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Da inserire come prima pagina della tesi

Il/la sottoscritto/a

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INTRODUCTION

A long line of works supports the idea that knowledge is a key resource for a firm. These studies have increasingly spawned in recent years emerging as an important area of inquiry in the business and management literature such as strategy, organization, marketing, innovation and R&D, operations and supply chain (Kogut and Zander, 1992; Grant, 1996). Most of research in these areas converges in maintaining that knowledge is a critical asset to compete in global industries and that knowledge has become the new “Mantra” of today’s business and management.

The concept of knowledge has been defined in a number of ways (Huber, 1991; Nonaka and Takeuchi, 1995) and has been studied in its several dimensions (Argote and Ophir, 2002 for a review of knowledge creation, retention and transfer) but despite a burgeoning literature, it continues to remain vague (Smith, Collins, Clark, 2005). More specifically, while for knowledge retaining and knowledge transferring there is an abundance of empirical investigations (Szulanski, 1996; Hansen, 1999; Ahuja, 2000; Argote and Ingram, 2000; Carley, 2002), limited progress has been made, to date, in measuring knowledge creation (King and Zeithaml, 2003) and in looking at its evolutionary trajectories (exceptions include Helfat 1994; Katila 2002; Nerkar, 2003). Indeed, the issue of knowledge creation has attracted the interest of several scholars in a variety of fields and disciplines (Grant 1996; Nahapiet and Ghoshal, 1998; Garud and Karnoe, 2001), but this research, though substantial theory-wise, notably lacks empirical studies investigating how new knowledge is created within firms. Similarly, studies that conceptualize knowledge as underlying a firm’s capabilities, that conceive it as a complex system, that analyze its architecture and structural properties and that explain its dynamics as the result of design and evolutionary processes are scarce and much needed.

Motivation for the research

Since knowledge and its management are an essential determinant of firm performance, knowledge strategies are a crucial area of firms' strategic choice (Bierly and Chakrabarti, 1996). Among the different types of firm's knowledge, product knowledge is particularly important because it represents a key source of innovation and often drives the development of firms' capabilities as well as their evolution. Generally a product may be defined as an artifact, a deliberately and purposely defined technology geared towards the satisfaction of customers' needs. Products are complex systems in that they comprise a large number of components with many interactions between them; it is made of raw materials, parts and components variously acquired, transformed and/or combined through technologies according to specific operational sequence. Instead product knowledge is a logical construct, a conceptualization of data, information, language and meanings, shared within an organization (Nonaka and Takeuchi, 1995; Davenport and Prusak, 1998) that underlies one or more products. Product knowledge may be defined as a complex system that partly mimics and overlaps product structure in its hierarchy and quasi-decomposability; an abstract and fluid concept that may refer to a variety of artifacts such as products, components and technologies. On this, I would refer to Perrow (1967) seminal work on technology, and its underlying information processing, cognitive, sociological structure.

More specifically product knowledge is here defined as the repertoire of knowledge a firm has developed over time which is embodied in its existing products. This knowledge is articulated into component specific knowledge – the knowledge incorporated in each product component - and architectural knowledge - the knowledge about how components are combined together. Product knowledge shares the fundamental properties of flexible complex systems: it is hierarchical – i.e. articulated into subsystems so that some structures provide constraints on lower-level structures, and near-decomposable – i.e. the patterns of interactions among its components are not diffuse but tend to be tightly clustered into nearly isolated subsets of interactions.

Limited progress has been made so far in understanding product knowledge dynamics and in measuring its evolutionary trajectories. Thus, even if new products are artefacts that embody existing and novel knowledge, deliberately designed to the satisfaction of customers' needs, how knowledge is generated, selected and diffused across a firm's products over time remains an under-investigated topic both in strategy and organization literature. Thus, the focus of this work is explicitly on product knowledge, its elements, architecture and dynamics.

Purpose of the research and expected contribution

Starting from these premises, my thesis aims at opening the black box of firm's product knowledge architecture and evolution. Understanding product knowledge dynamics and its impact on new product development and on the overall firm's product portfolio evolution is challenging and requires, method-wise, an approach able to reveal the complex structure underlying product knowledge. Indeed the intimate relationship between knowledge and new product development is largely documented in the innovation management literature (Clark and Fujimoto, 1991; Brown and Eisenhardt, 1995; Verona, 1999; Ernst, 2002). More specifically, it has become clear that the new product development process not only leads to the design of new products, but also generates, as a by-result, the knowledge base that ultimately nurtures the new product development process and the ability to sustain innovation over time (Liker et al., 1995; Morgan and Liker, 2006).

For this reason this dissertation draws upon strategy and organization literature using the conceptual tools of resource based theory and knowledge management, knowledge recombination, modularity theory and network theory to better understand product knowledge architecture and dynamics and its consequences on product management, business portfolios and innovation. These pieces of literature are briefly described inherently to the aim of this study.

