"FOSTERING INNOVATION SYSTEM OF A FIRM WITH HIERARCHY THEORY: NARRATIVES ON EMERGENT CLINICAL SOLUTIONS IN HEALTHCARE"

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ABSTRACT

A central finding in innovation research is that firms seldom innovate in isolation. Interaction with other agents such as customers, suppliers, competitors, regulators and various other private or public organizations contributes to the search of novelty by firms. A 'system perspective' is useful in understanding and analyzing such interactions. As shown by research scholars of innovation, the concept of system has been intensively explored but it arises several issues: first, the appropriate level of analysis and the closely related issue of identifying the actors or components, second, the measurement of the system. These issues are discussed with the respect to the interpretative hierarchy theory that adequately deals with complexity through a self-reflective process of observation and description. It provides us with some possible associated solutions, (i) the multi-level architecture of order and (ii) narratives on technological innovation. In turn, it fosters the hierarchical deployment of the 'innovation system' concept at the firm level and its empirical illustration through the emergence of clinical innovations in medical imaging in particular. Finally, we suggest that firm managers need an appropriate holistic approach to closely capture these emergent clinical solutions associated with lead user interactions.

Key Words: evolution, emergence, innovation systems, hierarchy, narratives.

INTRODUCTION

The systems approach to the analysis of economic and technological change has been captured by scholars of innovation, in various ways. National, regional, by-sector or technological systems of innovations have been suggested in the literature (Edquist 1997, Malerba 2004, Nelson 1993, Lundvall 1992) validating the systemic and dynamic dimension of innovation in industries and economics. In parallel, system scientists have intensively developed some disciplines about approaching complex systems and producing knowledge from system observation. While systems of innovation have been described over the past two decades by scholars of innovation in various ways, boundaries of innovation system have been a central issue, where the focus is the physical or geographical dimension at first. In other cases, the main dimension is a sector or technology and the determination of the relevant geographic boundaries is itself a methodological issue. Some have applied the innovative system concept in healthcare

(Consoli and Mina 2009, Metcalfe et al. 2005), contributing to close the gap of understanding the innovation process in healthcare (Gelijns and Rosenberg 1994) at the component level of the innovation system. The recent effort led by service innovation studies in the healthcare sector (Djellal and Gallouj 2005, Gallouj and Windrum 2009) has notably emphasizing the importance of such research direction. Additionally some effort has been put into unfolding the mechanisms by which progress in medicine can take place through a multidisciplinary (systemic) approach based on Kenneth E. Boulding's work applied to epidemiology (Wilby 2005). This paper is a tentative step towards bridging this gap by exploring the contribution of hierarchy theory to deal with complex systems such as innovation systems of firms. This paper is organized in twofold. First, this paper is to review some important issues which arise in applying a system approach to the analysis of technological innovation, with respect to this science tradition. Second, by carefully using this systemic framework, this paper investigates the advancement of clinical knowledge and the co-evolution of clinical innovation in the context of a micro-innovation system that emerges along a specific sequence of interrelated problems and associated solutions, engaging scientists, medical doctors, patients, firm practitioners and patients over a period of one decade.

INNOVATION SYSTEMS AND HIERARCHY THEORY

Properties and Function of the System

In the effort to develop the system of innovation approach, it is relevant to relate it explicitly to 'general systems theory' (Bertalanffy 1968), which has been used much more in the natural sciences than in the social sciences. In generic terms, by 'system' we mean that a set of two kinds of constituents. On the one hand, the components of the system and on the other hand, the relations among them form a coherent whole. System exhibits properties that are different from the properties of each component and it has a function. System has boundaries, where the observer can delineate the system from the rest of the world. The systemic approach of system of innovation suggests that the outcomes of such a system are not consciously designed or planned. Within this stream of research, innovation processes are evolutionary; systems of innovation evolve over time in a largely unplanned manner. In other words, even if we knew all the factors of innovation processes in detail involved in a system of innovation, we would not be able to control them and design a system of innovation on the basis of this knowledge.

The system of innovation places innovation and learning processes at the center of the focus (Edquist 1997). This emphasis on learning acknowledges that innovation is a matter of producing new knowledge or combining existing elements of knowledge in new ways. Recently, process innovation and service innovation have been studied as an outcome of system of innovation to emphasize this central dimension of knowledge creation or re-combination. By learning, we arguably advocate a broad definition that encompasses (i) the organizational learning taking place mainly in firms, (ii) the research and development activity that is carried out in universities, research centers and firms and (iii) the individual learning through training and education that leads to the creation of 'human capital'. Analyzing the relationships between these three kinds of learning within the system of innovation is an important area for research for understanding the emergence of innovation. This covers the knowledge transfer from basic research to applied research, as well as the location of the innovation, which varies a lot by country (Lundvall 1992, Lundvall et al. 2006, Nelson 1993) and by sector (Malerba 2004) based on the institutional environment in which the organizations are embedded. Laws, rules and norms differ considerably among nations and sectors, triggered by different technology bases (Carlsson and Jacobsson 1994). But institutions are also embedded in and develop within organizations. For instance, firms follow different norms with regard to the relations between novelties and risk-taking.

This systemic approach of innovation adopts a holistic and interdisciplinary perspective in the sense that it tries to include a wide array of the important factors of innovation, from organizational, social to political factors, in conjunction with economic ones. To achieve this holistic goal, this approach requires absorbing several perspectives from different social disciplines including economic history and sociology. Consequently, this approach highlights interdependence of firms and non-linearity, as well as path-dependence. The underlying assumption is that firms normally do not innovate in isolation but interact with other organizations through complex relations and complex networks that are often characterized by reciprocity and feedback mechanisms. Components of the system matters, as much as the relations between them (Pavitt 1984). In turn, this captures the non-linear features of innovation patterns and the dynamic dimension of innovation processes involved within these innovation systems. Traditionally, innovation systems have, to a large extend, focused upon technology-oriented process innovations (Carlsson and Jacobsson 1994) and to some extend upon product innovations but little argument has been developed on non-technological and intangible innovations, such as service, except notable exceptions (Djellal and Gallouj 2005, Gallouj and Windrum 2009). We argue that innovation system concept is well equipped to this comprehensive perspective, as we illustrate it through some empirical evidence.

The function of an innovation system is to create, diffuse and implement technologies that have economic value (Edquist 1997). We argue that by technologies we mean physical artifacts as well as technical ‘know-how’ that can be embedded in processes and practice. The dynamic properties of the system, such as robustness, flexibility, ability to generate change and respond to changes in the environment are among its most important attributes. Changes can be generated endogenously: new components (agents, technological artifacts) are introduced; the relationships among the agents change; and the attributes (capabilities of agents, nature and intensity of links among agents) change. In parallel, changes within the system can be induced by changes in the environment, e.g. the changes in the nature of the institutional environment.

Our aim is to contribute to the discussion of methodology with respect to the analysis of innovation systems, by considering two methodological issues that can be solved through a system science approach, grounded on hierarchy theory. The first is the level of analysis to which a multi-level architecture of order is applied. A second is how we can measure the performance of the system and where narratives introduce fruitful potential of understanding.

