of the system with the notion of localized increasing returns. At the same time, however, a growing confusion has been taking place about the origins of externalities.

At the system level externalities are not exogenous but rather endogenous. Externalities and specifically knowledge externalities are a specific and yet dynamic and changing attribute of the system that is produced by the interaction of the individual agents that belong to the system. This seems especially true when the generation and exploitation of knowledge matter: new knowledge is in fact at the same time, an output and an input and its generation requires the participation of a variety of agents because of its intrinsic characters of partial appropriability, non-exhaustibility and non-divisibility.

As soon as it is clear that externalities stem from the collective results of the behavior of the individuals, however, it becomes also clear that they cannot be exogenous, but rather endogenous to the system into which each firm is embedded. A recursive process takes place where structural change at the system level and technological change at the individual level are the two sides of the same coin. The performances of the firms and their interactions affect the structural characters of the system and these in turn affect the context of action of each individual firm with external effects.

6. THE EMERGENCE OF THE ORGANIZED COMPLEXITY OF INNOVATION SYSTEMS: THE RECURSIVE DYNAMICS OF STRUCTURAL AND TECHNOLOGICAL CHANGE

The recursive and systemic dynamics of technological change can now be explored in more detail. The actual capability of firms to react creatively to out-of-equilibrium conditions, and to change their own technologies depends upon the proper combination of internal knowledge and competence and the localized availability of knowledge externalities and interactions. At each point in time in fact the reaction of firms is qualified and constrained by their location and the consequent conditions of access to external knowledge. When external knowledge cannot be accessed properly, the reaction of firms is adaptive and consists in standard switching upon the existing maps of isoquants.

Their reaction can become creative as opposed to adaptive and engender the actual introduction of successful, productivity enhancing innovations, when and if the interactions and feedbacks shaped by the structure of the system provide the access to external knowledge and external learning conditions. The intensity and the effects of interactions are shaped by the structure of the system and specifically by the network topology of agents distributed in the multidimensional space, at each point in time: hence innovation as an emerging property of the system into which the dynamics takes place.

The creative reaction of firms however consists both in their innovative capability and in their strategic mobility in multidimensional space. Firms can change their location, enter and exit product and factor markets, create new links and communication channels, change their position in vertical inter-industrial linkages and in regional districts and do change their knowledge base, hence their complementarities with respect to other firms. Firms can introduce institutional innovations that help the emergence of new markets and new forms of organization of the system at large, such as in the case of venture capitalism. The distribution of agents in the multidimensional space is itself the endogenous result of the locational strategies of agents carried out in the past. Clearly knowledge externalities are internal to the system: they depend upon the specific combination of activities and channels of communication in place among them. Knowledge externalities depend upon the structure of the system. The organization and composition of the structure of the system into which firms are localized exerts a key role in shaping the dynamics both at the aggregate and the individual level. Hence the organization of the systemic complexity is it itself an emerging property.

Here it is clear how important are the contributions of both organization and population thinking. The former enables to appreciate to what extent the introduction of innovation depends upon the organization of the system, while the latter enables to grasp how population dynamics, in terms of entry and exit, reshapes the organization of the system. The analysis of the structural composition of the system, its effects on the conduct of firms and its evolution initiated by Simon Kuznets (1930, 1955, 1966, 1971, 1973) can be retrieved and enriched by the appreciation of other structural characteristics.

The systems of innovation approach has captured some aspects of the interplay between the structural characteristics of the system at each point in time and the actual capability of firms to react creatively and introduce productivity enhancing innovations (Nelson, 1993).

These structural characteristics of the system are the features of a rugged and evolving landscape into which firms are at the same time rooted and yet able to change as a result of their strategic conduct. The organization and composition of the structure of the system are neither static nor exogenous: they change through time, albeit at a slow rate, as a result of the dynamics of agents and of the aggregate. The meso-economic dynamics of the system act as a filter between the dynamics at the individual and the aggregate levels (Burt, 1992; Dopfer, 2005).

Several structural dimensions matter: institutional structures, economic structures, industrial structures, regional structures and knowledge structures, all contribute to shaping and framing the actual and effective access of firms to external knowledge and hence their chances to introduce productivity enhancing innovations.

The institutional organization of an economic system plays a crucial role in many aspects. Intellectual property right regimes qualify the exclusivity of proprietary knowledge and hence define the conditions for the use of external knowledge as an input into the generation of new knowledge. At the same time however they define the appropriability of the new knowledge generated. The interactions among users and producers of knowledge as well as the viability of the markets for knowledge are much influenced by the intellectual property right regimes. The institutional conditions for the interaction between firms and the academic and public research sector, whether based upon personal contacts or more organized transactions, are most relevant in favoring the bidirectional flows of knowledge so as to increase both the dissemination of existing knowledge and the active participation of the scientific undertaking in directions that are directly useful for the business community (Antonelli, Patrucco, Rossi, 2010; Antonelli Ferraris, 2010).

The analysis of the basic endowments is crucial to grasp the incentive structures for the direction of technological change. It is clear in fact that firms have a strong incentive to introduce technological innovations that make a more intensive usage of locally abundant inputs (Binswanger, Ruttan, 1978; Kennedy, 1964; Samuelson, 1965).

The distribution and organization of markets, both intermediary and final, is far from obvious and spontaneous. On the opposite the quality of markets vary across economic systems and affects their performances. The quality of the markets in terms of density of players on both the demand and the supply side, and thickness, recurrence, and distribution of transactions is a crucial structural attribute of an economic system and has powerful effects on its dynamics (Burt, 1992; Antonelli, Teubal, 2011).

The composition of the economic system in terms of primary, manufacturing and tertiary sectors and specifically the active role of knowledge intensive business service industries has a pivotal role in framing the access of firms to external knowledge. The analysis of the vertical structure of industrial and economic systems has appreciated the role intersectoral linkages as vectors of input flows and identified the central role of key sectors in the dissemination, appropriation and exploitation of knowledge as both an input and output (Pavitt, 1984; Fransman, 2007).