The resource based theory and knowledge-based view of the firm converge in maintaining that firms' resources and capabilities heterogeneity explain cross-firm performance variation and can be a source of sustainable competitive advantage (Wernerfelt, 1984; Barney, 1986, 1991; Dierickx and Cool, 1989; Kogut and Zander, 1992; Peteraf, 1993; Grant, 1996; Teece, Pisano, & Shuen, 1997). More specifically, performance variation among firms is rooted on their different knowledge endowment and on their diverse capability to develop and deploy knowledge into their products and processes. Indeed, among the different kinds of resources firms have, knowledge base and innovative capabilities such as information, know-how, and technologies, represent significant antecedents characterized by novelty, tacitness and firm specificity (Kogut and Zander, 1992; Grant, 1996; McGrath, Tsai, Venkataraman, and MacMillan, 1996; He and Wang, 2009). A fundamental aspect of the knowledge-based view of the firm is that organizations create, maintain, and apply their knowledge in order to continuously develop new products

(Kazanjian and Drazin, 1987; Cohen and Levinthal, 1990; Kogut and Zander, 1992; Grant, 1996; Drazin and Rao, 2002; Kim and Kogut, 1996). Similarly from a strategic standpoint, firm capabilities related to product innovation are central to continued corporate survival (Montoya-Weiss and Calantone, 1994; Henard and Szymanski, 2001) because the continuous introduction of new product and service offerings is considered an important element of a firm's prolonged success (Yalcinkaya, Calantone and Griffith, 2007). For this end firms should adjust their knowledge endowment to the characteristics of the marketplace (Pisano 1994; Grant 1996; Eisenhardt and Martin 2000).

Several strategic choices contribute to shape a firm's knowledge endowment and, consequently, determine the stock of knowledge a firm can count on at a certain point in time to develop new products (Bierly and Chakabarti, 1996). These choices can be clustered into two broad categories well known in the strategy and organization literature: exploration and exploitation (March, 1991). On the one side exploration implies making investment in product knowledge terrains diverse and new for an organization. It is riskier; it requires to be harnessed with the existing knowledge base but typically leads to more radical innovation or systemic innovation (Chesbrough and Teece, 1996). On the other side exploitation implies making investment in product knowledge terrains already explored. It can be focused on specific aspects such as types of use, component technology, interfaces, performance parameters, etc.

Therefore, product innovation can derive from firms exploring new knowledge and resources, which typically leads to new integral products, loosely coupled, knowledge-wise, with existing products, or form firms exploiting, i.e. refining, recombining, replicating with little variation, the stock of knowledge cumulated over time (Levinthal and March, 1981;

March, 1991; Garud and Navyar, 1994). Accordingly product innovation may be conceptualized as a process of search, with firms having access to a knowledge space or knowledge pool from which they can retrieve, refine, replicate and recombine knowledge with a dual outcome: the dynamic definition of their product portfolio and the dynamic redefinition of the knowledge space (Nelson and Winter, 1982; Katila and Chen, 2009). In synthesis innovative products may consist of new combinations of existing components (mix and match of modules within a given architecture) rather than creating a non existing product (integral product) (Baldwin and Clark, 1997). Consequently, the products firms develop over time are at least in part made of components carried over form existing products where the knowledge embodied in these components, as well as in the technologies that connect them, constitute a sort of catalogue, or design library, from which they remain available and can be retrieved for use when firms develop new products (Sanchez, 1996).

Thus this work looks on how the knowledge underlying a firm's products portfolio is recombined over time to create new products that may include upgrades, modifications, and extensions of existing products that may be new to the firm, the market or the world (Li and Atuahene-Gima, 2001) and where each new product embodies and refers to a knowledge base. This knowledge base, defined as product knowledge may be conceived, as defined above, a complex system. By discovering the hierarchical structure of such systems, decomposing it into knowledge chunks and analyzing their cross-product replication and/or variation over time allows understanding the foundations of product innovation processes, interpreting product innovation strategies and predicting likely innovations outcomes.

From this standpoint, the network perspective helps to conceptualize a firm's product knowledge as a network architecture, where nodes are knowledge components or chunks, and a connection between nodes is the association or the joint utilisation of such knowledge in performing specific activities of the products' production process.

This framework has managerial implications since it can be used to assess the current status and potential evolution of a firm's product knowledge base. More precisely, mapping a firm's product knowledge onto a network perspective offers several opportunities. First, visualizing product knowledge networks allows surfacing the structural properties of a firm's product knowledge illuminating the conditions that can stimulate the innovation process. Second, by analyzing how product knowledge components/subsystems are linked and nested over time, it is possible to track firms' knowledge trajectories and contribute to a better understanding of new product development processes. I will touch upon all the above issues and aspects by using an original longitudinal dataset on the product portfolio of a large food, beverage, sweet and confectionery Multinational Company.

Structure of the dissertation

The dissertation can be ideally divided in three main sections: the first is theoretical, the second describes the research site and the third present the results of two empirical studies. More specifically, an overview of the project together with its aim and its underlying motivation has been presented in the Introduction. Chapter 1 provides the literature review on knowledge recombination and modularity, and the main research questions that will be investigated. Chapter 2 presents the research site, a large food, beverage, sweet and confectionery Multinational Corporation where I collected primary and secondary data through an in-depth and original study of its product portfolio. In this chapter I will present a company description and expain why it is a good research setting for this study. Chapters 3 and 4 propose an analysis of the theoretical framework described in the previous part of the research.

