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COMPLEXITY AND ORGANIZATIONAL CHANGE IN THE COORDINATION OF TECHNOLOGICAL KNOWLEDGE: EVIDENCE FROM THE AUTOMOBILE CLUSTER IN TURIN

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COMPLEXITY AND ORGANIZATIONAL CHANGE IN THE COORDINATION OF TECHNOLOGICAL KNOWLEDGE: EVIDENCE FROM THE AUTOMOBILE CLUSTER IN TURIN[1]

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Abstract. The paper adopts a complexity perspective to understand the transformations in the organizational forms that coordinate the generation and dissemination of technological knowledge within firms. Complexity theory provides the framework to understand the evolution and transformation of economic systems. These are seen as emergent processes brought about by changes in the structure of interactions among actors. Changes in those interactions are steered by the modification in the pattern of specialisation and differentiation in the capabilities and technological skill of economic actors. The paper illustrates these elements through the evidence of the automobile cluster in Piedmont, in North-western Italy. This is characterized by the emergence of a distributed innovation platform, which is seen as a major organizational innovation in the organization of diffused technological capabilities.

Keywords: Complex systems dynamics; Coordination; Innovation platforms; Networks; Technological knowledge

JEL Classification: O31; O32; O33

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1. INTRODUCTION

Complexity theory has been receiving special attention in natural as well as human and social sciences in the last decades. In particular, complexity theory progressively emerged as a new approach able to appreciate and explain both the structural and dynamic properties of transformation processes characterizing biological, human and social systems (Anderson, Arrow and Pine, 1988; Barabasi, 2002; Kauffman, 1993; Pumain, 2006; Taylor, 2001; Waldrop, 1992; Wolfram, 2002).

In his original and seminal work on complexity, Herbert Simon (Simon and Ando, 1961; Simon, 1962 and 2002) viewed complex systems as hierarchical systems, i.e. architectures composed by many elements that are ordered with respect to position in the architecture, and where such position determines the scope of interaction between elements. Simon's focus was on the structure of interactions between elements. Elements are assumed as loosely coupled both vertically and horizontally and interact on an input-output basis. This means that the characteristics and dynamics of the elements are almost independent of one another. The characteristics and action of a single element of the system can change without affecting the characteristics and actions of other elements, and without producing changes at the level of the entire system. Consistently, Simon identified in near-decomposability the ultimate property that qualifies a system as complex. These features are well described by the most-cited example of the two watchmakers, Tempus and Hora[2].

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[2] Interestingly enough, this view constituted a point of departure for the literature on modularity in economics and management sciences. There is a substantial overlapping between Simon's view of complex systems as nearly-decomposable, and the notion of modularity subsequently developed. See for instance, Baldwin and Clark (1997) and Langlois (2002), where modular strategies are seen as appropriate solutions to manage complex and otherwise troublesome organizations and technologies.

Elaborating upon Simon's view, a number of evolutionary and systemic theorists in different disciplines, from psychology to physics, from computer sciences to biology and anthropology, integrated and augmented the notion of complexity. A growing body of literature dealing with complex systems paid attention not only to the structure of the connections between elements, but also and more importantly to the qualitative and structural transformation that produces rapid changes in the rules and direction of those interactions (e.g., Watzlawick, Weakland and Fisch, 1974; Gould, 1982). Interactions between micro and macro elements of the system are at the base of the reciprocal adaptation between individuals and their environment, and steer the transition from 'old' structures and architectures to 'new' ones (Bronfenbrenner, 1979; Bateson, 1973). Qualitative changes in the rules of interaction, due for instance to modifications in the pattern of specialization and differentiation between elements of the system, induce the introduction of new structures and architectures and mechanisms of coordination of the system (Von Foerster, 1982). Complexity is now, at the aggregate level, an emergent property of interactions between individual behaviors, rather than the intrinsic feature of top-down hierarchies. In other words, complexity is now viewed as a process distinguished by important threshold effects, where the emergence of aggregate properties is a process and is not merely reducible to the characteristics of the single elements of the system (Holland, 1998).

In this context, economics of innovation has been expanding as a fertile domain to apply, test and explore the dynamic tools of complexity theory to understand the transformation of economic systems. Consistently with the approach adopted in this paper, one of the most important consequences of this line of enquiry is the fact that innovation is understood in terms of the ability firms posses to cope and react through time to the boundaries and constraints imposed by their distinctive technological and organisational structure, and by the institutional conditions that characterise the environment in which the firm plays and with which firms interact (David, 1975; Nelson and Winter, 1982). The economic theory of innovation recognizes that the ability of the firm to innovate and change technology is the result of the introduction of competencies acquired externally, and implemented upon the internal resources of the firm by means of research, development and learning activities (Cohen and Levinthal, 1990).

Innovative firms are able to select and manage efficiently external linkages, and to implement learning processes enabled by such external linkages and by the strategic investment in technological communication with other organizations. These interactions and the transformation in their structure call for dynamic coordination processes in order to be effective sources of knowledge creation and dissemination.

This paper aims to adopt this new complexity perspective about economic system in order to appreciate the transformations in the generation and dissemination of technological knowledge and their effect onto the organization of innovation. The paper views complexity as the appropriate framework to understand the evolutionary process that portrays changes in the architecture of coordination of knowledge production. To this end, the paper illustrates the characteristics and dynamics of organizational change in the automobile cluster in Piedmont, in northwestern Italy. It describes the emergence, in the last 40 years, of a distributed innovation platform as a systemic architecture for the organisation and coordination of diffused innovation processes characterised by high degree of complexity, division of labour and specialisation of activities and competencies. The innovation platform emerges in this context as a major organizational innovation and appears as the result of complex systems dynamics (Consoli and Patrucco, 2008).