Levels of Analysis and Architecture of Order

The innovation system framework was originally defined as a network of agents interacting under a specific institutional setting and involved in the generation, diffusion and usage of technological innovation. This definition opens up for a number of different ways to delineate the system, each involving a different level of analysis. We argue that hierarchy theory may fruitfully be applied to unfold the different levels of analysis. Cognitive limits to decision making have been much theorized, going back to the seminal work of Simon on bounded rationality. Complexity adds another dimension to bounded rationality by denying reductionism in terms of chains of causality from the whole to its parts. Some aspects of complex systems are inherently unknowable. However, while complexity theory further constraints decision making, it also enables it through ideas such as partial irreducibility. Of greatest utility is Simon's concept of a multi-level architecture of order, in our view dealing with complex systems. In his seminal paper on the architecture of complexity, Simon (1962) argues that the inherent redundancy, partial decomposability or partial irreducibility of a complex system may be resolved through a nested, multi-level hierarchy of ordering. Order at one level is dependent on order or rules at a more fundamental level, that in turn are dependent on even more fundamental order. This multi-level ordering forms the basis of a radical evolutionary theory that suggests that evolution may occur at any level in the genetic hierarchy: genes, chromosomes, individuals and species (Allen and Starr 1982). The concept of emergence suggests a multi-level system where the whole is more than its parts through the interaction between its parts. For a complex system, each part may in turn be a whole at a different level, which in turns has parts, ad infinitum. Complex systems are not random, although they may appear to be random. The missing information is either not known or, more particularly, not knowable. Here reflects the concept of irreducibility or non-separability. A complex system ceases to be a complex system when broken into its many component parts. The characteristics of a complex system do not exist with the parts in isolation. By complexity we refer to theories of complex adaptive systems in the physical and biological sciences (Kauffman 1995, Gould 2002, Prigogine 1980) and also in social sciences (Foster 2000, Axelrod and Cohen 2000). From basic systems theory, the concept of emergence helps: the whole is more than the sum of the parts. Emergent properties are the properties of the whole and are meaningful only at the level of the whole (Checkland and Scholes 1990). Returning to the definition of a complex system, the connections or relationships between the parts are imperfectly known. Thus it is not possible to know or understand a complex system just by examining its parts. Emergence is the flip side to irreducibility. By emergence, we mean the appearance of new characters at complex levels of organization which cannot be predicted solely from the study of less complex levels.

Consequently studying a complex system becomes a tough order when (i) it has aspects that are inherently unknown or unknowable, and (ii) with emergent properties that can only be observed at the level itself, not at the level of its parts. An approach to the analysis of complex systems has been to treat some aspects as random, then assume they do not matter but one of the defining features of complex systems is path dependence and their sensitivity to small differences or to small disturbances, as popularized by the butterfly effect (Gleick 1988). In that sense, complex systems are partially irreducible, rather than perfectly irreducible. If a system was perfectly irreducible, we could not know anything of the parts of the system, or even the existence of the whole system. Perfectly irreducible systems are not knowable at any level of form. Simon (1962, 1996) described the phenomenon of partially irreducible as ‘partially-decomposable’. The description of a complex system requires that it is either partially or completely decomposable. In this section we have discussed a number of features of complex systems: path dependence, emergence, partial irreducibility among others. Identifying and describing patterns is one of the most basic tasks in science. Complex systems, in that they can only ever be imperfectly known pose a significant problem for the approaches of knowing. Epistemology of complex systems, as the nature and grounds of knowledge especially with reference to its limit and validity, raises several issues. In the next section, we would like to suggest some possible solutions, by grounding our arguments on the hierarchy theory.

Hierarchical Approach for Innovation Systems

Discussing level of analysis requires making the distinction between plans and emergence (Allen and Giampietro 2006). Planning is expressed through constraints that are coded in some sort of language. In turn, emergence comes from positive feedbacks that drive processes until a pattern unplanned appears. Consequently, considering the level of analysis is the decision of the observer in the sense that the observer decides which level is planned and which level is emergent. However the two sources of order are linked together when meaningless emergence quickly becomes stabilized in a meaningful, coded structure. Order simply refers to there being a level above and another below but it does not say whether coding or emergence that is responsible for that. At a given level, limits come from the level below and constraints come from the level above in biological and social systems (Allen and Starr 1982) . This Theory fits quite well with the innovation system approach where scholars of innovation recognize several levels of innovation, the national level being embedded in a regional one, while by-sector and technological systems seem to cross these defined geographical boundaries. While these systems may exhibit behavior, they are themselves frozen as structures. Organisms enter the world with a model of the world, their worldview. Successful model reinforces essence that is realized through a structure. The world contains other organisms with their own models and self-knowledge comes not from the organism itself but from how the world treats the model. For innovation, you do not know you create novel solutions, until other entities select and adopt these novel solutions.

In hierarchy theory, duality is central by recognizing entities at different levels. The lower versus higher level entities exhibit a hierarchical structure that recognizes the two way relationship. A pivotal point is the role of the observer in the study of complex systems in the sense that the concept of level is relative to the point of view chosen by an observer (Ahl and Allen 1996). When an observer notices an entity, the question of scale and type arises. Levels may be ordered according to the scale at which each entity operates. However, to analyze complex systems, several levels need to be considered simultaneously due to the intrinsic characteristic that low-level details are linked to large outcomes at high level and affect sometimes the behavior of the whole system. Mechanical approach and reductionism tend to narrow down on systems parts in order to appear simple, at least when disaggregated. Hierarchy theory proposes a meaningful alternative by allowing the study of multiple levels and the relationships between these levels. Considering the definition of a hierarchical system as composed of stable, observable subunits unified by a super-ordinate relation (Ahl and Allen 1996), we argue that the notion of innovation system can be considered as hierarchical, based on the observer's criteria for defining the boundaries of such a system. The question of progress in health care requires taking into account both low-level details and high-level entities. Then multiple levels of observation are required for investigating this question (Ahl and Allen 1996). At a single level of observation, we can refer to either definitional entities, postulated before measurement or empirical entities, observed beyond the observer's control. We do acknowledge that empirical entities are completely observer-dependent and scale- and rate-independent and then they are experience-derived. Consequently, this approach fits quite well with constructivism where knowledge is derived from our interaction with observables and viewed in terms of 'situated action' where 'representations' of the world are mentally constructed, not given (Valéry et al. 1987, Le Moigne 2002, Piaget 1970).

We argue that 'innovation systems of firms' are systems where observed entities are found empirically. We can refer to equivalence class where the point of interest is the correspondence across the class between members and the class gives a defining type to the observed entity (Rosen 2000). Having clarified the class of entity, we can now look at the relationships between the different levels and ordering the levels require to make a distinction between level of observation as opposed to level of organization (Ahl and Allen 1996). Levels of observation are ordered on scaling principles, whereas levels of organization are matter of definition. Because empirical entities are defined by spatial and temporal (frequency) characteristics, they are ordered into levels of observation following this general rule: high levels of organization are populated by entities that are spatially large, or whose characteristic behavior is low-frequency; and lower levels of observation are populated by spatially small or high-frequency entities (Ahl and Allen 1996). Some system scientists have described the difference between the upper and lower levels in terms of relational functional and organizational structure (Simon 1962), essence and realization (Rosen 2000). In our context, we aim to describe innovation as the creation of instability of a given system and as such able to drive two possible outcomes: either the system collapses to a low level of organization; or alternatively a new set of upper-level constraints emerges and the system moves to a higher level of organization. Here are embedded as sources of instability, evolution and emergence, change in objective 'laws' or in subjective rules, sometimes at the same time. 'Laws' capture the dynamical aspects of the phenomena, structure-independent, whereas 'rules' are local and structure-dependent (Pattee 1973). We argue that at the firm level interactions of heterogeneous parts (institutions, firms) result in emergent solutions that could be sometimes described at a higher level as technological advance for the whole industry or sector or in a particular geography, as shown in Fig.1.