The spatial distribution of the industry plays a key role. Economic geography has explored successfully the central role of regional districts and clusters as forms of governance of economic activity, analyzed the effects of the spatial composition of industries and economic activities in supporting the introduction of innovations and assessed the role of spatial proximity in the dissemination of technological knowledge (Breschi, Lissoni, 2003; Boschma, 2005)

The analysis of the composition of the knowledge base of an economic system is a recent important area of fruitful investigation. Technological knowledge is far from being a homogeneous aggregate of knowledge items. Knowledge is itself a complex system of highly differentiated elements related by intricate webs of complementarity and interdependence. At the aggregate level it is more and more clear that the composition and the organization of the knowledge base in terms of variety, whether related or unrelated, coherence, specialization and concentration in specific knowledge fields has important implications for the recombinant generation of new knowledge fields (Saviotti, 1996; Frenken, 2006, Frenken, van Oort, Verburg, 2007). At the meso level, the structure of knowledge networks and their governance are determinant to channel knowledge externalities (Nesta and Saviotti, 2005 and 2008).

According to Paul Krugman (1994) such rugged landscapes in geographical, technological, knowledge, market and product space are at the same time the consequence and the determinants of complex dynamics. The structure of the system acts as a vector of catalyzers of a self-sustained of positive feedback in supporting the creative reaction of firms. Yet it is the result of their action. This approach makes it possible to pay attention to the evolution of the organization and composition of the structural characteristics of the system in terms of the distribution of agents in the different space dimensions, and to appreciate the changing architecture of the relations of communication, interaction and competition that take place among agents in assessing the rate and direction of technological change.

The structure of interactions and the flows of knowledge externalities depend upon the organization of the system in terms of the architecture of sectors and markets, the forms of competition that prevail in each of them and among them, the geographical distribution of firms, their density in regional and technological clusters, the forms of organization within and among firms, the shape and structure of knowledge networks, the vertical organization of industrial filieres, the governance mechanisms, the institutional context. All these structural elements are the meso-economic carriers of history and, as such, embody the memory of the system and, occasionally, at the same time the product of the creative reaction of firms.

It is clear that positive feedbacks take place only in specific circumstances: some structures are more conducive than others. In some circumstances structural change leads to forms of organized complexity where the reaction of firms become actually creative and leads to the introduction of innovations. These in turn however affect the organization, composition and architecture of the structure of the system. The organization of the structure has lead to the introduction of technological changes that in turn affect the organization of the system: the dynamics loop between structural and technological change is set.

In special circumstances structural change leads to the emergence of strong innovation systems empowered by highly performing network structures that are the result of the collective dynamics of a myriad of agents in search of potential, vertical and horizontal- complementarities. The emergence of highly performing innovation systems leads to Schumpeterian gales of innovations. The successful accumulation and generation of new technological knowledge, the eventual introduction of new and more productive technologies and their fast diffusion are likely to take place in a self-propelling and spiralling process and at a faster pace within economic systems characterized by fast rates of growth where interaction, feedbacks and communication are swifter. In such special circumstances, the system can undergo a phase transition leading to the introduction of a new radical technological system.

The changing structure of the system is endogenous to the system itself: the architecture of knowledge networks, as well as the industrial, sectoral, regional, knowledge and economic composition is heavily influenced by the strategies of firms seeking to improve their multidimensional location within systems of interactions.

The national system of innovations approach framed by Nelson (1993) and widely used and implemented, contributed widely to appreciate the key role of the structural characteristics of economic systems in shaping their innovative capability, but clearly suffers from the basic assumption that the structure of the system is either given or exogenous. In this line of enquiry there is no effort to grasp the endogenous determinants of structural change (Patel, Pavitt, 1994).

Our approach makes it possible to focus the attention on the intertwined dynamics of knowledge externalities and interactions, localized technological changes and structural change. Our approach makes it possible to grasp that both the occurrence of creative reactions and the introduction of an innovation as well as its organized complexity are key emerging properties of an economic system.

Knowledge interactions and externalities, and hence positive feedbacks, are not exogenous, the amount of knowledge externalities and interactions depends upon the structure of the system. The structure of the system is determined by the conduct of firm including both market strategies, the introduction of innovations and new communication and interaction networks. The activation of knowledge interactions is the result itself of intentional action.

At each point in time, in fact, agents can change both their production and utility functions and their location. Agents are mobile, albeit in a limited range constrained by relevant switching costs, and they can change their production and utility functions, building upon their experience and competence based upon learning processes, hence in a limited span of techniques and preferences practiced in their past. Firms select their interacting partners, build communication channels, elaborate governance mechanisms: all actions that favor knowledge interactions. At each point in time the map of multidimensional space into which each firm is embedded is exposed to the changes brought by the changing location of firms. Firms are both creative with respect to their technologies, and mobile, with respect to their location in the space of knowledge, technologies, and reputation, hence they can change the structure of the system. The introduction of institutional changes adds on to the endogenous evolution of economic structures.

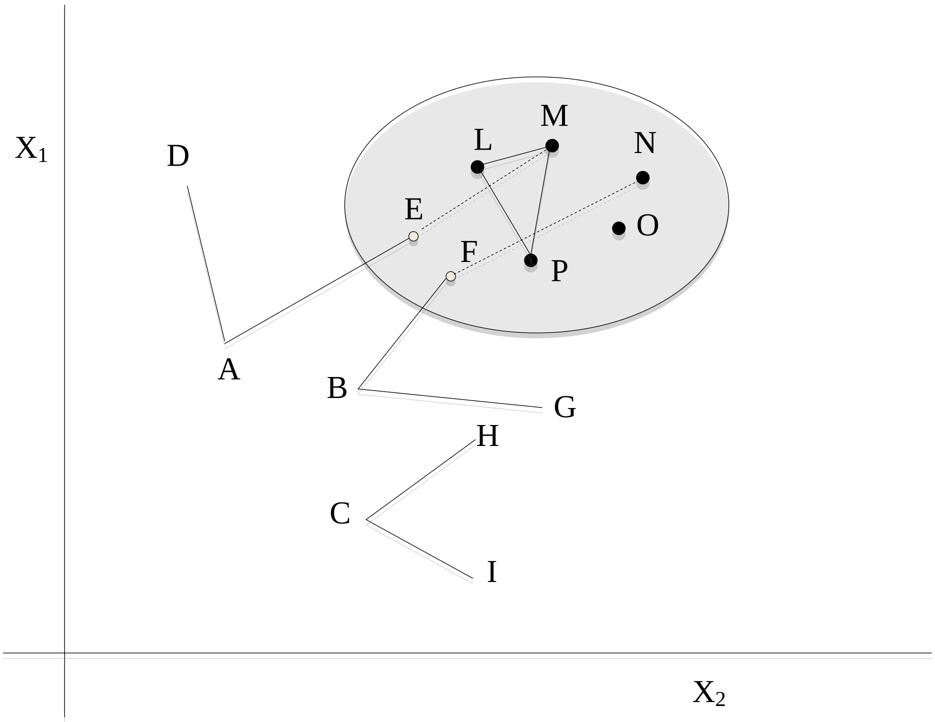
Innovation systems consolidate through time when the structural emergent properties leading to an organized complexity feed the introduction of innovations as emergent properties that in turn are able to feed further qualifications and improvements of the organized complexity of the system.