The complexity perspective is of special interest for the case of the Piedmontese car sector for different classes of intertwining factors: 1) the increasing diversity in both the organization and the technology of the automotive industry; 2) the strong process of specialisation and differentiation that characterizes the automobile filière in Piedmont; 3) the consequent importance of dynamic coordination of the division of innovative labour in car production; 4) the difficulties faced by leading car-maker, namely FIAT and the ongoing changes in the Piedmontese car sector.

The paper elaborates upon the case of the Piedmontese automobile system, in order to shed light onto the causes, characteristics and effects of the introduction of a new coordinating form, i.e. innovation platforms, for the organisation of production and innovation. The notion of innovation platform is put forward as the strategic organizational solution for the coordination of complex innovation systems. The evidence shows the emergence of a distributed innovation platform where interaction and cooperation between differentiated actors takes place both vertically (between actors at different levels of the structure) and horizontally (between actors at the same level of the structure). Such an emergence is the response to changes in the functional and technological specialisation of both the car-maker (namely FIAT) and its suppliers and therefore to the need for new forms of coordination. The result is deep transformation of the architecture (i.e. the structure) of the system through time.

The paper is structured as follows. Section 2 briefly integrates the complexity perspective into the economic analysis of knowledge and innovation. Section 3 is devoted to the understanding of the characteristics and processes of the coordination of the division of knowledge. Section 4 introduces innovation platforms as organizational innovations in the coordination of technological knowledge and illustrates the emergence of a specific innovation platform in the case of the Piedmontese car cluster. Section 5 summarizes main results.

2. COMPLEXITY, ECONOMICS AND INNOVATION

The theory of complexity is progressively emerging in the evolutionary economics of innovation as a new paradigm able to explain the structural and dynamic properties of knowledge generation and diffusion as well as the related emergence of innovation. Complexity theory is intrinsically both systemic and dynamic, and may be most useful in the understanding of the characteristics and processes of knowledge creation, diffusion, exploitation as well as the emergence and transformation of architectures for the coordination of knowledge through time (Antonelli, 2005; Frenken, 2006).

In broad terms, complex economic systems can be defined as a set of heterogeneous actors that interact in order to create new knowledge as well as to organise and change their activities through time. However, a deeper consideration of the properties of complex systems helps to identify a variety of intertwining elements that characterise complex systems. First, within complex systems actors are heterogeneous in terms of specific characteristics, especially in terms of competencies and knowledge. Second and consequently, actors have access only to limited and local portions of knowledge. They are characterised by limited cognitive resources and the creation of new knowledge take place through trial and error and continuous revision of behaviours. Third, interaction between heterogeneous actors is central in this context, in that it is through such interaction that new knowledge can be both accessed and created, and behaviours revised. Moreover, such interaction takes place in the local space, defined for instance in terms of economic, social, technological, cognitive and geographical characteristics. Furthermore, the behaviours of actors are characterised by some degree of inflexibility and difficulty in adapting and reacting to changes in the environment. In particular, the structure of the environment bounds such adaptation and reaction and in turn the conduct of actors is limited by irreversibility (Arthur, Durlauf and Lane, 1997; Rosser, 1999).

Recent advances in the evolutionary school provide major contributions to integrate and improve such understanding. Evolutionary economists built upon Nelson and Winter's (1982) analysis by developing the idea that the features of economic change are biased by the behavior of actors with idiosyncratic competencies, especially with regard to innovative capabilities and technological skills. Each agent and each firm is distinct and unique with respect to her technological knowledge and her ability to introduce innovation. Therefore there is very limited interchangeability and substitutability, high complementarity and strong specialization and differentiation in the space of technological competencies.

The analysis of the characteristics of knowledge and of the process of creation is a major step forward in the understanding of the dynamic properties of complex economic systems.

When applying the complexity perspective to the understanding of the dynamics of knowledge creation, complex systems are characterised by 1) intrinsic and radical uncertainty, i.e. the mismatch between firms expectations, planned strategies and actual results (for instance because of failures in facing changes in consumers' needs through new products), and 2) non-decomposability, i.e. complex systems are irreducible systems, where the behaviour and performance of a single actor may affect the behaviour and performance of the entire system. Albeit agents are myopic and characterised by irreversibility in their choices and behaviours, they are also creative and can react to unplanned and unexpected interdependencies typical of complex environment. Imagination and creativity are required in order to introduce changes in the environment as well as for the environment itself to evolve. In turn, the changes and the evolution of both the system and the behaviours of agents can be understood only in historical time: complex systems are intrinsically dynamic. In a dynamic perspective, therefore, in such systems the behaviours of individual agents and the evolution of the environment shape each other because of the interaction between individual creativity and structural irreversibility. The dynamics of complex systems depends upon the interaction both between micro and macro elements, and between individual actors themselves (Antonelli, 2007; Arthur, 2007; Foster, 1993 and 2005; Hanusch and Pyka, 2007; Lane and Maxfield, 2005; Loasby, 2002).