The Chapter 3 offers two interconnected contributions; first it contributes to knowledge management research by proposing a new methodological approach, the application of network analysis to product knowledge mapping. Indeed, by adopting the network analytic approach I take on the challenge of modelling firm product knowledge development as network evolution. For this reason insights from graph theory and network topology to identify evolutionary trajectories of product knowledge are very helpful. Second, by modelling and analyzing over time the patterns of structural evolution of product knowledge networks this Chapter grasps the ability of a firm in making product innovations offering an unexplored view of knowledge architecture evolution. More specifically in this Chapter I give a description of the product knowledge trajectories and the theoretical mechanisms underlying, and explain how a new approach to recombination via network perspective and the elaboration of firm's knowledge as a network of components, can offer a methodological improvement to several studies that have measured knowledge especially via patents or patents citations analysis. This Chapter provides the analysis unpacking product knowledge in all its knowledge components; by using network analysis, carried out through UCINET VI (Borgatti, Everett and Freeman, 2002) I model over time product knowledge as a network of knowledge units. This method is valuable because it permits to construct an evolutionary model of firm's knowledge dynamics and helps to investigate and deeply understand knowledge recombination processes and how they lead to new products development. This analysis describes the evolving patterns of knowledge recombination to trace the capacity of a firm to assimilate and re-use knowledge from other products over time shaping its firm's knowledge trajectories. Doing QAP and Core/Periphery analyses among product knowledge networks (PKN) over time I can explore the patterns of evolution that PKN have and whether they follow a more local search characterized by similarity and exploitation of previous knowledge or distant search capturing more explorative and unconventional patterns of evolution.

While Chapter 3 offers an investigation of the product knowledge learning trajectories within the firm, Chapter 4 aims to move the debate on product modularity and product innovation at a different level showing that, thanks to the hierarchical and quasi-decomposable nature of product knowledge, Alfa can innovate its product portfolio adding new integral products by recombining (mixing and matching) existing knowledge modules. Knowledge modules provide the underlying cognitive structures on which product innovation is based and are used as templates for product innovation. By inductively deriving the knowledge modularity construct from the in-depth multiple cross-products analysis of the Alfa's product portfolio this Chapter tackles the issue of what is beyond the typical mix and match paradigm applied by modularity literature and the static controversy about its advantages and disadvantages. While modularity paradigm is split into two contrasting streams of literature, on the one hand who affirms that mix and match is a source of innovation and on the other hand who argues the opposite, an extensive exploration of the product portfolio of the Company reveals a non investigated aspect offering insight for theory development. Here, a new product neither is the result of a mix and match procedure nor shows the characteristics of an integral product, but it derives each time from something that is simultaneously invariant (what I define knowledge module in the) that gets recombined in different artefacts.

Finally the Conclusion closes this work by elaborating its implications and limitations and by pointing out which steps may be taken in order to extend this line of research.

PART I: THEORY

CHAPTER 1: Literature review and goals of the research

1.1 Introduction

This chapter offers an overview of the theoretical perspectives this project draws upon. These can be summarized in the literature on “knowledge recombination” that will be considered in the paragraph 1.2 and in the literature on “modularity and product architecture” that will be examined in the paragraph 1.3. In these two paragraphs the main issues and contributions of these two streams of research will be critically analyzed and reviewed, highlighting their flaws and the outstanding research gaps. The ways to manage these gaps will be presented in the paragraph 1.2.1 about product knowledge and knowledge trajectories and in the paragraph 1.3.1 about knowledge modularity. Since both theoretical perspectives share and rely on the use of network perspective, I will model product knowledge as a network and apply network analysis - which may seem unorthodox but is also ground-breaking - to not “strictly social” research objects. This original application of network analysis to product knowledge will be described in the paragraph 1.4. Finally, paragraph 1.5 illustrates the main research questions undertaken by the dissertation.

1.2 Knowledge recombination

The ability to carry out innovation mainly depends on the ability to create new combinations and to reconfigure existing solutions. Particularly in uncertain environments characterized by strong interdependencies, the use, reconfiguration and integration of existing bodies of knowledge contribute to explaining performance and, ultimately, firms' survival and profitability. For this reason, a large body of scholarly research has investigated invention, and more in detail technological invention, as the process through which novel combinations come into being.

More specifically, a productive stream of research has asserted that resource and knowledge combinative capabilities strongly influence firms' innovation outcomes (Kogut and Zander, 1992). Recombination processes have been defined as the novel and original combination of existing elements of knowledge as well as the reconfiguration of existing knowledge architectures. Along the same line, Nahapiet and Ghoshal define knowledge recombination "[..] the process of bringing together elements previously unconnected or by developing new ways of combining elements previously associated." (Nahapiet and Ghoshal, 1998: 248). These processes feed the creation of new products (Schumpeter, 1939; Nelson and Winter, 1982; Fleming, 2001) or inventions (Henderson and Clark, 1990).

In order to produce successful combinations two distinct types of knowledge are required. On the one hand, firms need knowledge and competences related to each specific element, or subsystem, that is combined, such as the component knowledge; on the other hand, effective reconfiguration requires knowledge about the interdependencies between different elements and about the ways in which they can be integrated into a coherent whole, such as the architectural knowledge (Henderson and Clark, 1990). Understanding the invention process as development of novel combinations requires thinking on where the aforementioned types of knowledge reside and on the role they have in surfacing novel combinations.