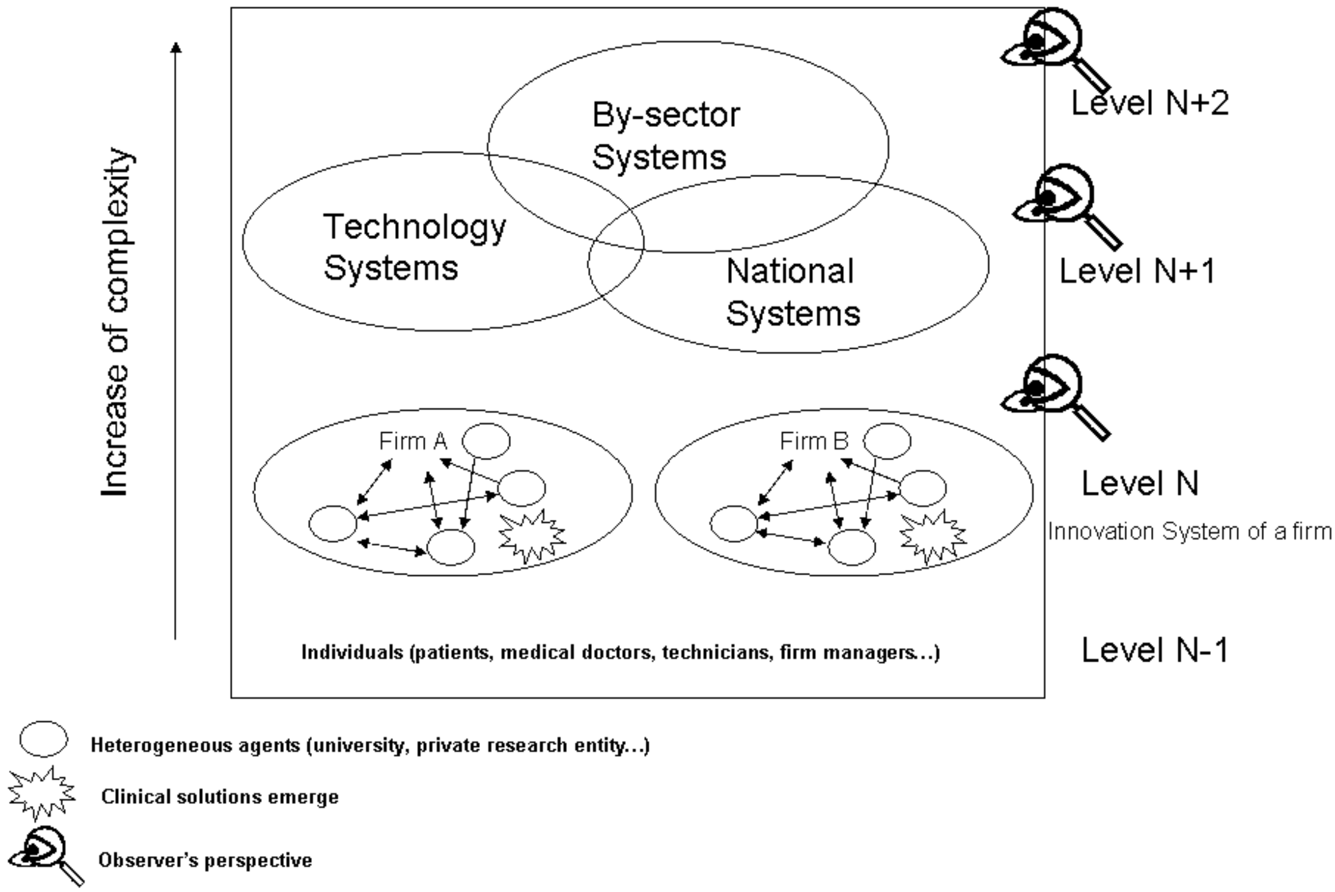

Figure 1. Innovation Hierarchical Approach

Source: Inspired and adapted from Allen, T.F.H. *et all*, Confronting economic profit with hierarchy theory: the concept of gain in ecology, *Proceedings of the 52nd Annual Meeting of the ISSS*, 2008, Madison, USA

Narratives and Emergence

Recognizing innovation systems as complex systems does not prevent us from measuring them. A measurement indicates some version of degree and we have to find a way to appropriately measure them. Complex systems cannot be modeled (Rosen 2000) for various reasons: parts have multiple identities. For instance, in the innovation system of a given firm in health care, medical doctors can be at the same time providers for the patient and customers for the firm. Moreover, units of measurement are incommensurate, scale changes become as large as to have qualitative implications and adequate description demands more than one level of analysis due to the specific properties of the complex systems we did elaborate earlier on. In this context, narratives exhibit important characteristics that position the use of narratives quite well to overcome the absence of modeling. Absence of modeling does not mean absence of meaning to this extent that justifies the use of narratives. By narrative, we mean some kind of retelling, often in words, of something that happened (a story). The narrative is not the story itself but rather the telling of the story. While a story just is a sequence of events, a narrative recounts those events, perhaps leaving some occurrences out because they are from some perspective insignificant, and perhaps emphasizing others. Narratives shape history (the series of events, the story of what happened). Thus, narratives capture relationships which appear at the level of analysis chosen by the observer (Allen and Giampietro 2006). A narrative implies a hierarchy that links different types of objects, even uncertain or contradictory. Unlike models, narratives do not claim being objective and unambiguous about the external world. The use of paradigms, as relevant narratives that support the conscious decision about discrete significance with regard to some set of events, simplifies on purpose complexity in the sense that paradigms assert structure and relationship simply enough that models can be tested. Narratives are designed to describe the meaning of experience and do not pretend to any form of prediction, unlike formal models. Using narratives, we recognize the validity of verbally expressed theory and we argue that our framework refers to 'appreciative' theorizing' (Nelson and Winter 1982) where attempted descriptions and explanations of what is going on are central to properly describe emergent innovation, rather than a more abstract and more formal theory. Relevant to this discussion, evolutionary theory in biology is largely articulated verbally, and the empirical phenomena that evolutionary theory addresses largely described in narratives accompanied by pictures and charts. Similarly for firms, we argue that a better understanding of innovation patterns requires more detailed observations of firms including a variety of their qualitative features. Our argument here is not to denigrate efforts to develop a formal dynamic modeling but to complement these tools with detailed narratives of what has been going on in an industry. Actually, the dynamic processes involved in innovation are much more complicated than that models suggest, due to some evolutionary characteristics (Nelson and Winter 1982).