As Figure 2 shows, each firm directs the generation of technological knowledge in a simple Lancastrian knowledge space with two characteristics (X_1 and X_2) depending on the opportunities to benefit from the locally available pecuniary knowledge externalities (Lancaster, 1971). At time 1 each firm moving respectively from point A, B, C, directs its technological strategy either towards D or E, F or G, H or I depending on the conditions of the external context. In turn, once rooted in either point, new possible directions can be chosen, within corridors defined by the firm's internal characteristics that include the preceding path.

The technological path of each firm reflects the characteristics of both its own internal quasi-irreversibilities and learning processes and of the structure of the local context. The initial conditions play a key role in defining the context of action. The external context however, at each point in time, has powerful effects on the dynamics. According to the quality of knowledge interactions, some directions are favoured and others impeded. In Figure 2 the firm in A is induced to direct its innovation process towards E rather than D. The firm in B would move towards F rather than G. If other firms act as firms A and B the structure of the existing network LMMNOP will change. A new architecture of the network emerges. Its governance will change according to the ability of each new and old member respectively to enter and to participate to the new communication flows within the new architecture of the network.

By no means the new structure of the network is bound to be superior to the previous one. If the structural change increases the actual amount of knowledge externalities and interactions, a self-propelling process takes place. As long as additional changes reinforce this dynamics and consolidate the network each the process gains momentum.

INSERT FIGURE 2 ABOUT HERE
FIGURE 2. THE DIRECTION OF TECHNOLOGICAL OF KNOWLEDGE



Positive feedback is likely to reinforce the process as the effort to increase the complementarity of each firm's research activity reinforces the local pools of knowledge that, in turn, increases the possibility to access external knowledge. At the same time increasing awareness of the opportunities for better knowledge exploitation provided by the intensive use of locally abundant and idiosyncratic production factors increases the intentional convergence of knowledge generation strategies towards a common direction shaped by the collective identification of the local idiosyncratic inputs. At the population level, the effects of individual convergence are reinforced by selection mechanisms. The success of the localized knowledge exploitation strategies acts as a powerful focusing mechanism that, through selection processes, favors the survival and growth of firms that have selected convergent paths of knowledge generation and exploitation (Antonelli, 2008b).

Each firm engaged in generating new knowledge and appropriating its benefits in terms of extra-profits, discovers that the convergent alignment of its internal research activities with the complementary research activities of other firms, co-localized in both geographical and knowledge space, is a powerful factor of competitive strength. It is immediately clear in fact that the lower the unit costs of external knowledge are, the larger is both the amount of knowledge that the firm is able to generate and the larger is its localization in a specific context. A firm that is located in a conducive knowledge environment, and is able to identify and access the local pools of knowledge at low cost, is induced to take advantage of it and hence to base the generation of its new knowledge in the characteristics of its environment. This in turn is likely to affect the architecture of the local pools of knowledge and their governance.

Firms are able to try and change their environment and to influence its evolution by an array of actions ranging from the intentional mobility across regional and knowledge space, the creation of new communication links with other firms and institutions active in the generation of knowledge, the organization of networks and clubs, the introduction of better knowledge governance mechanisms. Here the notion of *coalition for innovation*, a term borrowed from political science, plays a key role. Firms and economic agents, at large, try and organize coalitions that are effective when they succeed to improve knowledge governance mechanisms by aligning and converging incentives and interactions based on their complementary competences. The *aligned* and *mutual* directedness of their interactions emerges, as the product of collective actions, aimed at increasing the quality of knowledge governance and enhance the cohesion of the group and to organize the inherent complexity of the system around shared objectives (Antonelli, 1997b; David and Keely, 2003; Lane et al., 2009).

The dynamic coordination of creative agents emerges as a key issue. At the system level the creation of platforms that enable to implement the dynamic complementarities of firms helps the emergence of clusters and favors the intensification of knowledge interactions and hence the rates of introduction of localized technological changes. At the firm level the counterpart consists in the design and implementation of dedicated governance mechanisms to implement knowledge interactions such alliances, technology clubs, long term contracts (Consoli and Patrucco, 2008).

Innovation systems emerge, through historic time, articulated in horizontal and vertical blocks of industrial sectors and filieres, technological districts, clusters, and networks when the generation of new technological knowledge is reinforced by the emerging structure of complementarities based on communication channels provided by the intentional research strategies of firms that discover new sources of complementarities and move within the knowledge space. The active role of the lead users and their fruitful interactions with their customers are encapsulated in these structures of the systems. The institutional features of the system complement the geographical and industrial ones and qualify the characterization of the mesoeconomic structure of the economic system.

The changing organization and architecture of the structure of networks within and among sectors, clusters and filieres is the result of a collective process. Each firm is able to move in such a knowledge space and generate new knowledge taking advantage of increased proximity and reinforced communication and interaction channels with other firms within knowledge coalitions clustering in nodes (the shaded region of Figure 2) where potential knowledge complementarities can be better understood. As a result, new systems of innovation, based upon coalitions and nodes of coherent knowledge complementarity, emerge (and others decay) while the direction of technological knowledge is shaped by the alignment towards a collective convergence of the research strategy of each firm. The levels of organization of the complexity of an economic system are endogenous and are themselves an emerging property (Antonelli, 1997b and 2010a).