Research in this stream of literature focused at organizational level looking at organizations as system integrators that develop new products by monitoring, integrating and reconfiguring the several bodies of knowledge embedded in different components (Henderson and Clark, 1990), where studies investigated knowledge structures embedded in organization's knowledge bases (Yayavaram and Ahuja, 2004), organizational forms characterized by a specific architecture (Brusoni, Prencipe and Pavitt, 2001), organizational co-evolution in the process of technology development (Brusoni and Prencipe, 2006); the alignment of organizational structure and product architecture (Sosa, Eppinger and Rowles, 2004). Other studies focused at group level exploring how novel solutions through reconfiguration and adaptation of prior combinations are generated (Hargadon and Sutton, 1997; Brown and Duguid, 2001). Furthermore, studies at inventor level viewed how successful generation and use of knowledge combinations rely on the position of the inventor in its collaborative network (Fleming, Chen and Mingo, 2007) and on the decomposability and interdependence of technological problems (Sorenson, Rivkin and Fleming, 2006). Moreover, studies at technological level investigated evolving technological trajectories (Dosi, 1982), technological knowledge domains (Carnabuci and Bruggeman, 2009) and evolution of technological capabilities (Stuart and Podolny, 1996).

The common denominator of these streams of literature resides in the search paradigm; in fact in order to create new technological solutions organizations, groups and inventors are usually in front a big dilemma: reinforce their pre-existing knowledge and focus problem solving activities on what has formerly demonstrated to be useful (March, 1991; Helfat, 1994; Martin and Mitchell, 1998; Stuart and Podolny, 1996) or reinvigorate their existing knowledge and generate new capabilities through the access to more distant knowledge (Gavetti and Levinthal, 2000). In the first case prior experience with the knowledge helps firms to think about which combinations are most likely to work well together in the knowledge landscape and whether chances for enhancement may exist, since knowledge that firm has applied frequently in the past is more understood and legitimate (Dougherty and Hardy, 1996). Moreover existing firm's knowledge base and current capabilities can be a constraint to the acquisition of new information (Kim and Kogut, 1996; Nelson and Winter, 1982) because knowledge that deviates from a firm's core technical abilities is often difficult to be understood and applied from firm members (Rosenkopf and Nerkar, 2001) and because managers know that developing products incorporating major changes relative to existing designs will force firms to acquire new technological skills and organizational routines (Dosi, 1988).

Whereas in the second case firms can depart from its current knowledge base creating new competitive and knowledge space through the identification of new opportunities and combination (March, 1991; Miner, Bassoff and Moorman, 2001) and pursuing new and different learning trajectories to search of new knowledge (Gupta, Smith and Shalley, 2006; Levinthal and March, 1993) but when the new search falls outside the domain of firm's past activities can be source of a competency trap (Levitt and March, 1988) and a source of rigidity (Leonard-Barton, 1992).

Another common denominator is the predominant focus on technological inventions and the exclusive use of patent data to analyze the process of knowledge recombination at organization, groups, inventors and technological levels of analysis (Fleming, 2001; Fleming and Sorenson, 2004; Rosenkpof and Nerkar, 2001; Yayavaram and Ahuja, 2008). The undeniable merit of this influential stream of research is the enhancement of our understanding of knowledge recombination processes and their implications on innovation. Nevertheless, this body of research has considered only specific types of firm knowledge, namely technical and scientific knowledge, as it is often embodied and/or emerging in patents. But the knowledge embodied in artefacts like products is more complex, and includes not only technical and scientific knowledge to be protected by patenting, but also know-how on production processes, knowledge of product components, raw materials and semi-finished goods. Product knowledge is especially important because it represents the source of innovation as well as technical knowledge and furthermore it drives the development of firm's knowledge and its evolution (Teece and Pisano, 1994; Teece, Pisano, and Shuen, 1997).

To the best of my knowledge, no one has empirically studied, yet, how knowledge recombination actually takes place at the firm level, how this transforms a firm's product portfolio and how product accrues and cumulates over time. This work is an explicit attempt to explore a firm's product knowledge, describe its evolutionary trajectories and, hence, explore this new research avenue. In order to answer to this question I firstly describe what firm's product knowledge represents in this study and the meaning of recombining it in the paragraph below.

1.2.1 From technical knowledge and technological trajectories to product knowledge and knowledge trajectories

Previous literature on evolutionary trajectories defined "normal modes of technological progress, which propel a product's progress along a defined, established path and the introduction of new technological paradigms" (Dosi, 1982: 147). According to Dosi technological paradigm is as a “pattern of solution of selected technological problems, based on selected principles derived from natural sciences and on selected material technologies” (Dosi, 1982:152). As a consequence, new paradigms correspond to discontinuities respect to earlier ones and thus trace out new trajectories of evolution; while when it is existing knowledge that outlines the trajectories of knowledge search, that consequentially remains bounded in the area of previous experience, firm follows a path-dependent trajectory.

While literature on path-dependency mainly focuses on technological path dependencies caused by firm’s choices pursuing certain technological trajectories (Helfat, 1994; Schilling, 1998) this work provides a view of path-dependency rooted in product sequencing and not on technology. Indeed in the creation of a new product firms cope with the decision of introducing new design or design that are similar to the existing one, where the concept of design similarity means closeness to the existing knowledge base (Dosi, 1988). Therefore, in this project, the knowledge elements that the firm has accumulated over time are approximated by its product portfolio that includes all the products created and commercialized by the company from the beginning of the activity to nowadays.