The structural and dynamic characteristics of complex systems involve the integration of different and complementary elements and components, which in turn reflect different and complementary spaces of technological competencies. Individual actors put in place connections in order to access and generate new knowledge, and thus to react to cognitive and structural boundaries and the changes that have occurred in the environment. Learning takes place in myopic, i.e. characterised by limited and specific knowledge, but creative firms and this learning underpins the generation of new knowledge. The process of creation of new knowledge relies upon the complementarity between internal and external portions of knowledge (Patrucco, 2009). The larger the adoption of networking as a means to access and use external knowledge modules, the larger the complementary internal know-how required by the firm to be able to understand, command and recombine this modules of external knowledge. Increasing returns in the generation of new knowledge build upon the exploitation of complementarities between internal and external knowledge and the implementation of a collective pool of knowledge and competencies through interactions (Patrucco, 2008).

In turn, creative firms benefiting from complementary modules of knowledge are able not only to introduce new knowledge but also to change the structure of their connections and the architecture of the network in which they are embedded, eventually modifying the processes and mechanisms of coordination. Connections and interactions between actors emerge as a crucial institutional element to understand the dynamic properties of complex systems and the governance of complex knowledge (Antonelli, 2005; Arthur, 2007).

The network of interactions between agents is the central mechanism through which they can access and create new knowledge, exploiting complementarities. Changes in the organisation and architecture of such network, introduced by myopic but creative agents as a response to modification in their environment, induce changes in the institutions of coordination of complementary activities and competencies. The feedbacks between micro behaviours and the structural boundaries of the system in turn shape the evolution of the system itself as a path dependent process (Antonelli, 2008).

Complex economic systems are characterized by non-ergodicity, social interactions, phase transition and emergent properties. Non-ergodic path dependency applies when a little shock at one point in time, and not necessarily at the onset of the process, affects the long run dynamics of a system. Phase transitions consist in qualitative changes that can be determined by small changes in the parameters of the system. Emergent properties are properties of a system that apply at a specific level of aggregation of a system. In the theory of complexity, feedback and interactions play a key role in assessing the conduct of agents and specifically the chances of changing their behaviour (Durlauf, 2005).

Complex systems are characterised by phase transition precisely because, in a non-decomposable system, a shock occurring to a single actor, for instance a firm unable to face the structural uncertainty of changing market conditions, has effects that dramatically impinge on the behaviour of the interdependent actors. The innovation we eventually observe is exactly an emergent property of the creative reaction of the system of interactive firms to the shock and the changes in the performance of the system itself.

Most importantly, complex dynamic systems are distinguished by processes of true transformation (rather than mere transition), where the changes in the system affect both the properties of the architecture of the system and the properties of its entities, namely firms and organisations. The dynamics of complex systems are based on evolutionary processes that are not driven by variety and selection (as traditionally in evolutionary thinking) but by differentiation of the activities of actors and the changes in the institutions the coordinate the division of labour among those actors. In other words, two kinds of differentiation are at works here: 1) differentiation in the functional and technological specialisation of firms; 2) differentiation in the architecture of the system. In particular, changes in the functional specialisation of firms makes individual actors non independent and not even nearly independent of one another. Differentiation changes the structure of the system since new characteristics of the firms are introduced. These transform the relationships between actors, in turn transforming the architecture of the system, i.e. the structure of interactions between actors. The two processes clearly co-evolve by means of the feedbacks between the behaviours of actors and the architecture of the system in which firms are embedded. Such a co-evolution qualifies the openness of the system and the coordinating architecture (Lane et alii, 2008; Metcalfe, 2007).

Economic complexity is an emerging phenomenon that is the outcome of a continuously transforming process of interaction between firms, each of which is characterized by different capabilities and placed in different technological domain.

The notion of the coordination of the division of knowledge is central in this context, in order to understand in which way complex systems evolve and the dynamics of knowledge creation and change take place. Dynamic coordination occurs in turn through the connective and generative structure of interactions between actors and the changes in such structures operated by bounded but creative actors. It is in turn such dynamic coordination that drives the evolution of complex systems themselves (Lane and Maxfield, 1997; Potts, 2000 and 2001).

3. THE COORDINATION OF TECHNOLOGICAL KNOWLEDGE

The analysis of the firm as a system integrator operationalizes such an understanding of complex innovation system and puts system integrators as organizations at the center of the flows of components and technologies in complex innovations (Sturgeon, 2002; Prencipe, Davies and Hobday, 2003). Specialisation requires to broadening the knowledge base of system integrators (or hub-firms) as coordinating institutions in order to manage the network of outsourced components and modules of technologies and knowledge, as well as to develop, test and adopt new organisational and technological architectures. The increasing division of labour brought about by complexity in both product and technologies engenders an increase in the number of specific components and modules of technology and knowledge that need to be recombined in the final product. System integrators need to command a wider and wider set of technologies and competencies in order to be able to play their coordinating role within the network of suppliers, i.e. to organise cross-company interactions. A major case for dynamic coordination arises in this context. Dynamic coordination refers to search and exploring new product and technological solutions, as well as new organizational architectures able to cope with those changes in product and technologies (Brusoni, Prencipe and Pavitt, 2001; Brusoni and Prencipe, 2001).