Among the possible consequences, however, it is clear that, at the system level, the mix of activities that engender knowledge externalities and interactions may deteriorate over time: the entry of new members in the network as well the changes in the governance of the networks may cause congestion so as to lead to the actual decline of the amount of knowledge externalities and interactions available within the local system.

Each agent is both myopic and localized in a limited region of the space, hence it is not able to make a global choice. Exit from an old location, be a product market, a network, an industrial sector, or a region and entry in a new one may improve its own individual chances to access external knowledge and yet it can engender a decline in the overall viability of the innovation system.

The mobility of agents in multidimensional space affects the organization of the system. The latter in turn affect their chances to be creative and hence to introduce technological changes. Technological and structural changes are knitted in a close and dynamic interdependence. It becomes better clear how population dynamics affects the organization of the system and viceversa. Hence the need to rely both upon organization and population thinking (Lane et al., 2009).

The changes in the organization and architecture of the structure of the system have a direct bearing upon the amount and the quality of externalities interactions, and specifically upon the flows of knowledge externalities and knowledge interactions that make available, to each agent, external knowledge. The endogenous and dynamic character of externalities is set. New structures emerge and with them new architectures of externalities, communication and interactions. These in turn affect the dynamics of feedbacks and ultimately convert the chances that the creative reaction of firms leads to the actual introduction of productivity-enhancing innovations (Consoli Mina, 2009).

Within local and sectoral systems of innovation the organization and architecture of the communication channels that link each agent to other, the distribution of nodes can be seen as the result of an endogenous process of emergence that shares the complex dynamics of Internet network creation. The evolution of these networks, however, can exhibit both positive and negative features. Scale free networks, as opposed to random networks, based upon 'preferential attachments' may emerge and favor the access to external knowledge for a variety of actors. Some firms can emerge as the stars of the system as they are able to act as general switchboards of the communication flows (Barabàsi, and Albert, 1999; Barabàsi, Jeong, Neda, Ravasz, Schubert, and Vicsek, 2002; D'Ignazio and Giovannetti, 2006; Pastor–Satorras and Vespignani, 2004).

The industrial structure of the system is changed by the emergence of new industries both upstream and downstream with important effects for the system at large. New markets become effective with new opportunities for supply and demand to interact and new possibilities for division of labor and specialization. New flows of intraindustrial externalities may be caused, while others may be hampered by the structural changes.

The introduction of directed technological changes biased towards the intensive use of locally abundant production factors affect their prices and hence changes the structure of relative endowments. Antonelli (2008c) has shown that when firms are able to align their research strategies so as to take advantage of locally abundant knowledge, the amount of knowledge generated is larger. The amount of external knowledge that has been used in the knowledge generation process has a direct bearing not only upon the amount of knowledge being generated and hence on the efficiency shift engendered in the production process, but also on its characteristics. Firms that rely more upon external knowledge are more likely to produce complementary knowledge (Antonelli, 2010c).

Antonelli and Teubal (2008 and 2010) have shown how venture capitalism has changed the structure of interactions and transactions in financial markets with important effects upon the capability to fund, select and exploit new technological knowledge. Venture capitalism itself is a major institutional and organizational innovation that has activated a new mechanism for the governance of technological knowledge. Venture capitalism, as well, is the result of a systemic dynamics where a variety of complementary and localized innovations introduced by heterogeneous agents aligned and converged towards a collective platform. The new mechanism favors the creation of new science based start-up and has lead to the creation of new, dedicated financial markets. These new financial markets, specialized in the transactions of knowledge intensive property rights, combine the advantages of polyarchic decision-making in screening and sorting radical innovations with the direct participation to the profits of new outperforming science-based start-up typical of the corporate model.

Agglomeration within clusters in the long run may engender negative effects. Knowledge governance costs may increase along with the number of firms accessing the same knowledge pools because of congestion effects in coordination. Eventually density may have negative effects in terms of reduced knowledge appropriability: the case of excess clustering can occur when proximity favors the uncontrolled leakage of proprietary knowledge within the local system (Antonelli, Patrucco, Quatraro, 2008 and 2010).

The convergence of the direction of technological change and the emergence of innovation systems in geographical and technological space occurs as long as the positive effects of knowledge interactions are larger than their negative effects. In specific contexts the interplay can lead to logistic processes of emergence with S-shaped dynamic processes that identify critical masses.

At each point in time the emergence of new innovation systems may be blocked by a number of countervailing forces. The process is far from being past dependent: it is shaped, at each point in time by the ability of the actors to contrast the dissipation of pecuniary externalities. Both at the firm and the regional level these processes are likely to occur with a strong non-ergodic and sequential stratification (David, 1994). The path dependent dynamics stems from the interplay between past dependence and intentional action. The internal stock of knowledge acquired through learning by each firm together with the features of the local pools of knowledge and of the economic structure is the past dependent components as at each point in time they are the result of historic accumulation. The amount of knowledge being generated, the direction of technological change being introduced, the levels of knowledge governance costs and the price of locally idiosyncratic production factors are, at each point in time, the result of the intentional action of agents. Hence they provide the opportunities for intentional action to change the original path. At each point in time the intentional action of the embedded agents adds a new layer to the original structure: the original shape exerts an effect that the new layers can modify, depending on their thickness and density. Each firm in fact is able to interact with the system and to change it. This occurs at different levels: by introducing changes to the structural conditions and the topology of the system's communication channels, with the introduction of organizational innovations in knowledge governance mechanisms, and by changes in the factor markets due to innovations that change the supply of the idiosyncratic production factors. The emergence and decline of innovation systems is the result of continual feedback between the structure of the system and the innovative action of its agents.