Since innovation outcomes strongly impact on firms’ competitive advantages, understanding the logic and the mechanisms behind the combination of resources and knowledge in the new product creation is a valuable avenue of investigation (Katila and Ahuja, 2002). As Usher (1954; quoted in Hargadon and Sutton, 1997: 716) argued “new product creation finds its distinctive feature in the assimilation of pre-existing elements into new syntheses, new patterns, or new configurations”. The recombination of existing knowledge components leads firms to new knowledge configurations that may act as a platform which includes both new and adapted knowledge combinations (Van den Bosch, Volberda and de Boer, 1999). The focus of this work is explicitly on firm's product knowledge and on its evolutionary trajectories.

Product knowledge is the repertoire of knowledge a firms has developed over time which is embodied in its existing products. This knowledge is articulated into component specific knowledge – the knowledge incorporated in each product component, and architectural knowledge - the knowledge about how components are combined together. Moving from this intuition and building on evolutionary economics, I conceptualize product knowledge as a recipe (Nelson and Winter, 1982) that details how to combine ingredients, such as physical components and processes, in which proportions, in what order, under what circumstances, in order to achieve a desired end (Sorenson, Rivkin and Fleming, 2006). This idea is consistent with previous studies (Schumpeter, 1939; Gilfillan, 1935; Usher, 1954; Nelson and Winter 1982) that explicitly view innovation and new product creation as a knowledge search process, exploring the space of possible combinations of ingredients for new alternatives (Levinthal, 1997; Rivkin, 2000; Fleming and Sorenson, 2001). Under this perspective, firms own a knowledge space where they can search and combine different knowledge elements according to an "[..] input-output combinations achievable with all possible mixes and levels of activities known to the firm" (Nelson and Winter, 1982:63-64).

Product knowledge shares the fundamental properties of flexible complex systems: it is hierarchical – i.e. articulated into subsystems so that some structures provide constraints on lower-level structures, and near-decomposable –i.e. the patterns of interactions among its components are not diffuse but tend to be tightly clustered into nearly isolated subsets of interactions (Simon, 1962, 1981). This systemic –i.e. hierarchical and nearly-decomposable - view of product knowledge underlies the structure of production and the sequence of input-output relationships that tie together raw materials, technologies and product parts. Each knowledge component or combinations of knowledge components are enablers of the activities that a firm should perform when creating and producing products. In other words, product knowledge can be conceived as complex, hierarchical and nearly decomposable systems in which each knowledge component is associated and combined to others, and can be assimilated to neural networks (such as feed-forward networks - Stergiou and Siganos, 2007) or other cognitive systems, to perform specific activities (Lyles and Schwenk, 1992; Walsh, 1995; Porac and Thomas, 2002).

More specifically, this study represents a first attempt to theorize and empirically investigate how product knowledge evolve over time and how it is recombined, creating new products, in a firm's product portfolio (Ahuja and Katila, 2001; Fleming, 2001). More precisely, following the idea of knowledge structure and platform, in this project I take up a network analytic approach to model firm's product knowledge and knowledge recombination processes. Looking at the product knowledge within a network approach[1], where product's components are nodes and ties are knowledge associations among components, I can define the firm's knowledge base as the knowledge whole product's components and all the links among them. Using this approach I build up on Yayavaram and Ahuja's topic according to "the issue of structuring at network level organizational knowledge represents an important frontier for

[1] Network approach is explained in the paragraph 1.4.

organizational research with growing and stimulating possibilities (Yayavaram and Ahuja, 2008: 360).

1.3 Modularity and product architecture

Since in this research a product represents a certain configuration of knowledge chunks, literature on modularity can be helpful to offer several explanations but at the same time to arise new questions. Schilling (2000) defines "[...Modularity as a general system concept describing the degree to which a system's components can be separated and recombined, and it refers both to the tightness of coupling between components and the degree to which the rules of the system architecture enable or prohibit the mixing and matching of components]". Modularity is a general set of principles for managing complex systems such as product, organization, technology and according to Simon, a complex system is "one made up of a large number of parts that interact in a non simple way" (Simon, 1962: 195).

The modularity concept has been applied in a variety of fields and disciplines, including computer science, engineering, biology, architecture, literature, education and music (Blair, 1988), and during the last decade it has attracted the attention of numerous management scholars in the areas of product, production systems and organizational design, as well as in industry architecture and evolution (Schilling and Steensma, 1999; Snow, Miles and Coleman, 1992; Jacobides, 2008). The common denominator of these studies is system complexity that can be managed through decomposition of the sub-system. Complexity regards both the number of individual parts a system comprises and the interconnections or interdependencies among those parts. One way to cope with complexity in system design or, alternatively, to increase a system's flexibility is to make it hierarchical and nearly-decomposable. This implies reducing the number and types of relationships (and hence, dependencies) among the system's parts, and consequently, creating an order by grouping the several elements belonging to the system into a smaller number of subsystems - what Simon defined “decomposability in modular design”- that can be designed independently, yet function together as a whole (Baldwin and Clark, 1997). The key principle of modularity is information hiding (Parnas, 1962) or knowledge encapsulation (Langlois, 2002); more specifically the idea that every module/subsystem includes information (knowledge) and provides some architectural rules (Baldwin and Clark, 2000) has not to be taken into account to design properly the other modules/subsystems.