Evolution lines up with continuity of structures and the generation of complicatedness. Changes occur in a continuous way, whereas emergence corresponds to discontinuous change (Allen et al. 1999). In evolution, we can distinguish two levels of structure: the upper level is the unit of evolutionary change, while the lower level includes the units of selection. The units of selection are passed through a filter. Consequently the population that existed before the selection process still exists but in a different state. Evolution can be described a change of state. Meanwhile, emergence invokes a new structure coming into existence that did not exist before. Emergence involves a structural change and consequently an increase of complexity (Allen et al. 1999). Definition of types of interactions between species (e.g. parasitism, mutualism) are categorized in basic ecology, where the concept of co-evolution appears (Odum 1983). Evolution includes competition but accounting for long-term, mutualism in biological evolution builds relationships which take on a life of their own (Allen and Giampietro 2006). Similarly, we argue that the meaning of experience in an innovation system of a firm corresponds to the emergence of new structures, opposed to the straight evolution of this system. A central proposition of this view is that this co-evolution determines the fates of organizations. The structures that emerge spontaneously in complex systems constrain the choices of individuals and fashion their experience. Each actor is co-evolving with the structures resulting from the system. In case of innovation, what emerge are ecologies of behaviors, beliefs and strategies, clustered in a mutually consistent way, and characterized by a mixture of competition and cooperation. The theory of innovation contained in the framework stresses features that are prominent in complex dynamics systems. One is path dependence. What happens to the system today can profoundly influence how the system will evolve in the future. In other words, history matters. The framework presents a picture of strongly path dependent innovation process. A second feature is the possibility of strong interactions among variables. Firm innovation and its correlated result, its growth, are not the result of only technical advances or capital intensity or any other variable. Conventional economic theory stresses the primacy of for-profit firms, in competition with one another, operating in markets in which supply and demand are so as to determine equilibrium prices and quantities. In this setting, other entities such as universities or scientific and technical societies are not placed in this picture. We alternatively argue that technical advance is a driver and a catalyst, in which aside from firms alone, a set of institutions play a significant role. It is not necessarily 'optimal' because there are a multiplicity of subjectivities and intentions, fed by a network of imperfect information and diverse interpretative frameworks. In this kind of human systems, at the micro level, decisions reflect the different expectations of individuals based on their past experience (Hippel 1988)

Boundaries and Worldviews

Due to the improvement in communication technology as well as the interconnection of local economic activities, an important issue is how to delineate this system of human activities including interactions, exchanges and discourse, within inter-organizational networks of heterogeneous agents. The interaction of these decisions actually models the future but in turn will often fail to fulfill the expectations of many of the actors. This may lead them to modify their understanding of the world, their worldview. Evolution of this kind of complex human-based systems is therefore a continual, imperfect learning process, spurred by the difference between expectation and experience, but rarely this process provides the actors with enough information for a complete understanding. In turn, this multiple understanding allows search for diversity, exploration and hence, learning for innovation. The idea that in our settings, evolution and its outcome, innovation, might lead to a community of interlocking behaviors is itself an important result. Successful innovation system is largely a tale of increasing cooperation and complementarities, not competition (Gelijns and Rosenberg 1994, Malerba et al. 2007). An innovation system is a set of different activities that to some extend 'fit together' and need each other. Consequently, aspects of this innovative system are local skill development and specialization, co-evolution of activities to each other, networks of information flows that lead to a collective generation of innovative solutions shaped through exchanges and discourse within the system. Through narratives, the innovation system of a firm adequately describes the complex interactions between firm and lead users and it suggests the creation of 'webs of significance' based on the epistemological model inspired by Vickers and developed by Checkland and Caesar (Checkland 2005). Applying the 'appreciative system' model of Vickers, we argue that firms may facilitate the creation of the webs of significance that define and constitute for firm managers the perceived world they refer to. In this framework, groups of various sizes gain experience of the world. These experiences stem from both events and ideas in the world and also from previous perceptions, interpretations, judgments and actions of heterogeneous agents. In turn, experiences generate new interpretations of the perceived world by firm managers in the sense that the real-world experiences support the generation of standards, norms and values. Interpretations and standards together enable firm managers and lead users to make the judgments that are a source of action within the world. That action will simultaneously have impact on the current world and condition future experience, modifying over time the ability to recognize certain features of perceived situations as significant. Consequently, action and the related judgments attached to it will modify standards, norms and values previously used.

The whole cycle combines thought and action in a dynamic way, where lead users help firm managers to change their 'appreciative settings' about the innovative path in medical imaging. This holistic perspective provides also firm managers with a platform for improvement by viewing firm and network of lead users as a system and in particular a system of knowledge creation, where gaps and incompleteness may still exist. Finally, holism encourages reflection of the worldview adopted and reflection on other potential worldviews (Checkland 1981). In the innovative system of a firm, this could include a shared worldview where scientific discovery, technological change and lead user practice are all important and become a common goal, opposed to a worldview where knowledge is a tradable commodity. This common goal would help firm managers to delineate the innovation system of their firm, by recognizing incompleteness of their knowledge base and existence of alternative sources of knowledge. Then, boundaries of the system fundamentally vary upon firm managers' worldviews: movement of new members into the networks enables the re-formation of the inter-organizational network that selects among competing technological and clinical alternatives. We arguably consider hierarchy theory as an adequate system theory for making use of trans-disciplinary analogies, enhancing this holistic perspective. It helps us conceptualize the complex organization-environment relationships and it allows us to capture the dynamics of the system where change and flow co-exist. Hierarchy theory explicitly and correctly describes the role of the observer in his ability to recognize the boundaries of the system he draws and by identifying characteristics of the system and delineating the system, the observer does so from a particular worldview, producing partial knowledge that could be challenged by other worldviews. In our settings, firm managers may act as observers of the innovation system of their own organization and by doing so, may create through narratives a unified story from which each of the parts contributes to the generation of innovative ideas. In turn, they may acknowledge that by managing such complex systems in this way, they will never solve their problems for ever (Ackoff 1981, Checkland 1981) but at least they will get a holistic perspective of things happening in their direct environment.

CASE STUDY: EMERGENT CLINICAL SOLUTIONS IN MEDICAL IMAGING

In order to link the hierarchical development of innovative system at the firm level in respect with emergence, this section provides some historically grounded illustration of the co-evolutionary cycle, using the Medical Imaging computed tomography industry as the focal example. The co-evolution of the technological environment, firms and lead user interactions is briefly sketched, in order to identify some central relationships, which will be examined in more detail in the discussion section.