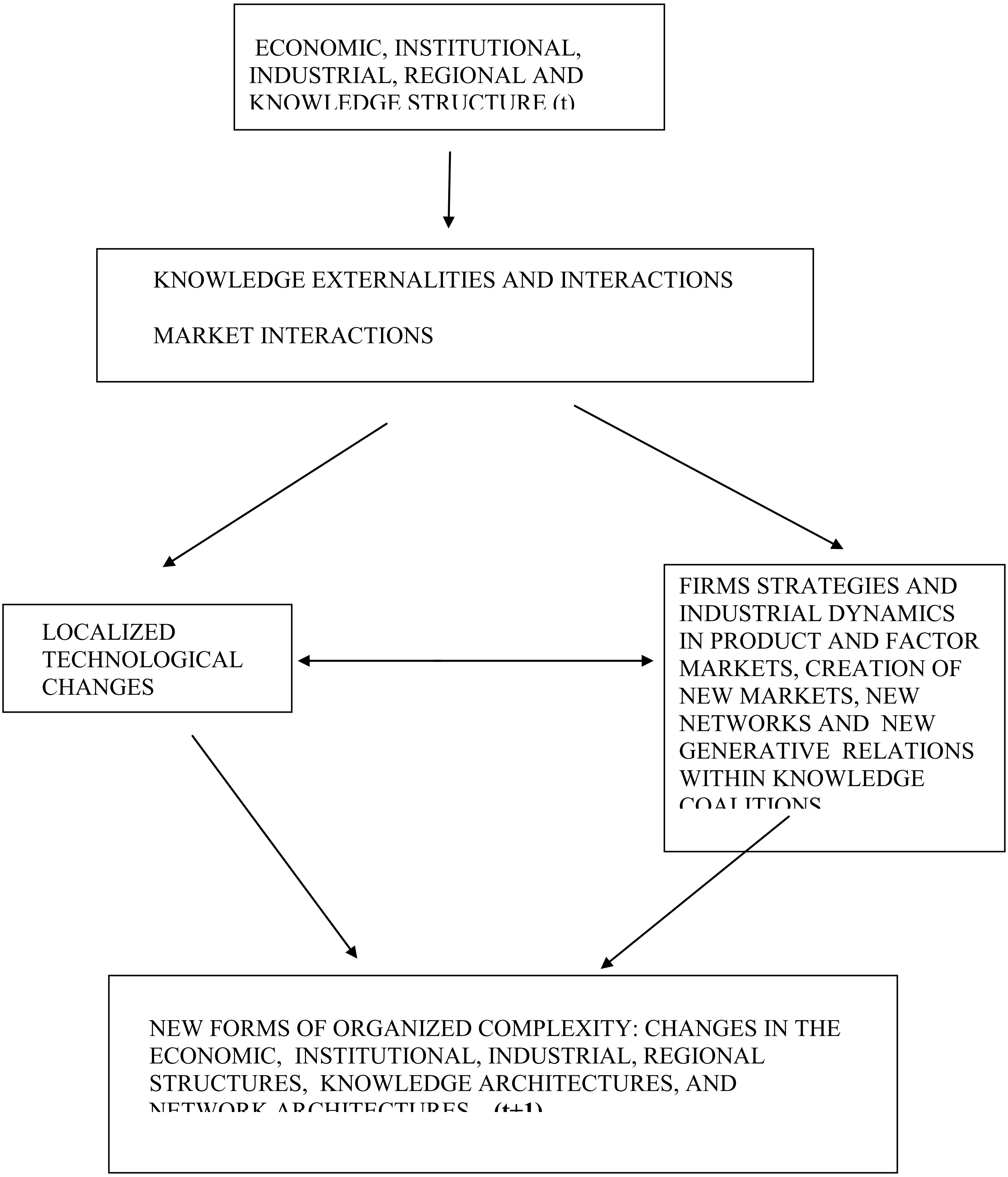
When the negative effects of agglomeration exceed the positive effects, the mobility of firms in geographical and knowledge space is centripetal and leads to divergent path of exploration. Firms leave existing pools of knowledge and search for new possible agglomerations around new platforms and other sources of knowledge complementarity.

Externalities are endogenous and dynamic. Their dynamics is characterized by non-ergodicity. The past has a consequence on the future. Such non-ergodicity however cannot be characterized as sheer past-dependent.

Structural and technological changes interact and shape at each point in time the new architecture of the structure into which firms are localized. The new structural conditions shape the creative reaction of firms as well as their strategies. These in turn change the structure of the system. The key determinants and characteristics of the systemic dynamics of technological change are set. Technological change and structural change are intertwined and mutually interdependent. The introduction of innovations is part of a more general and dynamic process of self-organization of the structure of the system.

The actual introduction of technological and organizational innovations by each agent at each point in time is the result of a long term process of feedbacks that make possible their creative reaction at the system level via the continual changes in product and factor markets and the related strategic reactions of firms including research and development expenditures and the mobilization of internal tacit knowledge and competence, on the one hand, and the changes in the structure of knowledge interactions and externalities that provide and implement the access to external knowledge, on the other. Hence the conversion of adaptive responses into creative reactions is not a punctual and individual event that takes place isolated in time and space, but rather a collective process that finds its sustainability at the system level. Consistently the innovative capability of a system is an emergent property of the system, a fragile process that takes place when a number of complementary conditions and circumstances are set and their coherence is the result of constant implementation and maintenance over time. The dynamic coordination of structural and technological change appears necessary and yet extremely difficult because each element in the system is changing. Here the notion of path dependence plays a key role to grasp the dynamics of innovative systems.

FIGURE 3. THE EVOLVING INTERACTION BETWEEN TECHNOLOGICAL AND STRUCTURAL CHANGE



7. PERSISTENCE, PAST DEPENDENCE AND PATH DEPENDENCE

Historic analysis provides the key information to understand the determinants of the long-term dynamics of economic processes. This is true both at the microeconomic, mesoeconomic and macroeconomic level. Historic analysis reveals the features of the quasi-irreversibilities that shape much of the tangible and intangible assets of firms. Historic analysis provides key information to grasp the mesoeconomic features of the systems in terms of the economic, industrial and regional structures, the composition of preferences and tastes of consumers, the architecture of the networks within and among sectors, clusters and filieres into which firms are embedded and the amount of knowledge externalities and interactions that are available to each of them. Finally, historic analysis provides the key elements to understand the processes that shape the reactions of agents and make them creative, as opposed to adaptive and hence make the actual introduction of innovations possible (Antonelli, 1997a).