The term modularity appears in the literature referred to several issues: modularity in a strict sense (Baldwin and Clark, 1997; Sanchez and Mahoney, 1996; Meyer and Utterback; 1993), modular innovation (Henderson and Clark, 1990; Christensen and Rosenbloom, 1995; Hsuan, 1999a), modular system (Baldwin and Clark, 1997; Langlois and Robertson, 1992), modular components and modular product design (Sanchez, 1995; Schaefer, 1999; Sanchez and Mahoney, 1996) and modular product architecture (Ulrich and Eppinger, 1995; Sanchez and Mahoney, 1996; Lundqvist et al., 1996; Sosa, Eppinger, Rowles, 2004).

Although several applications, the concept of modularity is strongly related to the issue of product architecture; indeed the product modularity research is the most extensive stream of literature. Product architecture is the way in which the functional elements of a product are arranged into physical units and the way in which these units interact (Ulrich, 1995). Accordingly, product architecture is often thought in terms of its “modules” (Ulrich and Eppinger, 1995) where a module is a physical or conceptual grouping of components. Hence, generally the concept of modularity refers to the decomposition of a system into independent parts, exactly defined modules, which can be treated as logical units (Pimmler and Eppinger, 1994). This issue is important because the choice of product architecture has several implications for product performance, product change, product variety and manufacturability (Ulrich, 1995) as well as is strongly related to firms' development capabilities and product strategies (Pimmler and Eppinger, 1994).

The core research regarding product decomposition and its architecture begins with Alexander (1964), who describes a design process decomposing it into minimally coupled groups. Before him Simon (1962) proposed that complex design problems can be described in terms of hierarchical structures of "nearly decomposable systems" characterized by stronger interactions within groups and weaker among groups. Accordingly, the decomposition of a product design into functional components and the identification of the interfaces establishing the functional relationships between those components, shape the product architecture. Thus, the product architecture and the principle of modular design act as the guideline in subsequent design processes (Ulrich, 1995; Sanchez and Mahoney, 1996).

Products are complex systems in that they comprise a large number of components with many interactions between them. The scheme by which a product's functions are allocated to its components is called its "architecture" (Ulrich, 1995). Understanding how architectures are chosen, how they perform and how they can be adapted are critical topics in the design of complex systems. Modularity is a concept that helps us to characterize different product architectures. It refers to the way in which a product design is decomposed into different parts or modules. Scholars converge in identifying three main features of modules: they are separable from the rest of the product; they are isolable as self-contained, semi-autonomous chunks; and they are re-combinable with other components (Ulrich, 1995; Gershenson, Prasad and Zhang, 2004; Mikkola, 2006; Fixson, 2007; Salvador, 2007; Campagnolo and Camuffo, 2009). Furthermore, separability, isolability, and re-combinability are properties deriving from the way functions are mapped onto the components and from how components interact, i.e. from their interfaces.

Ideally, a perfectly modular product is made of components that perform entirely one or few functions (1:1 component/function mapping), with interfaces among them well known, defined, and codified (Ulrich, 1995). If these interfaces - i.e. the communication protocols among components - are widely diffused within a given industry, these components have open standard interfaces. However, if the protocols are designed specifically to suit a certain firm's requirements, i.e. they are firm specific, these protocols are closed and non-standard, unless we consider closed interfaces as proprietary standards used by a single firm or a specific network of firms (Fine, Golany and Naseraldin, 2005). Only open standard interfaces allow to fully separating, isolating, and re-combining product components as modules (Ulrich, 1995; Fine et al., 2005; Salvador, 2007). Interestingly, modular products are characterized by standard interfaces among components, but the other product's features and attributes –including technologies- may change. Thus, a modular component is not necessarily standard.

There are a number of advantages and disadvantages of employing increasingly modular product designs, but the advantages most often cited is modularity's ability to greatly increase flexibility in the end product by allowing a variety of possible configurations to be assembled that are available both for firms and customers (Garud and Kumaraswamy, 1995; Sanchez, 1995; Sanchez and Mahoney, 1996; Baldwin and Clark, 1997). Moreover modularity offers other several advantages such as booting the rate of innovation because it allows to independently experiments with new product and concepts (Baldwin and Clark, 1997); increasing product variety because it combines old and new versions of various subsystems along product family (Schaefer, 1999); learning about the interactions between components due to the process of mixing-and-matching (Mikkola, 2006); reducing overall manufacturing costs (Shirley, 1990); increasing strategic flexibility since it becomes easier to re-use modules across product models or model generations (Worren et al., 2002).

A deep investigation of this stream of literature reveals that there are still few quantitative metrics available to measure modularity because a large part of research on modularity is qualitative and exploratory in nature (Mikkola, 2003; Cabigiousu, Camuffo and Schilling, 2009). Furthermore Sosa, Eppinger and Rowles (2007) called for longitudinal studies of modularity to understand how it can change over time across several product generations as well as for developing alternative measures capturing architectural properties of components and the modularity impact on new product creation. Moreover past studies have mainly focused on aircrafts, consumer electronics, automobiles, personal computers, household appliances, software and power tools where the investigation of modular product architecture that allow mixing and matching of modular components is most readily recognizable (Sanchez and Mahoney, 1996).