Computed Tomography Industry Dynamics

At the early stage, the X-ray tube rotated around the patient and acquired one slice. Then the table moved, while the X-ray and detector went back to their initial position, in order to get the next slice of the patient. In 1990's helical Computed Tomography devices (CT) were introduced by Willi Kalendar and Kazuhiro Katada, allowing a complete freely rotating motion of the X-ray tube/detector couple around the patient. The table moves while the X-ray tube/detector rotates, resulting in a helical path of the X-ray beam. The slip rings for data transfer and the power supply miniaturization were the key technology enablers for helical CT's. In 1993, the Elscint Company (Haifa, Israel) introduced a dual-detector ring, with a complete rotation in a second: the multi-CT was born, with the beginning of the race to higher rotation speed and multiple detector rings (2, then 4, then 8). In 2000, the multi-slice CT's were widely distributed as dual-slice CT, 4-slice, 8-slice CT systems. The number of slices was originated by the number of detector lines receiving the X-Ray beam, associated with a critical characteristic, the sickness of detector lines. In 2000, was introduced the first 16-slice CT system with sub-millimeter resolution: combining 16 slices of acquisition per rotation, this new CT was designed with more lines and even thinner detector lines, allowing further spatial resolution, for instance for brain vessel analysis or for heart coronary check-up. In 2004, the 1st 64-slice CT was presented during the world radiology congress, in Chicago, USA as a prototype and in 2005, the 64-slice CT was introduced, achieving in a single rotation 64 slices at a sub-millimeter resolution: in less than 5 seconds, the entire heart is acquired, in 20 seconds, a head-to-toe scan is performed, in a routine manner. In 2007, a 320-row detector CT was announced, allowing to scan the entire heart in one second and to see for the first time a dynamic blood flow in the brain. Such performances drive several consequences for medical procedures. For instance, Heart has always been considered as the most difficult organ to scan: the heart motion could be slow down (breath hold, beta blockers…) but never stops, while the anatomical structures involved, the coronary arteries which bring oxygen and energy to the muscle, are very small (0.5mm diameter at the lowest point).

The exponential Information Technology development brings big improvements to the CT device: at the early stage, the radiologist did have to wait up to several hours between the native images and the reconstructed images, due to the needed complex algorithm calculation (Fast Fournier Transform matrix). Nowadays, the CT provides reconstructed images on the flow of the acquisition, directly on the operator console. Moreover, the micro-processor speed increase allows the development of specific software applied to dedicated clinical applications, on separated workstations from the operator console: from reconstructed images, the Medical Doctor (MD) uses clinical application software to perform a complete Vessel Analysis based on a body run-off, or a coronary assessment for the heart, or nodule detection for the lungs. With the Computed Aided Diagnosis, the physician even gets a pre-visualization of the areas of interest, for Nodule detection. With faster reconstruction engines and increase of detectors, the CT system provides physicians with numerous images for a given area of interest: with a 64-row detector CT system, in less than 10 seconds, for a heart exam, the radiologist has to deal with 4,000 reconstructed images, showing all the heart phases and the coronary artery system. The CT system is no more the bottleneck for getting a timely diagnosis, the physician now is. A key concept emerges, so called the workflow, which describes the routine work from acquisition to diagnosis reporting, involving streamlined processes and optimized work for the radiologist, overloaded by the exponential number of images.

Recent advances in medical imaging technologies have expanded doctor ability to closely examine the internal workings of the human body. Not only structure of the body but also the working of organs and cells can now be visualized in detail. Such technologies are useful for doctors for making diagnosis and planning treatment. While ordinary X-Ray examination takes a front-view picture of the inside of the body, CT uses X-ray to depict human body as a series of cross-sections. In this way, it reveals a deeper image of the body that would be hidden behind organs from a front view. Physicians can examine the body in greater detail when they obtain more cross-sections at smaller intervals. CT Technological advances result in easier and quicker exams of the body, depicting greater details. Our case study shows a high stability in the hierarchy of leading innovators, which is related to high appropriability and high cumulativeness conditions (Dosi and Malerba 1996) as shown in the Table 1.

Date	Company	Product name	Row Detector	Technology Regime or Wave of innovation	Clinical Performance	Cardiac Imaging
1971	EMI		1	Invention		
1989	Siemens		1	Helical CT	Exam time	
1993	Helscint	CT Twin	2	Dual Slice	Exam time	
1994	All		4	Multi-slice CT	Exam time	
1998	All		8	Multi-slice CT	Angiography	
2000	Siemens	Sensation 16	16	Multi-slice CT; Isotropic view	Cardiac, angiography	12 secs
2001	GE	Lightspeed Pro 16	16	Multi-slice CT; Tube Power	Obese patients	12 secs
2003	Siemens	Sensation 64	32	Flying Focal spot	Image quality	7 secs
2004	Philips	Brilliance 40	40	High-resolution CT	Body coverage	7 secs
2004	GE	VCT	64	High-resolution CT	ER, Cardiac	5 secs
2005	Siemens	Somaton Definition	64	Dual-source X-ray	Cardiac; Metal artifact reduction	5 secs
2007	Philips	Brilliance iCT	256	Dynamic CT	Dynamic flows (cardiac, Brain...)	2 secs
2007	Toshiba	Aquilion One	320	Dynamic CT	Dynamic flows (cardiac, Brain...)	1 sec

Tab. 1 Innovation in CT and Clinical Performances

As Nelson argues (2005), technologies are to be understood as involving both a body of practice and a body of understanding. There is a belief that modern fields of technology are, in effect, applied science, in the sense that advancing technology essentially is a task of applying scientific knowledge to achieve better products and process. Yet the proposed theoretical framework suggests that technological advance follows an evolutionary process in the sense that it derives from technological practice and understanding of several actors, beyond a strict planning of a scientific search. CT Cardiac exam practice grew up not a science per se, but as a field explicitly dedicated to solving particular kinds of practical problems and advancing bodies of practical technology. Advance of understanding sometimes leads to effective efforts to improve practice and advance in practice sometimes leads to effective advance of understanding. The use of a CT scanner to look at the heart initiated in 2000 by a French radiologist in a private cardiac center, in the north of Paris was a pioneering effort to better assess the growing demand on coronary assessment, despite some medical device alternatives (Nieman et al. 2001). Later, the combination of improvements in terms of temporal and spatial resolution made this non-invasive practice becoming a standard procedure within the industry, resulting in an advance in terms of pre and post-surgery understanding. In that sense, paraphrasing Nelson, our model suggests the co-evolution of technological practice and understanding, not only at the firm level but at the whole industry level. The criterion of usefulness for the technical advance lies in the adoption of the different actors and its validation occurs at the end of a selection process, which combines competitive firms and institutions.

Computed Tomography Manufacturers and Lead users

Looking at the official firm background of the top medical imaging manufacturers, we find a commonality in terms of mission statement and the international dimension of their operations.

About GE Healthcare "GE Healthcare provides transformational medical technologies and services that are shaping a new age of patient care. Our expertise in medical imaging and information technologies, medical diagnostics, patient monitoring systems, […] is helping clinicians around the world re-imagine new ways to predict, diagnose, inform and treat disease"

About Siemens Medical Solutions: "Siemens Medical Solutions, with headquarters in Malvern, Pa., and Erlangen, Germany, is a healthcare technology innovation leader"

About Philips Medical Systems, "[…] Today, Philips Medical Systems is a global leader in diagnostic imaging systems, healthcare information technology solutions, and patient monitoring and cardiac devices."

About Toshiba Medical: " […] Today, Toshiba's focused offering of imaging technology continues to save lives and improve the health of people around the world with some of the most powerful and patient-friendly systems available"

The choice of the Computed Tomography product line is linked to specific reasons from a methodology standpoint. First, among all the product lines of the various medical devices makers, the Computed tomography is a fairly new product line, originated in 1970's and has been developed mostly internally by the main device makers. Second, the CT product line is considered as a mainstream medical device, distributed globally and used all over the world from the low-end CT (mono-slice CT) to the high-end medical equipment (64-row detector CT and above).