At each point in time the historic processes that have defined the present conditions of each agent characterize their conduct including their capability to innovate. Hence, at each point in time, firms and agents can change their location in space, their competence, their access to external knowledge, their systems of interactions. In so doing agents can change the structural conditions of the systems (Antonelli, 2007).

The introduction of innovation and the related generation of new knowledge is shaped by cumulative forces, substantial irreversibility and positive feedbacks only when a set of qualified circumstances applies. Hence innovation is expected to be a persistent process that is reinforced by external feedbacks and contingent factors only when the interplay between technological and structural change sustains the capability of firms to introduce innovations. The dynamics of positive feedback in fact is far from linearity both with respect to an array of factors such the density of agents, the architecture of their relations, the quality of communication channels the conditions at which the communication hubs work. Beyond some –changing- levels, congestion, exclusion and saturation may take place and negative externalities become larger than positive externalities.

Both centripetal and centrifugal effects characterize these dynamic processes with major effects in terms of discontinuity. Centripetal effects are found when the convergence towards local attractors is stronger than divergence. Technological districts, knowledge platforms and networks, new vertical filieres emerge and favor the persistence of the rates of introduction of innovations. When centripetal effects prevail the rates of introduction of innovations are stronger. At the system level growth rates increase together with the variance of the performances of firm's. Eventually the diffusion of technological and organizational innovations exerts a strong effect in terms of reduction of the spatial and economic dispersion of firms. Centripetal forces prevail when congestion and knowledge dissipation cause negative net externalities that prevent the creative reaction of firms. Adaptive responses prevail and firms prefer to switch upon the existing maps of isoquants and are no longer able to change them. The rates of growth of the system decline, as well as the variance in the performances and in the characteristics of the firms. The distribution of firms in regional and knowledge spaces tends towards higher levels of homogeneity.

The persistence of the innovative activity takes place when A) the competitive pressure pushes firms to react by means of more than traditional price-quantities adjustments but to try and change their technologies. Firms can actually react creatively to face unexpected events by means of the introduction of new technologies and new organizational methods and introduce successful innovations when two conditions are fulfilled: B) they are actually able to learn to learn and C) the external context qualifies the intentional action of firms and provides the access to complementary and indispensable inputs in terms of external knowledge. In such cases the dynamic process is likely to be characterized by significant hysteretic, non-ergodic features (Antonelli, Crespi, Scellato, 2010a, b).

This dynamics in fact is characterized by recursive feedbacks. The introduction of new technologies and new organizations methods affects the systems on two counts as it engenders further waves of unexpected events and Schumpeterian rivalry, and, at the same time, makes available new knowledge spillovers. Hence the introduction of innovations can be considered as the persistent and emerging property of an economic system where the interdependence between the dynamics of learning, internal to firms, and the evolving structure of interactions among firms that determines the actual amount of external knowledge available within the system, exert path dependent, rather than past dependent, effects. Non-ergodic dynamics in fact can be either past dependent or path dependent: in the latter case the effects of hysteresis are qualified and shaped by the localized context of action. In the former the process is shaped by the initial conditions only (Antonelli, 2008a).

When a process is non-ergodic, initial conditions exert their effects without alteration upon the full sequence of developmental steps and hence on the final outcome. Past dependence, or 'historicity', is an extreme form of non-ergodicity. Historic, as well as social and technological, determinism fully belongs to past dependence. Here, the characteristics of the processes that are analysed and their results are fully determined and contained in their initial condition.

In our approach, instead, it is clear that small and contingent events may change the fragile set of conditions that favor the persistence of innovation because of structural changes that undermine the prevalence of positive knowledge externalities and with them the chances that firms are actually able of creative, as opposed to adaptive, reactions. This process is characterized by historicity, as such, however, it may exhibit strong discontinuities. The direction of the process, moreover, may be influenced by the sequential emergence of contingent factors that can modify the path shaped by quasi-irreversible factors. Both the rate and the direction of technological change are affected by the combination of hysteresis and flexibility. The process is indeed path-dependent rather then past-dependent.

Path dependence is the specific form of complex dynamics applied to evolving economic systems. Path dependence provides a unique and fertile analytical framework which is able to explain and assess the ever-changing outcomes of the combination of and interplay between factors of continuity and discontinuity, growth and development, hysteresis and creativity, routines and 'free will', internal and external factors which all characterize economic action in a dynamic perspective that is also able to appreciate the role of historic time.

According to Paul David, path dependence is an attribute of a special class of dynamic processes. A process is path dependent when it is non-ergodic and subject to multiple attractors: 'Systems possessing this property cannot shake off the effects of past events, and do not have a limiting, invariant probability distribution that is continuous over the entire state space' (David, 1992: 1; David 1988; David, 1994; David, 2007).

Indeed, historic analysis and much empirical evidence in economic growth and specifically in the economics of innovation and new technologies confirm that these characteristics apply and are most relevant to understanding the laws of change and growth of complex systems. Path dependence is the specific aspect of complex dynamics most apt to understand the process and the outcomes of the interactions among myopic agents embedded in their own context and constrained by their past decision, yet endowed with creativity and able to generate new knowledge by means of both learning and intentional innovative strategies as well as through structural changes. Path dependence differs sharply from past dependence.

In the theoretical economics of innovation, past dependence has often been assumed: the epidemic models of the diffusion of innovations and the notion of innovations ‘locked in’ a technological trajectory are typical examples of the deterministic representation of essentially stochastic technological and social phenomena. The notion of technological trajectory is another example of extreme past dependence. The development and implementation of a new technology would follow a well defined and pre-determined sequence of steps that are all defined by the initial characteristics. The notion of technological trajectory is a typical example of the so-called technological determinism according to which technology changes according to its internal rules and, while it is able to have important effects on the economic system, there is no possibility for the on-going changes in the economic system to affect the sequence of innovations that characterize its evolution.