Thus this work explores product architecture from an evolutionary viewpoint providing a deep analysis of an original longitudinal dataset representing the entire firm’s product portfolio. Furthermore, this work offers a step over the acknowledged issue of "product modularity" toward a more widen concept of "knowledge modularity". In fact to the best of my knowledge, product modularity and in particular product modules have been generally investigated as invariant components that firms mix and match to achieve a particular aim, such as create a new product. This work is an explicit attempt to offer a micro-analysis of product module and to better recognize what is behind and what may be beyond "the mixing and matching paradigm" giving a more fine-grained view of modularity and more specifically on knowledge modularity. In the paragraph below I will better illustrate this concept and its significance in the modularity literature.

1.3.1 From product modularity to knowledge modularity

This research moves from the static controversy about the pros and cons of modular product design towards a more realistic conception of how new products come to life. Since research on product modularity needs micro-foundations that capture more accurately the cognitive and social processes behind product creation, this work tries to make a step forward from the current debate around product modularity toward a broader concept of knowledge modularity. In order to develop the idea of knowledge modularity this work refers to what according to Fodor (1996) is one of the most important features of modularity, the information encapsulation. As the author notes "The informational encapsulation of the input systems is, or so I shall argue, the essence of their modularity" (Fodor, 1996: 71). Thus a module is not a static and persistent entity that can be only mixed and matched into different products but it is a dynamic entity representing localized processes rather than simply incipient structures (Raff, 1996: 326).

In fact while according to the modularity paradigm, product systems can be decomposed into a number of components that can be mixed and matched in a variety of configurations (Garud and Kumaraswamy, 1995; Sanchez, 1995; Sanchez and Mahoney, 1996) because they are standardized (Garud and Kotha, 1994); at the same time firms must ensure that enough degrees of freedom are built into modular components that allow for significant improvements in its evolutionary capabilities (Garud and Kumaraswamy, 1995; Garud, Kumaraswamy, Langlois, 2003). Thus, it is reasonable that a new product may be never the consequence of a simple mix and match process but it may come from something that is simultaneously variant and invariant that is “knowledge modularity”. In this dissertation I convey that this concept may be valuable in grasping what is really behind the mixing and matching paradigm.

By using Ulrich’s definition of product architecture (1995: 420) where it is defined as “the arrangement of functional elements, the mapping from functional elements to physical components, the specification of the interfaces between interacting physical components”, I may define “product knowledge architecture” as the arrangement of knowledge elements, the mapping from knowledge elements to physical product’s components and the specification of the interfaces between interacting physical product’s components”. Consequentially, product knowledge architecture is a common, stable and recursive pattern framing the overarching cognitive structure of products. Product knowledge architecture incorporates knowledge modules representing a bundle of information, inputs and capabilities ongoing shaped by the firm over time and strictly inherent to product components and that put up the “product knowledge architecture”.

Knowledge, though invariant, may be characterized by different degree of ambiguity and potentially product components variety. They may also have different potential in terms of the number, variety and characteristics (technical and physical nature) of the product components - physical and recognizable entities performing a well defined function and behind which specific knowledge modules have been developed – without any changes in the cognitive and architectural one. Knowledge modules simultaneously are "static" and "stable" but even "malleable" and "multi-purposive" and these characteristics represent may open up a huge variety of product components. Thus, while the knowledge modules are intrinsically equal every time they are used in different products, they may take different shapes contingent on the product in which they are included.

This conceptualization of knowledge modularity will be empirically investigated in the Chapter 4.

1.4 Network perspective

In the last years network has been a powerful paradigm in management theory, both on theoretical and methodological sides. This growing interest is shown by a prolific literature on the most important academic journals (for a review see Borgatti et al., 2003 and Brass, Galaskiewicz, Greve and Tsai, 2004) and by several special issues on top journals such as *Academy of Management Journal* (2004), *Academy of Management Review* (2006), *Advances in Strategic Management* (2008) and the last *call for paper* on "The Genesis and Dynamics of Networks" made by *Organization Science* (2009). A core belief underlying network perspective in organizational research is "the importance of the system of relations between actors" (Freeman, 2004: 16) or as Tichy, Tushman and

Fombrun, (1979: 507) state "[...] the social network approach views organizations in society as a system of objects (e.g. people, groups, organizations) joined by a variety of relationships". These relationships are of several types and they include "strategic alliances and collaborations, flows of information (communication), affect (friendship), goods and services (work flow), and influence (advice), and overlapping group memberships such as board of directors (Brass, Galaskiewicz, Greve and Tsai, 2004: 795). While network research has already a consolidated tradition and its richness and spread are acknowledged, it still bears all the marks of a research tradition that will further flourish, given that unresolved theoretical and empirical questions remain and several critiques have emerged (Brass, Galaskiewicz, Greve and Tsai 2004: 809). For example current research focuses more on network outcomes and on how network structures influence the creation of outcomes at individual, team and organizational levels, rather than to investigate how and why networks emerge, evolve and change over time (Borgatti et al., 2003; Powell, White, Koput and Owen-Smith, 2005; Ahuja, Soda, Zaheer, 2010).