In this technology-dominated industry where group of buyers interact with limited players, to acquire complex types of system, several business characteristics surface. First, a tension exists between the willingness of each competitive firm to gain market share and the CT market growth tends to slow down under the local budget constraints (in terms of reducing both the reimbursement rate and the volume of procedures). Second, incompleteness of information for each of the players in a competitive environment tends to get a specific meaning in this industry, where physicians get access to various CT systems, while working and while attending Radiology congresses (ECR, RSNA, Arab Health, Japan Radiology Congress…). In such an open information context, we aim to assume that each player knows at least the next CT generation projects from the competition, that we claim being the common knowledge base. Third, if at the beginning of the industry, simple specifications were the key technology differentiators (number of detector, acquisition time, reconstruction time…) of simple CT systems, the multiple choice of new technology applications combined with the versatility of the CT system in the daily medical practice aims to make the possible offering more complex and as such the strategy formulation for CT manufacturers: what technology should they push? Where and how should they sell it? Fourth, manufacturers deliver privileged information to their "opinion leader" customers in order to retain them and to ask them validating from a clinical standpoint any technology innovation. Manufacturers create local, regional or global "show sites" where the CT system operates in optimized conditions, under the leadership of opinion-leader radiologists, in well-known hospitals and clinics, creating a "word-to-mouth" marketing effect. For instance, Siemens Medical Solutions develops strong relationship with Prof. Kalendar at the Erlangen-Nueremberg University Hospital, Germany and at the Mayo Clinic, Rochester, MI,USA, while GE Healthcare Europe actively supports the "Centre Cardiologique du Nord" (CCN) in Saint-Denis, France, where operates Dr. JL Sablayrolles, pioneer of the CT cardiac imaging. Toshiba Medical Systems intensively uses the medical expertise of the Fujita Health Center in Japan to test their new CT systems.

Co-evolutionary innovation is characterized by the dynamic capability for a given firm to select the medical sites, co-developer of the technology advance and to integer in the design the proposed changes during the development process. The paradox lies in the fact that a possible dominant design may only exist if the number of actors using this new design exceeds the community of actors involved by the firm at its initial stage. Until this turning point, the firm design remains a proprietary design and will be limited in its diffusion by the number of actors the firm can convince. However, if the firm design becomes dominant design, then the firm has to see its technological advance being copied by other firms. In 2000, GE did launch a new 16-slice CT system, claiming a bigger aperture for the gantry: such a new feature was directly influenced by the large proportion of over-sized US patients that could not previously benefit from CT, due to their circumference. Such a product feature claim, resulting in higher costs, did not find any echo in Asia and Europe. In contrast, Toshiba did always focus on small footprint designs for their CT line up, as a key product characteristic, to fit into the small radiology rooms of the urban Japanese hospitals. Consequently, GE large footprint CT designs did not get strong interest from the second Healthcare Market in the world, Japan, until they developed in 2004 a small footprint CT scanner, designed by the Hino GE R&D site.

CT Co-evolutionary Innovation Pattern: Emergence of New Clinical Solutions

In Health care, the innovation system of the firm, it is argued, consists of complex interactions between medical technologies and clinical practice where developments emerge from and feed back into the system through transfers of knowledge between firm research centers and clinical practice performed by independent lead users. These developments are a combination of technology and clinical practice, in other words, lead user prototype on site new clinical solution that connects distributed technology and service delivery component of the innovation system. Clinical solutions are then defined as a development of technologies and techniques through medical practice, with respect to the problem-solving dimension for the patients. In healthcare, it implies that clinical solutions are progressively refined through experience as pictured in Fig. 2.

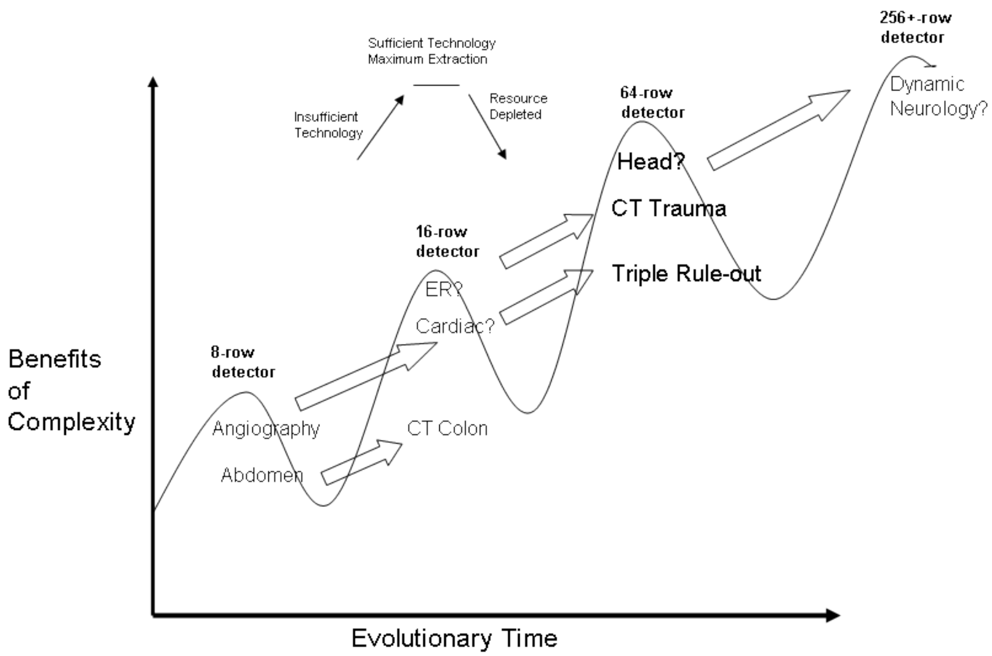

Figure 2. Emergent Clinical Solutions in Computed Tomography (1998-2008)

Source: Inspired and adapted from Allen, T.F.H. *et all*, Confronting economic profit with hierarchy theory: the concept of gain in ecology, *Proceedings of the 52nd Annual Meeting of the ISSS*, 2008, Madison, USA