As such, these non-ergodic models are analytically informative but empirically uninteresting. The process takes place within a single corridor, defined at the outset, and external attractors cannot divert its route, nor can the dynamics of the process be altered by transient random disturbances in its internal operations.

Path dependence differs from deterministic past dependence in that irreversibility arises from events along the path, and it is not only the initial conditions that play a role in selecting from among the multiplicity of possible outcomes. The analysis of a path-dependent stochastic system is based on the concepts of transient or ‘permanent micro-level’ irreversibilities, creativity and positive feedback. The latter self-reinforcing processes work both through the price system and by means of knowledge pecuniary externalities including the effects of social, strategic and generative interactions. The conceptualization of stochastic path-dependence can be considered to occupy the border region between a view of the world in which history is relevant only to establish the initial conditions, but has no bearing on the developments of the process and another where the dynamics unfold deterministically (Antonelli, 2006).

Path dependence takes place when events that occur along the process can have long lasting consequences and divert both its rate and its direction. A path-dependent process is a non-ergodic process that is not fully determined by its initial conditions: it allows for the contingent effects of localized events that may change the rate, the direction and the sequence of events.

Path dependence is the conceptualization of historical dynamics in which one ‘accident’ follows another relentlessly and unpredictably and yet the past narrows the scope of possible outcomes, shaping the corridor into which the dynamics takes place. Path dependence gives economists the scope to include historical forces without succumbing to naive historical determinism because it makes it possible to identify the reduced portions of the relevant spaces into which the system is likely to move at each point in time. The understanding of the historic forces that constraint the dynamics of both individual agents and aggregate system, in fact, provides a clue to foresee, with some degree of indeterminacy, the regions into which the future developments of a dynamic process are likely to take place. In so doing path dependences make it possible to substitute the deterministic fallacy of general equilibrium analysis with the stochastic understanding of long term dynamic processes.

The analysis of the structural determinants of the rate and the direction of technological change enables the identification of the path-dependent interplay between structural and technological change. Technological change can alter the characteristics of the system and yet it is itself the product of the characteristics of the system at each point in time. A strong common thread links the analyses developed with the notion of life cycle and technological trajectory and the notion of path dependence. Only the latter, however, provides a theory to understand why and how technological change takes place sequentially along axes defined in terms of complementarity and cumulability, both internal and external to each firm. From this viewpoint the technological path represents significant progress with respect to both the technological trajectory and the life cycle.

Path dependence applies both to each agent and at the system level: hence we can identify and articulate an individual and a systemic path-dependence. Individual path-dependence provides the tools to understand the combination of hysteretic, past-dependent factors such as the quasi-irreversibility of tangible and intangible production factors, stock of knowledge and competence, and localized learning, with the generative relationships and creative reactions that make possible, at each point in time, a change in the direction of the action of each agent, including the introduction of innovations. At the firm level the generation of knowledge shares the typical characteristics of a path-dependent process where the effects of the past, in terms of accumulation of competence, mainly based on processes of learning in a localized context and interaction with a given structure of agents, exert an influence and yet are balanced by the specific creativity that is induced by the changing conditions of the system. Systemic path dependence defines the elements of non-ergodicity that characterize the changes in the industrial, regional and economic structure of the system including the architecture of the networks of social, knowledge and strategic interactions.

The notion of path dependence provides one of the most articulated and comprehensive frameworks from which to move towards an analysis of the conditions that make it possible to conceive the working of an economic system where agents are able to generate new technological knowledge, introduce new technological innovations and exploit endogenous growth. The notion of path dependence can be considered the analytical form of complexity most apt to understand the dynamics of economic systems where heterogeneous agents are characterized by some level of past dependence, as well as by local creativity, interdependence and limited mobility in a structured space that affects their behaviour but is not the single determinant.

Path dependence is an essential conceptual framework that goes beyond analysis of static efficiency and enters the analysis of the conditions for dynamic efficiency. It applies to each agent, in terms of the quasi-irreversibility of their own endowment of tangible and intangible assets, networks of relations in both product and factor markets, stock of knowledge and competence, and to the system level in terms of general endowments of production factors, industrial and economic structure, and the architecture of the networks in place.

The identification and articulation of individual and system path-dependence makes it possible to catch the basic laws of the continual interaction between the hysteretic effects of past dependence, both at the agent and at the system level, and the feedback dynamics that allows the intentional conduct of the creative agent to change both the course of their actions and the characteristics of the structured space. In so doing, path dependence retains the positive contributions of complexity, and at the same time has the capability to overcome the intrinsic limitations stemming from its origins built on natural sciences where human decision-making is not considered. Indeed, the notion of path dependence is one of the main forays in the challenging attempt to apply the emerging theory of complexity to economics.

8. CONCLUSION

Standard economics assumes that utility and production functions are exogenous or, at best, change smoothly and evenly, following the rates of learning processes and ubiquitous positive externalities. In evolutionary economics the introduction of innovation is assimilated to the result of random mutations, as such its causes and determinants are not investigated. No clues are provided to understand the historic, regional and institutional determinants of the generation of innovations. By contrast the selective diffusion of innovations is analyzed as the result of a systemic process.

Complex dynamics elaborates the view that change and dynamics are intrinsic to systems characterized by the variety and creativity of their components. Complex systems are characterized by the heterogeneity of agents with different functions, different endowments, different learning capabilities and different perspectives, and most important, different locations in the multidimensional spaces of geography, knowledge, technology and reputation. These heterogeneous agents are complementary components of the system and their action can affect the dynamics of the system. The working of each of them as well as the working of the system can be understood only if the web of interactions and interdependencies are identified and qualified in terms of organized complexity.

The merging of the theory of complexity with the Schumpeterian and Marshallian legacies in economics provides a frame of analysis into which the systemic dynamics of technological change can be better understood, but only if the microeconomics of innovation is fully elaborated and integrated and the relations between individual and systemic change respectively at the micro and macro level are clearly articulated. Our approach makes it possible to appreciate the intertwined dynamics between the introduction of innovations and structural changes that implement the levels of organization of the complexity of the system.