Dynamic coordination implies the capabilities and resources necessary to cope with changes in production, technologies and the structure of the network of suppliers, components and modules of knowledge. This paper draws attention to innovation platforms as organizational forms in the coordination of the division of knowledge and innovative activities. Innovation platforms have recently gained attention among scholars as well as policy-makers (Ciborra, 1996; European Commission, 2004; Consoli and Patrucco, 2008). The introduction of the notion of innovation platform bears important implications for the analysis of the coordination of technological knowledge and innovation in the Piedmontese automobile cluster. This has been characterised by an increase in the complexity of products and technologies paralleled by important changes in its structure precisely as the effect of the loosening role of FIAT as central actor in the '90s.

The notion of innovation platform put forward in this paper, views platforms as architectures for organizational coordination[3]. Following Sah and Stiglitz (1986 and

[3] In this regard we make a distinction between innovation platforms and technological platforms. The notion of technological platform (Gawer and Cusumano, 2002) has been developed in order to account for the role played by ICTs, virtual networks and the related set of technical infrastructures, interfaces and standards that make possible interoperability and technological coordination between different firms and technologies, within the context of high-tech industries as well as scientific clusters (Robinson, Rip and Mangematin, 2007). Our notion of innovation platforms insists on the organizational issues of coordination among specialised agents. ICTs and virtual networks are instrumental and yet subsidiary to this. What is common to both technological and innovation platforms is the idea of a directed and coordinated organization as distinct from spontaneous organization of economic activities such as in the traditional notion of market.

1988), the analysis of the architecture of the organization is focused on the way in which it gathers, processes and transmits information and knowledge. Such an architecture is defined in terms of 1) the way in which units are arranged together within a given system, 2) the characteristics of the flows (i.e. unidirectional or bidirectional) of information and knowledge between units, and 3) the extent of communication between different levels of the organization. This architecture eventually determines the way in which the organization takes accumulates, uses and produces knowledge (Garicano, 2000).

Innovation platforms are emerging architectures for coordination in contexts where innovation is the outcome of the integration of specialised activities across differentiated organisations. Innovation platforms can be seen as a particular form of coordinating solution, different from vertically integrated firms, spontaneous markets and networks, and particularly able to organize the innovative activities of specialised and heterogeneous actors. In this regard, we consider innovation platforms as particularly appropriate institutions for the coordination of complex innovation systems.

Innovation platforms appear as endogenous organizational innovations in the coordination of technological knowledge. Endogenous organizational change is seen as a complex process where the firms are constrained by the systemic and historical characteristics of their environment and yet are able to creatively react to those constraints and to introduce changes in the form of coordination of the division of the innovative activities. Organizational innovation supports and at the same time co-evolves with innovation in products and processes, and more generally with the process of new knowledge generation within the firm (Aoki, 2007). As Antonelli (2005) emphasized, the generation of new knowledge takes place through endogenous structural changes in the coordination of innovative activities, i.e. through changes in the form and number of the relations within the system, as well as through changes in the number and in the characteristics of the actors involved in the network.

Implications for the strategic management of the innovation process and the technological competencies of the firm are most relevant here.

The strategies firms need to identify and implement in order to develop and acquire new competencies and introduce innovations have immediate consequences on the organizational form the firm may adopt and subsequently change in order to achieve better performances. A major trade-off emerges between static and dynamic coordination and the appropriate organizational structures (Bruce and Jordan, 2007). On the one hand, the vertically integrated and hierarchical firm is the efficient governance structure in terms of static coordination in that it reduces the transaction costs due to the integration of different components, modules and know-how. The firm achieves more efficiently the structural dimension of complexity, by the internal production and integration of the variety of elements and capabilities that are needed in order to give place to the final product. However, in a dynamic environment, subjected to continuous changes in product characteristics and production technologies, and thus complex in a truly way, the firm is not able to keep the pace of such changes because its capabilities are limited. In this case, the market is the efficient coordinating institutions where economic actors have access to a diffused and common pool of resources, and where firms benefit from those economies of specialisation and learning well known since Adam Smith. The implementation of inter-firm cooperation, distributed coordination through networks and hybrid organizational forms emerged precisely as the appropriate strategy in order to make possible bureaucratic organisations reacting to improvements in product or services by acquiring externally the know-how necessary to innovate (Casselman and Samson, 2007).

A theory of the strategic management of the innovative activity at the firm level able to include the role of organizational strategies can be articulated following the approach developed by Crémer, Garicano and Prat (2007). The choice concerning the way in which firms can implement organizational strategies depends upon the dimension of the space of technological competencies of the firm and the trade-off between specialization and coordination. Such a trade-off defines the scope, boundaries and forms of inter-organizational relations. More precisely, specialization favours efficient communication within a narrow set of partners, while it limits the scope and advantages of coordination in terms of potential accessibility to a wider set of innovative opportunities and capabilities. At the opposite, coordination of a wider range of inter-firms and inter-organizations links opens up technological opportunities but lowers the benefits of specialization and the efficiency of interactions.

The choice concerning the way in which firms can implement organization architectures depends upon the dimension of the space of technological competencies of the firm and the trade-off between specialization and variety in technological capabilities (Kogut, 2000). Such a trade-off defines the scope, boundaries and forms of inter-organizational relations. More precisely, specialization favours efficient communication within a narrow set of partners, while it limits the scope and advantages of coordination and potential accessibility to a wider set of innovative opportunities and capabilities. At the opposite, coordination of a wider range of inter-firms and inter-organizations links opens up technological opportunities but lowers the benefits of specialization and the efficiency of technological communication. Common organizational principles and communication processes are necessary to combine internal and external technical competencies among the different actors of the systems (ranging from producers to suppliers to intermediate and final users), due to intrinsic stickiness and tacitenss of competencies belonging to the different actors of the system (Kogut and Zander, 1992).