Narrative of CT emergency clinical practice

Since 2001, French University Hospital La-Pitie Salpetriere did make the decision to install their GE 16-slice CT, not in the radiology department but directly in the emergency department: the fast acquisition of a large set of anatomical structure appeared to secure the vital diagnosis of poly-traumatized patients, coming from the south of Paris (more than 250 poly-trauma patients are treated on an annual basis at this hospital). A unique medical expertise was consequently built between radiographers, radiology doctors and emergency doctors: for instance, to “save” broken vertebral spine nerves, the “golden hour” guideline has to be strictly followed between the accident and the surgery. After this 60-minute timeframe, there is unlikely no chance to get the spinal nerves working and as such, patients encounter high paralysis risk. Each minute counts for poly-trauma patient: vertebral spine assessment, pulmonary embolism diagnosis, internal bleeding, pleurothorax, and aorta dissection, heart failure, all life-threatening causes need to be properly diagnosed and treated in a very limited amount of time. From 2001 to 2004, Dr C. Beigelman and her colleagues developed step-by-step settings of the CT system with pre-defined acquisition protocols and reconstruction views for whole-body scan, routinely used when receiving a poly-trauma patient (Fanucci et al. 2007). GE Healthcare using this site to promote their 16-slice system rapidly acknowledged the unique value of tailored settings for specific clinical applications and decided to support further IT development on this clinical CT-based Emergency application, in close relationship with Dr Beigelman. Moreover, with the coming 64-slice CT system, scanning time could be reduced to 10 seconds from head-to-toe, opening new areas of clinical progress (Anderson et al. 2007). Combining pre-defined protocols dedicated to Emergency and available technology, in 2004, GE Healthcare claimed having unique clinical emergency CT-based applications and used La Pitie-Salpetriere as a show case. In 2004, the largest Trauma center in Sweden, Karolinska Hospital in Stockholm acquired two GE 64-slice CT systems, based on this unique value. On site, emergency doctors and radiology doctors designed and implemented a dual innovation to manage trauma patients. First, they agreed to install the medical device in the emergency department, rather than in the radiology department, creating a more efficient workflow in terms of patient management. Second, the radiology doctors developed new scanning protocols and post-treatment protocols, for faster acquisition and body area visualization, going far beyond the initial CT manufacturer software capabilities. This new set of clinical applications was named 'CT Suite', corresponding to two forms of innovation: on the one hand, for unstable patients, the 'CT triage' workflow with fast acquisition without fine-grained details, on the other hand, for stable patients, the 'head-to-toe protocol' characterized by complete assessment of the patient, before being transferred to the operating room (Broder and Warshauer 2006). The supply-side and the demand-side interact according to a co-evolutionary pattern: firms request opinion-leading institutions to define their medical-oriented needs. The field study illustrates the mechanics and the causal drivers of this co-evolution process. This co-evolution has two distinct stages, or aspects: one, which moves from variation to selection, one from selection to adoption.

CT cardiac imaging narrative

The previous section presented some empirical evidence of the emergence of clinical applications within the previously defined innovation system of the firm. Such a system is characterized by a distributed activity across professional groups that feature a remarkably relational nature and progress is a collective process that relies on semi-open systems of understanding. Within the system, agents share some knowledge bases, evolving in time and in location. More fundamentally, we argue that the 'innovation system of the firm' in healthcare lies at the front-line of patient-care delivery and extends the classical function of clinical researchers, who often assess the impact of basic research and R&D efforts, through clinical trials. Lead users formulate, design and implement new protocols based on their experience and their history-dependent trajectories of change, clearly spanning across the public-private divide. In turn, they tend to be involved in some paradigm shift occurring in health care. Coronary artery disease (CAD) is the result of a process called atherosclerosis through which plaque forms on the inner layer of the coronary arteries and impedes the flow of blood to the heart. If untreated the eventual outcome of the process may be a heart attack. For some years now cardio-vascular disease has been the leading cause of mortality in western countries. Progress in the field of cardiac imaging has encouraged the development of a reproducible, reliable, non-invasive technique that provides clinicians and patients with timely relevant clinical information. Multi-row scanners (16 sub-millimeter slices in one 0.5-second rotation of the tube) made it possible to obtain 2D and 3D images of all cardiac structures and the coronary arteries in one single 20-second ECG-gated volume acquisition with injection of iodine-based contrast medium. This non-invasive imaging procedure did emerge as a solution for early CAD diagnosis, supporting some heath care paradigm shift, from reactive medicine to preventive medicine. Some pioneers in hospitals did compare these new techniques to current examinations (coronography, myocardial scintigraphy, echocardiography) by intensively exchanging results within their institution and sometimes outside through publications and conferences in medical congresses (Nieman et al. 2001). In the north of Paris, the 'Centre Cardiologique du Nord' (CCN) has been among the early inventers of this new technique in the radiology world since 2000, leading to achieve the challenge of replacing invasive diagnostic coronary angiography by a non-invasive innovation, the CT cardiac imaging (Sablayrolles 2002). Dr J.L. Sablayrolles and his team has developed this technique in the context of close collaboration between internal actors of CCN (radiologists, technicians, cardiologist and heart surgeons) and external actors (CT device research engineers of the CT manufacturer and contrast media producer). This private clinic did not only validate the performance of new scanners by providing CT manufacturer with clinical cases but also improved acquisition technology and post processing to validate new cardiac CT applications, so called clinical applications. This set of innovation is a combination of new acquisition techniques: patient preparation (including oxygen therapy to facilitate breath-holding), acquisition parameters (compromise between spatial and temporal resolution) and injection parameters. This innovation includes post processing techniques that have been introduced by radiologists on site. At first, fast, reliable reconstruction software packages have been developed by CT manufacturers, providing 2D and 3D images in any plane but the extensive clinical experience of the CCN radiologists required new tools to extract all the information contained in this ECG-gate, multiphase volume acquisition. With a 64-row detector CT, any cardiac exam represented a set of 2,700 images and the radiologists of CCN developed a new workflow in order to cope with this amount of data, while managing the accuracy of the potential CAD assessment. Consequently, they initiated a rigorous multiphase review protocol: (1) morphologic and kinetic study of left ventricular wall and cardiac valves, (2) selection of diastolic and systolic phases for function analysis, (3) selection of the best phases for the right coronary artery and for the left coronary system. Such a workflow was then codified and incorporated by the CT manufacturer within its next release of advanced clinical applications, creating a new set of clinical solutions for radiology doctors using the CT medical device. Innovation of that kind contributes in health care to some paradigm shift: the CT cardiac imaging enables coronary investigation and a search for myocardial lesions in a single out-patient visit, when its non-invasive dimension and its 'protocolisation' expand the number of patients who may benefit from this technique. In turn, this new clinical solution being introduced, clinical practitioners face the difficulty of fixing the right indications for its use in specific clinical situations. Prescription of the new exam will depend not only on its clinical relevance but also its freedom from risk, its cost and the availability of equipment. For some indications it is complementary to traditional techniques, while in others it can replace them. Consequently, this co-evolutionary innovation depends on the contexts of use in which it is embedded and on the differential cost structures generated by the uneven progress of knowledge across pathways of learning in different clinical areas and domains of know-how (Nelson 2003).