The integration of the Marshallian partial equilibrium approach and Schumpeterian economics of innovation with the theory of complexity enables to consider economic systems as complex dynamic mechanisms where innovation and organization are the key emerging properties of the system.

The actual rates and direction of change are determined by the matching between the response of creative agents anchored in a well identified portion of space by the quasi-irreversibility of their tangible and intangible inputs, and exposed to systemic and endogenous events that alter the expected conditions of product and factor markets, and the structure and quality of knowledge externalities and interactions that make external knowledge accessible within the system, according to its structure. The quality of the localized context of action is crucial to enable the creative and hence ex-adaptive, as opposed to adaptive, reaction of firms.

Organized complexity is crucial to make innovation possible. Yet the organization and composition of the structure of economic systems are themselves the endogenous result of technological change and population dynamics in terms of introduction of innovations and differential rates of natality, entry, mobility, exit and mortality. A recursive loop takes place between structural and technological change.

Summarizing the building blocks of our analysis, we have shown that out-of-equilibrium conditions push agents to react (Chapter 3). Their reaction builds upon localized learning processes. It can lead to the actual introduction of productivity enhancing innovation if and when the local context is structured as an organized complexity where knowledge feedback, interactions and externalities support the recombinant generation of new knowledge and hence innovative effort of firms (Chapter 4). The introduction of innovations is an emergent property of an organized complexity that brings together the individual efforts and the quality of the contextual feedbacks (Chapter 5). The introduction of innovations in turn affects the structure and architecture of the local innovation systems (Chapter 6). New innovation systems emerge and other decline. Resilience and persistence both at the system and the firm level shape the change of the structure of the system and lead to path dependent dynamics. The organized complexity of the system is the complementary emerging property of an economic system able to grow (Chapter 7).

Some mesoeconomic architectures are clearly more conducive than others. Some knowledge structures enable the dynamics of positive feedbacks and the successful recombinant generation of new knowledge. With other structures knowledge dissipation may prevail. The architectures of the structural characters of the system may exhibit high levels of resilience, yet they are not given, nor are they exogenous. They are themselves the path-dependent products of the intentional choices of location and mobility of agents as well as of their collective interaction. Each agent is localized in a limited region as major switching costs limit its mobility. Hence he cannot be fully aware of the effects of its re-location in such a multidimensional space on the viability of the knowledge externalities and interactions. The topology of the network structure of interactions is also likely to be changed. New communication channels are built and the search for external knowledge is intensified. The amount of knowledge externalities and interactions is likely to increase. The amount of knowledge that each firm can now generate with a given amount of resources also increases because of the higher levels of external knowledge available and the lower cots of communication and networking.

The introduction of innovations may engender a chain reaction that leads to innovation cascades consisting in the generalized introduction of new systemic gales of innovations. In other circumstances, however, momentum can decline and adaptive reactions prevail. Contingent factors may affect the interplay between structural and technological change and tilt the dynamics of positive feedback: growth and change are characterized by discontinuity.

The relationship between the structure of the system and the actual emergence of innovation in fact is clearly recursive. The chances of introduction of innovations are indeed influenced by structure of the system as it stands at time *t*. The structure of the system shapes the amount of knowledge externalities and interactions that engender positive feedbacks and hence the introduction of localized and productivity-enhancing innovations. The localized structure of interactions plays a key role in qualifying and augmenting the creative reaction of firms caught in out-of-equilibrium conditions so as to enable them to actually generate productivity-enhancing innovations. Innovations, together with other conducts, moreover engender structural change and hence influence the characteristics of the structure at time *t+1*. A new structure is determined with effects both on the flows of knowledge externalities and interactions and on the conditions of product and factor markets. The changes in the markets cannot be fully anticipated by firms. In order to cope with then, firms elaborate new strategies that include the introduction of further innovations.

The understanding of this recursive relationship paves the way to grasping the basic elements of the continual and dynamic system of feedback between the conduct and performance of firms, the rate and direction of technological and structural change with a growing awareness of its evolving and historic characteristics.

A recursive loop takes place between: a) the structural conditions of the system, b) the ensuing amount of knowledge externalities and interactions, c) their crucial role in enabling myopic but creative agents, caught in out-of-equilibrium conditions, to generate new technological knowledge and to introduce new localized, productivity enhancing technologies and d) the consequent changes in the structure of the system. When such a recursive loop takes place and exhibits some levels of historic sustainability, the notion of path dependent complexity becomes relevant. The special case of the general equilibrium fades as a multiplicity of changing attractors emerges. The dynamics of markets, knowledge and social interactions feed each other and engender a dynamic process. In a system with no strategic interactions, agents are not induced to try and change their technologies. On the other hand it is clear that a system with low-level knowledge interactions is not able to convert the inducement exerted by strategic interactions into the actual introduction of technological innovations. Social interactions on the other hand have a powerful effect in terms of introducing the endogenous dynamics on the demand side.

Innovation is the emergent property of a system where there is a conducive mix of strategic interactions, able to stir the creative response of firms, and knowledge interactions able to implement them with the supply of external knowledge. Innovation is both the result and cause of out-of-equilibrium conditions.

Complex dynamics, based upon systemic and creative reactions, substitutes adaptive convergence towards a single attractor. Complex dynamics provides an analytical framework into which much economics of innovation can be usefully encapsulated. On the other hand complex dynamics makes it possible an important step forward with respect to evolutionary economics as it enables to overcome the embarrassing role of random variation as a source of innovations. Innovations are the deliberate outcome of the intentional and creative action of firms localized in a well-defined context that characterizes both their competencies and their position in a web of social, strategic and knowledge interactions.

The integration of the economics of innovation and specifically of the economics of localized technological change into the frame of the economics of complexity has two important advantages. On the one hand it shows that innovations are the collective and systemic result of the intentional action of a variety of heterogeneous and interacting firms when embedded in proper innovation systems that favor their creative reaction when facing out-of-equilibrium conditions. On the other it provides the economics of complexity with an articulated analysis of the dynamic interactions between intentional decision making at the agent level and the changing characteristics of the system into which economic action takes place.

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