The matching between specialization and coordination is required to the firm in order to exploit the benefits of the complementarities between internal economies of R&D and learning and the access to external resources through linkages and technological communication.

4. ORGANIZATIONAL CHANGE IN THE EVIDENCE OF THE PIEDMONTESE AUTOMOTIVE CLUSTER[4]

The automotive industry has many characteristics of complex systems from both a structural and a dynamic viewpoint.

The technological and knowledge base required in car production has been characterised by a complex technological and knowledge base from its very beginning. This complexity is however recently increasing from both the static and dynamic viewpoint. Car production requires the full understanding of the complementarities within a wide range of different technologies and materials, and therefore the command of a very complex set of knowledge modules in engineering, electronics, chemistry, plastics technology, robotics, informatics and telecommunications. Each of these modules however cannot be fully commanded internally by the firm. Knowledge is complex because it requires the integration and recombination of external and internal knowledge via the supply and demand of products, components and process technologies.

[4] This section elaborates and develops material previously presented in Consoli and Patrucco (2008).

Historically, the integration, recombination and in turn the coordination of such a growing number of components, technologies and modules of knowledge has been achieved through an increasing division of labour, specialisation and outsourcing. These are the results of the intertwining effects of market saturation, product differentiation, demand uncertainty and financial pressure that bring about increasing needs of operational efficiency and therefore organisational and technological change. From the organizational viewpoint car production is therefore clearly characterised by strong specialisation, strong division of labour and therefore important coordination costs.

Such increasing specialisation and fragmentation cause a range of ways and paths along which Original Equipment Manufacturers (OEMs, i.e. car-makers) decide to outsource production processes and activities. Know how and capabilities are distributed quite differently across both OEMs and suppliers. Product architecture in the car industry can differ substantially from model to model and the notion of interchangeable modules, components and activities across models, OEMs and suppliers is limited due to significant variations in know how and competencies. Different suppliers are characterised by different capabilities: providing even the same activity or component to different clients implies for the same supplier, different competencies. Selection among suppliers and the emergence of preferential relationships are important in this context. Suppliers' activities and capabilities are not fully interchangeable and modular, nor fully reversible. Knowledge modules are not completely interchangeable because of the specific, idiosyncratic and non-disposable part of know-how. This in turn bears important costs for OEMs. Important switching costs are associated to shifting from one supplier to another, and related high costs are due to changes in the technology modules and in the design of the system and the architecture of coordination. Preferential interactions between OEMs and suppliers emerge in turn as an effect of such costs (Sako, 2003).

Interaction between actors is crucial for such coordination, and successful product innovation (i.e., the introduction of a new car) implies the ability to coordinate in the more appropriate way the wide networks of specialised suppliers and partners. In other words product innovation is directly related to the ability to introduce and manage changes in both the organisation and production processes.

In this regard, the Piedmontese automotive sector underwent and is currently undergoing a phase of strong structural and organisational change due to the difficulties experienced especially in the '90s by the main actor, namely FIAT. As the mingled result of increasing complexity in the knowledge base and the crisis of FIAT, car production in the Piedmontese system has been characterised by progressive vertical disintegration and strong externalisation of more and more complex and specialised components and processes. This results into the stronger and stronger need of coordination of the division of labour and communication between specialised producers and users. Such a need for coordination mechanisms is paralleled by the declining role of FIAT as the traditional "hub" of the network of small and large suppliers and R&D institutions. The lack of centralised coordination was one of the main problems due to the crisis of FIAT, which was instead by no way a crisis of the Piedmontese automotive system as a whole. This is in fact today a sophisticated multi-firm productive system characterised by a complex network of highly specialised suppliers for the international market, design firms (such as Pininfarina and Giugiaro), machine tool firms, research and training organizations (CRF and ISVOR), and university programs (Enrietti and Bianchi, 2003).

The evolution of the organisation and coordination of innovation in car production paralleled the disappearing of technological capabilities internal to Fiat (at least in the first three phases) and can be articulated in four phases: 1) coordination through vertical integration, 2) coordination through a centralised network of local suppliers, 3) coordination through a decomposed network and 4) coordination through innovation platform (Table 1). Fiat moved from a vertically integrated production structure to the outsourcing of manufacturing activities and the production of components to local small suppliers, to the decomposition of the production and innovation processes, together with the outsourcing of strategic and high-valued activities such as design and R&D, and the adoption a modular architecture, and finally to proper co-innovation and co-design.

Major implications for the coordination of the innovative activity of the firm can be specified in this context, taking into account the role of organizational change, i.e. the evolution of the architecture according to the characteristics of the business environment in which firms are playing. We can specify the characteristics of the changes in the organization of innovation as follows:

1. Coordination through vertical integration was typical in the '70s. Coordination of innovative and productive activities takes place through the Fordist firm and is based upon internal accumulation of R&D, capabilities in the design of cars models, and capabilities in technology design. In this model innovation do take place exclusively within FIAT and in isolation.
2. Coordination through centralised networks of local suppliers progressively takes place during the 80s, as a reaction to uncertainty in both demand characteristics and the supply strategies appropriate to meet the changes in consumers' needs and

requirements. The vertically integrated car-maker is induced to change its coordinating structure. Here FIAT outsources manufacturing activities and the production of components to local small suppliers, creating a local and closed productive network of suppliers still dependent on and coordinated centrally by the OEM. R&D and design are defined ex-ante by FIAT and the results of such activities transmitted in a top-down and unidirectional fashion to suppliers.