CT Colonography narrative

Computed tomography colonography (CTC), known as virtual colonoscopy, is as accurate in screening for colorectal cancers and pre-cancerous polyps as conventional colonoscopy, the current invasive screening standard. Colorectal cancer is the third most common cancer in Western countries and the second leading cause of cancer death in the United States. Yet screening rates are low, most likely because current screening methods are invasive and unpleasant for patients. However, almost all colon cancers are essentially preventable. With lung or breast cancer screening, doctors look for the cancer itself. In contrast, colon cancer screening identifies precancerous lesions, which are removed before they become cancer. Consequently screening is absolutely. Conventional methods carry a higher risk of perforation and infection than CTC and patients must undergo sedation, which takes them out of action for an entire day. With CTC, patients can be in and out within 30 minutes, and back to work the same day, with no sedation and no loss of function. Since 2001, Dr. D. Hook, a pioneering researcher in CTC, has trained hundreds of radiologists to perform and interpret CT colonography in Europe (Hock et al. 2008). Dr. Hook by her daily practice demonstrated that CTC uses safe, non-invasive X-ray technology to create detailed two- and three-dimensional images of the colon and surrounding organs in less than one minute, in contrast to conventional colonoscopy, which uses a 200-cm long scope inserted in the patient's colon. Dr. Hook did experience CTC with a CT 16-row detector scanner by developing new clinical acquisition protocols for abdomen scans and by designing new post-processing visualization of the Colon on her post-processing console. Both improvements were the results of trial-and-error processes, associated with several hundred of clinical cases. In 2005, the 'Clinique Saint-Joseph' in Liege, Belgium did celebrate the 1,000th CTC performed by Dr. Hock by organizing a press conference for medical doctors in order to promote this non-invasive screening practice. Such a clinical experience was captured by a software engineer of a CT manufacturer, who did automate virtual dissection of the colon, based on the doctor's requirements. This beta-version was installed in some other European leading University hospitals, such as Hospital La Pitie-Salpetriere with Dr. M. Cadi, France, 'La Sapienza' University Hospital with Prof. A. Laghi, Italy, to capture additional feedbacks. This co-evolutionary innovation pattern did result in features such as 3D virtual endoscopy, 2D reformats in any spatial plane and auto-dissection of halves in rotation around the long axis of the colon, embedded in the clinical application software of the CT manufacturer. Rapid clinical dissemination was highly facilitated by the professional association, ESGAR, European Society of Gastrointestinal and Abdominal Radiology, which has been organized since 2003 series of workshops or hand-on trainings taught by CTC experts in Rome/Italy (2004), Bruges/Belgium (2005), Edinburgh/U.K. (2006), Pisa/Italy (2006), Nizza/Italy (2007), Malmö/Sweden (2007), Vigo/Spain (2008), Berlin/Germany (2008) (Taylor et al. 2007). In parallel, this clinical procedure was widely tested in the United States (Yee et al. 2003) and it rapidly gained acceptance, having been endorsed earlier in 2008 in new screening guidelines issued by the American Cancer Society (McFarland et al. 2008).

DISCUSSION

Applying our hierarchically-based framework provides us with some practically insights for firm managers: (i) the interdependence understanding requires a holistic perspective for firm managers; (ii) the way of learning for firm managers is to cope with relationships dynamics and unpredictability; (iii) the need for firms to globally build complex institutional networks, to develop opportunities for growth. We will argue each point in some more detail.

First, faced with complexity, change and diversity, firm managers may turn to external resources for search of novelty in the context of technological change. This holistic perspective missing, firm may concentrate on the parts of the innovative system, rather than the whole and by doing so they may not acknowledge the pivotal interactions between the parts of this specific innovative system. Going further, firm managers may tend to optimize the performance of their own organization, without recognizing that this ‘sub-optimization’ may have consequences that affect the whole (Jackson 2006). Consequently a systemic approach is required to provide firm managers with some benefits of holism. Critical systems thinking provides a framework to guide firm managers in the use of system theories (Jackson 2003, Jackson 2006) and the specific context of inter-organizational collaboration between firms and other parts of the innovation system implicitly recognizes the importance of this holistic perspective in several ways. It concentrates on the system as a whole, rather than parts of the system, avoiding the limitations of reductionism. It explicitly recognizes the structure and process in the development of new ideas, such as clinical solutions in medical imaging. In the same vein, ‘soft systems methodology’ (SSM) effectively supports the development of a narrative about structures and processes interacting within a given environmental paradigm (Checkland 1981) and empirical evidence has shown SSM as a useful vehicle to structure the problem situation and to channel the search for possible solutions related to technological innovation (Löffler et al. 2009).

Second, we argue that under high uncertainty, in terms of a rapid change of technology, there is a greater need to engage in outside relations, for the sake of flexibility and cognitive distance. We argue that in contrast with forms of organization between market and hierarchy, complex evolving environment drive a variety of network structures between firms and institutions. Some strategic management theories advise managers what to do in order to achieve goals in an optimum way. It teaches them how to organize the parts of a firm into a coherent structure. It seeks conformity from employees to managers and emphasizes detailed control procedures to ensure that this is realized. By contrast, our framework argues that the central strategic function of firm managers is to change their way of thinking, abandoning mechanism and determinism. The way of learning is to appreciate and cope with relationship dynamics and unpredictability.

Organizations co-evolve with their environment and therefore managing relationships with the environment is pivotal. Managerial cognition (belief formation) is to intuitively grasp the patterns that are driving the behaviors of firm organizations and the environment they are confronting. Managerial cognition looks for patterns in the whole and seeks small changes that can have the maximum impact. With its emphasis on holism, emergence, interdependence and relationship, our model definitely uses a systems approach. Firm strategy makers are increasingly interested in understanding the evolutionary dynamics of their business environment, in the interest of extending their bounded foresight in dynamic settings. What matters is represented by the forces that shape the structure of their competitive environment, forces that we describe as parts of an evolutionary mechanism between firms and lead users.

Third, we arguably advocate that firms need to build complex institutional networks for new opportunities to grow. However co-evolutionary innovation is difficult to manage precisely because the structure of the firm organization is designed to manage the primary interdependence within its own organization, not the complex informal institution-firm relationship that may become the innovative partnership. To cope with the diversity of viewpoints, these complex networks are not only developed in a specific country but include institutions from several parts of the world, requiring both permanent balance between poles and collaborative relationships between involved institutions and the firm. This dimension reflects the pivotal question of diversity of worldviews from heterogeneous agents and its correlated question of selection through a learning process by firm managers. Hence, the existence of institution-firm network is a necessary but not a sufficient condition for co-evolutionary innovation.

In addition to the above theoretically and practically contributions, the study suggests several potentially fruitful directions for future research. Additional studies are needed to explore the generality of our results over longer periods of time and in subsequent complex industries (Ultrasound, Magnetic Resonance for instance). The possible difference between short-term and long-term patterns of innovation as emerging strategic moves is a complicated issue, both conceptually and methodologically. On the one hand, it is tempting that innovation strategies and their interactions with the industry can only be evaluated in the long run, as the pattern of innovation unfolds over the time. On the other hand, innovation is an ongoing and emergent phenomenon and resource deployments are made in real time according to short-term feedbacks. This suggests that patterns of long-term innovation are primarily aggregations of short-term decisions and our focus on short-term strategy and actionable solutions is not only appropriate but preferred. Adjudicating between these two interpretations of our results will be possible only with the collection of cognitive data over a longer time period with a cross-sector approach.

CONCLUSION

This research investigates the relationship between firm innovation, lead user interaction and industry dynamics, within a system perspective. Drawing upon economics, innovation and systems science literatures, we have constructed a hierarchically-based framework that contributes to explain the emergence of clinical solutions by recognizing the existence of innovation systems of firms. Our hope is that this narrative-based analysis of emergent innovations in business complex environments will help bridge the distance between the evolutionary approaches on innovation and the systems theory. Understanding how firms identify effective strategic positions for innovation in a complex world requires a holistic perspective. With the current work, we try to provide some substance of that link and a framework on which we can build.

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