3. Coordination through decomposed and decentralised network arises more and more importantly in the '90s. Suppliers able to benefit from economies of specialisation and learning, accumulated competencies that make these firms emerging as first-tier suppliers. On the one hand, these first-tiers suppliers are also able to integrate themselves into international productive networks and become international suppliers of car-makers. On the other hand, they are able to move from the mere provision and supply of simple components to the provision of product design services. Now FIAT chooses to outsource those strategic activities such as design, and to transfer to supplier not only activities, but also autonomy and key decision processes in terms of the design features. This is clearly possible only in that suppliers accumulated specialised competencies with regard to product design, and more generally innovative skills. Innovation takes place in a bottom-up manner, driven by the competencies of first-tier suppliers, yet progressively spoiling the OEM of both its innovative competencies and its coordinating role in the network.
4. Finally, coordination through innovation platforms is possible only when FIAT decided to bring back R&D and design in house, reacting to the loss of innovative capabilities experienced in the previous phase, and yet being still able to rely on the complementary R&D and design competencies developed by first-tier suppliers. FIAT can now combine its internal know-how with that of the first-tier suppliers,

thus being able to take advantage from synergies and technological partnerships through appropriate collaborative strategies. Moreover, FIAT is now again able to coordinate the innovation process because of new internal R&D and design activities. In parallel, coordination strategies support the introduction of a variety of "de-layered" organizational relations, which benefit from a wider pool of resources and knowledge, where technological cooperation can take place vertically (i.e. within FIAT supply chain), horizontally (i.e. between FIAT and different OEMs) and diagonally (i.e. through different supply chains by means of first-tier suppliers that cooperate with different OEMs). Innovation is the result of the integration of top-down and bottom-up innovative processes and takes place in a truly cooperative way, through the bidirectional exchange and communication of technical information, innovative capabilities and the results of R&D and design activities developed both by FIAT and the first-tier suppliers. Here, transformation also includes changes in the number and quality of actors, integrating in the platform new suppliers and partners according to new emerging technological needs, and excluding old ones.

INSERT TABLE 1 ABOUT HERE

Four models of organization of innovative activity can be identified according to the different scope of communication and transmission of knowledge (Figure 2). Important changes involve the structure of relations between actors. The network transforms from centralized, limited in the number of connections and characterized by one-way relations (in phase II – The centralized network), to vertical and yet limited (to OEMs and FTSs) cooperation (phase I – The decomposed network), to distributed, horizontal and vertical communication strategies (in phase IV – The innovation platform).

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As a matter of fact, important changes involved not only the choice between make and buy, between internal production and external provision, but also the way in which Fiat coordinates and manages external supply. A straightforward example of such changes is the adoption by Fiat of the so-called Advanced Product Quality Planning (APQP) methodology in managing the suppliers network and their activities. Prior to the adoption of APQP, the definition of new cars and component characteristics and the process of their acquisition from suppliers was defined ex-ante and dominated by the design centrally specified by FIAT: given ex-ante characteristics of components, FIAT set prices and identified the appropriate suppliers. With the adoption of APQP and progressive decentralisation of activities also engendered by the accumulation of competencies by suppliers, the process reverted. Now Fiat defines the general design and characteristics of a new car model and communicates such information to the network of suppliers. Each supplier, according to its specific technological knowledge and to the price/quality requirements, elaborates a project for the production of the given component or system. The competition among suppliers makes the more appropriate projects emerged and allows Fiat to select the more appropriate suppliers. Only after such competition and selection processes, the negotiation between Fiat and the selected suppliers defines ex post and precisely the characteristics and the prices of the given component or system.

Such a change contributes to the emergence of an innovation platform (Figure 2) where medium sized suppliers acquired new centrality in both the organisation of and innovation in car production in Piedmont, thanks to their ability to accumulate and create new internal technological knowledge. The performance of the system now is very much dependent upon the performance of these first-tier suppliers, together with the restored innovation and coordination capabilities of Fiat, especially in terms of higher efficiency in production, better quality of components and modules and innovative capabilities brought into the process.

Paralleling the difficulties Fiat went through in the '90s, a new organisational structure in the sector emerged, where medium firms are more and more key actors both in productive terms and in terms of their innovative and design capabilities, as well as actors that progressively acquired coordinating functions that were previously demanded only to the large firm.

From the viewpoint of the external governance and the coordination of the network of suppliers, the process of progressive transfer of upstream strategic activities and autonomy from Fiat to suppliers (Whitford and Enrietti, 2005) put in place in the '90s involved not only first-tier suppliers but also, nowadays, second-tier suppliers and can be seen as an effective mechanism of the dynamic coordination of the division of innovative labour.

Although the decision to adopt and the implementation of the innovation platform has been decided centrally by Fiat, the new mode of coordination implies the integration of top-down resources and capabilities provided by the OEM (i.e. the general and macro template of a new car)[5] with the bottom-up innovative activities provided by specialised suppliers (i.e. the actual implementation of modules and

[5] For an in-depth analysis of the corporate strategy on this point, see Becker and Zirpoli (2007).

components with new features and performances). This integration is especially relevant in terms of the dynamic coordination of the production of new car models. A given new car model is now an emergent property of the cooperative efforts of Fiat and suppliers along the entire production chain, aiming at the development and exploitation of complementarities in different activities, technologies and spaces of competencies. The introduction of a new car model is now possible only in that the OEM and the specialised suppliers co-design the features of the variety of components and modules that need to be integrated into the new final product. The effective coordination of this innovative process, and the successful introduction of new cars, is now possible only because of the adoption of a distributed platform that supports the interaction between the different organisations.

INSERT FIGURE 2 ABOUT HERE

In sum, in the case of the Piedmontese automobile cluster the emergence of a new organizational form for the coordination of innovation is the result of the matching between bottom-up processes of differentiation in the specialised activities of suppliers firms, and top-down implementation of new organizational principles and a new management of the suppliers network. The latter is developed by Fiat as a reaction to two main factors: 1) the differentiation process put in place by FTSs in particular – i.e. their accumulation and acquisition of new technological competencies in R&D and design, that are added value and knowledge-intensive activities, contrary to their previous focus on mere supply of components, and 2) the diminishing innovative competencies of Fiat, as a result of the adoption of strong outsourcing strategies in the ‘80s.

The new structure of relations we finally observe is the emergent outcome of the interaction between micro behaviours and macro elements of the system. As a consequence of the renewed business model and recovered innovative competencies at the level of the entire system, FIAT is experiencing a remarkable industrial and financial turnaround (The Economist, 2008).

5. CONCLUSIONS

The theory of complexity is gaining momentum in the economics of innovation as a new and emerging paradigm able to explain the structural and dynamic properties of knowledge generation and diffusion as well as the related emergence of new technologies.

To summarise the results of the growing literature on complex systems, and importantly enough when applying the complexity perspective to the understanding of the dynamics of innovation, complex systems are characterised by the following four elements: 1) heterogeneity of organisations each of which is specialised in specific knowledge spaces and innovative activities, 2) which interact each other in order to exploit complementarities in their activities and coordinate the division of labour; 3) intrinsic uncertainty, i.e. the mismatch between firms expectations, planned strategies and actual results (for instance because of failures in facing changes in consumers' needs through new products); 4) non-decomposability, i.e. complex systems are irreducible systems, where the behaviour and performance of a single actor affect the behaviour and performance of the entire system. Complex systems are characterised by phase transition precisely because, in a non-decomposable system, a shock occurring to a single actor, for instance a firm unable to face the structural uncertainty of changing market conditions, has effects that dramatically impinge on the behaviour of the interdependent actors. The innovation we eventually observe is exactly an emergent property of the creative reaction of the system of interactive firms to the shock and the changes in the performance of the system itself.

The implications of such properties of complex dynamic systems for the identification and implementation of appropriate technology and innovation strategy are most important. Complex dynamic systems are characterized by unexpected and unplanned interdependence between actors, as a result of radical uncertainty and non-decomposability. Decision making in general and the process of selection and implementation of the correct innovation strategy in particular, are constrained by such limitations. Innovation platforms emerge as new organizational solutions for firms confronting with complex economic environments. They support strategic choices in the management of technological knowledge in that they combine top-down corporate decision making with the access to a diffused pool of technical competencies at the level of suppliers and sub-contractors. Innovation platforms favor the integration between internal R&D and learning and the external knowledge enabled by strategic communication and linkages.

In this context, innovation platforms can be defined as systemic architectures for the organisation and coordination of distributed innovation processes characterised by high degree of complexity, division of labour and specialisation of activities and competencies.

The case of the car industry in Piedmont shows that organizational change, involving the shift in the architecture of producer-suppliers relations from vertically integrated coordination of innovation to the implementation, lead by FIAT, of a localised innovation platform, engenders cooperation between the OEM and specialised suppliers on the technological design of new models and components, as well as between different OEMs. These highlight the importance of organizational responsiveness to distributed innovation in complex environment through the creation of architectures able to integrate individual efforts into collective activities.

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Table 1. The phases of institutional change in the coordination of car production in Turin

Phase	Coordination structure	Organisation mode	Innovation
I phase: Ō70s	The firm	- Vertical integration of production - Internal accumulation of R&D - Internal accumulation of capabilities in the design of cars models - Internal accumulation of capabilities in technology design	- Innovation in isolation
II phase: Ō80s	The centralised network	- Outsourcing of components production - Central coordination of suppliers by the OEM - Exclusive supply from small suppliers to the OEM	- Ex-ante and top-down design of both cars models and components - Innovation undertaken internally by the OEM
III phase: Ō90s	The decomposed network	- Suppliers benefit from economies of specialisation and learning - First-tier suppliers emerge as innovators at the local and international levels - Outsourcing of components production - Outsourcing of design in both components and modules - Modular product and system architecture design	- Outsourcing of R&D and design - Bottom-up (first-tier suppliers driven) innovative process
IV phase: ongoing	The innovation platform	- In-sourcing of innovative and value adding activities - Acquisition of external resources built in phase III - Vertical cooperation between OEM and FTSs - Horizontal cooperation between OEMs and between FTSs - Internal to the OEM product and system architecture design	- Integration of top-down (OEM) and bottom-up (first-tier suppliers) innovative process - Co-design - Co-innovation

Source: Consoli and Patrucco (2008)

Figure 1. The evolution of the coordination of innovation activity in the Piedmontese car system

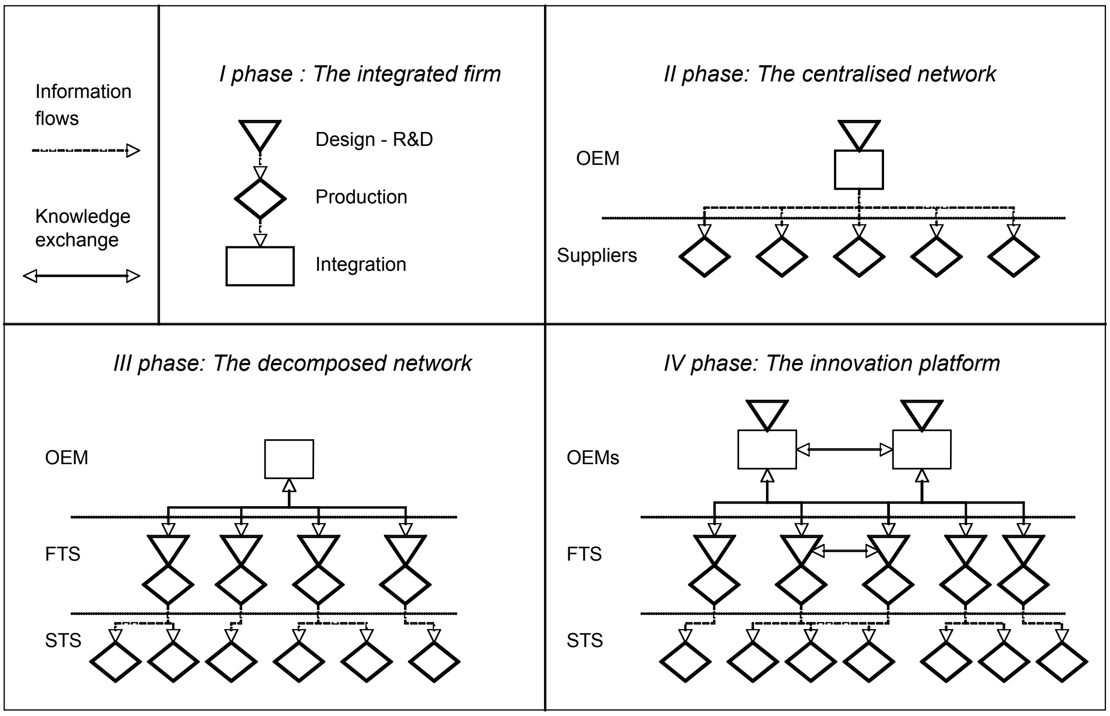
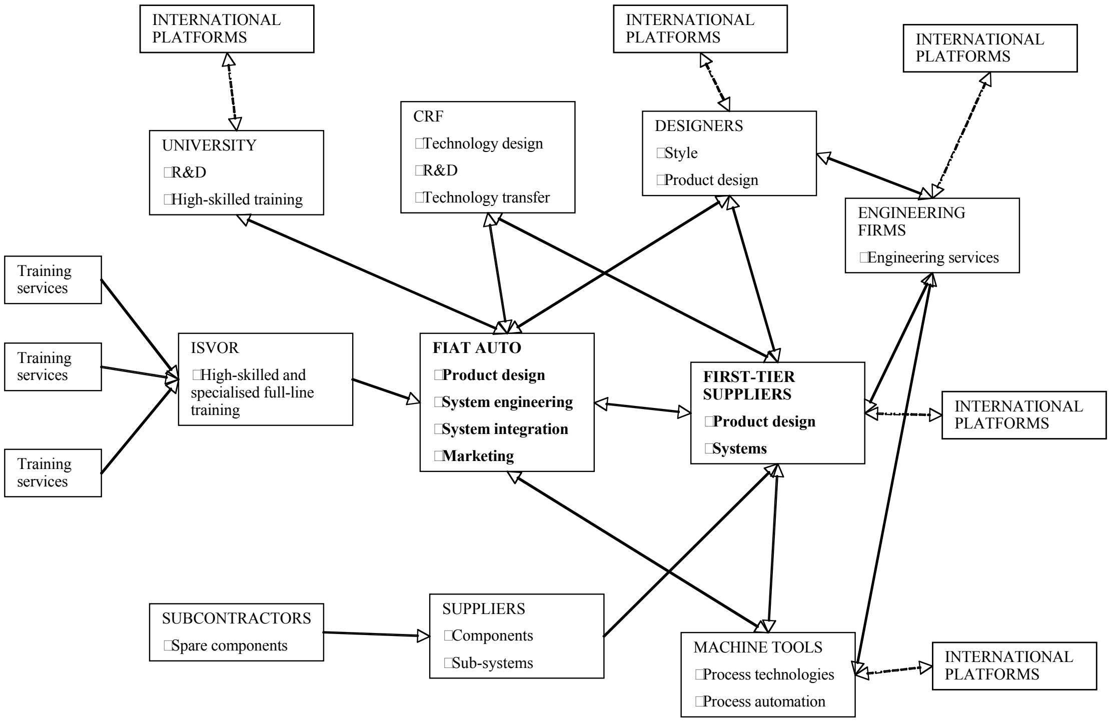


Figure 2. The innovation platform in the Piedmontese car industry



Source: Consoli and Patrucco (2008)