Moreover after several decades spent to investigate both theoretically and methodologically social networks at individual, team and organizational levels of analysis (such as using friendships, co-memberships, alliances etc), new frontier for organizational research is the "issue of structuring at network level organizational knowledge" (Yayavaram and Ahuja, 2008: 360). These authors are one of the first to look a firm's knowledge base as a network where a "coupling" is a tie between two knowledge elements and a node is a cell of knowledge. In this brilliant paper they define "how the structure by which different knowledge elements of knowledge base are coupled together or are isolated from each other in different clusters, will affect the organization's ability to combine knowledge elements for innovation" (2008: 333). Thus, firm's knowledge base is a set of knowledge components that firm creates along time and that corresponds what the organization harshly knows (Jaffe, 1989; Ahuja and Katila, 2001; Fleming, 2001; Katila, 2002; Yayavaram and Ahuja, 2008) where components and coupling structure together contribute to its shape (Yayavaram and Chen, 2009).

Furthermore, other studies published on Journal of Knowledge Management such as Kim, Suh and Hwang (2003) proposed a practical methodology to capture and represent organizational knowledge where they define a knowledge map as a diagrammatic representation of corporate knowledge, having nodes as knowledge and links as the relationships between knowledge.

Following theses ground-breaking applications of a network perspective for something not "strictly social" as relationships between individuals, groups or organization this work inspects, within an evolutionary framework, the dynamics of the firm's knowledge base of a large food, beverage, sweet and confectionery Multinational Company throughout the exploration of its product portfolio over time. Thus this project applies the methodological tools typical of social network into the analysis of firm's product knowledge structure.

Firm's product knowledge structure is here considered a co-relational and a retrieval interpretative structure where knowledge is represented as a network with nodes that are knowledge chunks, connected by links meaning the joint utilisation of different knowledge chunks (Krafft, Quatraro, Saviotti, 2009; Pentland and Feldman, 2007). A network may be defined as a graph made of nodes that are tied each other by one or more types of interdependency. Relationships among nodes are expressed by arcs, which in turn may be directed or undirected.

Two nodes that are connected by a line are said to be adjacent to one another. Adjacency is therefore the graphical expression of the fact that two nodes are directly related or connected to one another. The evolution of the knowledge network may occur in several ways. First, new knowledge chunks can be developed or acquired by the firm; as a result the knowledge network structure will change because the new nodes. Second, new connections might be established between new or old nodes of knowledge, giving rise to consequent new links. Third, the importance, such as the weight of old and new nodes and links can change with the passage of time. Finally, some old knowledge nodes become extinct disappearing from the whole knowledge network. All these concepts correspond to firm's product knowledge life cycle, beginning with the emergence of a new type of knowledge chunk and continuing with the gradual maturation of the same knowledge.

Another new avenue of research is in combining, especially in the area of engineering design, product architecture representations and social network analysis (Sosa, Eppinger, Rowles, 2007) and in using network measures to evaluate the degree of component modularity. This work represents a contribution on this stream of research in using network analysis to study longitudinally the evolution of the firm's product knowledge architecture.

1.5 Goals and research questions

This work gives a contribution at breaching the black box of firm's product knowledge architecture design and evolution both on theoretical and methodological sides. On the former this project integrates evolutionary and network theories contributing to improve the understanding of the firm's product knowledge base. Building on evolutionary economics, this work conceptualizes product knowledge as a recipe detailing how to combine and in which order, proportions and circumstances each knowledge chunks. By using the metaphor of the pastry chef who has written in the mind the exact combination of several knowledge chunks in order to obtain the desired product, on the on hand by mixing and matching what he has previously used and on the other hand by searching for new knowledge chunks, this study offers an original way to more deeply comprehend the knowledge recombination processes.

As showed in the literature review knowledge recombination framework has always studied this phenomenon and more specifically how firm's knowledge evolve over time, at technological level through the use of patent data and not at product level. This study offers a new perspective in the analysis of knowledge recombination at product level where a more micro study on knowledge disentangling may be helpful. On the latter this work aims at applying the methodological tools of network analysis to the exploration of the structure of product knowledge bases in order to mapping and studying their evolution over time. I plan to use graph theory and network topology to identify evolutionary trajectories of product knowledge. This methodology helps to investigate and deeply understand knowledge recombination processes and how they lead to new products development and through modelling and analyzing the patterns of structural evolution of product knowledge networks over time this work grasps the ability of a firm in making product innovations and offers an unexplored view of firm's knowledge architecture evolution.

Moreover by working on the mixing and matching paradigm this work offers a more fine-grained view of modularity and more specifically on knowledge modularity that better grasp the issue that a module is not a static and persistent entity that can be only mix and match into different products but it is a dynamic entity that encapsulates information. Consequentially, new product is never or almost never the consequence of a simple mix and match process but it comes from something that is simultaneously variant and invariant that is “knowledge modularity”. In my opinion this concept could offer a strong contribution in enhancing the modularity literature.

Thus, the main goals of this project can be summarized in the following research questions that are addressed in Chapter 3:

- Which are the knowledge processes behind products?
- Which are the structural patterns of product knowledge evolution?
- Which kind of longitudinal structural patterns of knowledge evolution lead to product innovation?

And Chapter 4:

- Given the integral nature of sweets and confectionery products, what are the mechanisms that allow innovating while leveraging on existing products and resources?
- Since for integral products innovation can not be the result of components’ recombination (mixing and matching of existing components), what mechanisms allow to innovate leveraging on existing products?
- Does product knowledge have a hierarchical and quasi-decomposable structure? Do these properties allow recombining product knowledge components in order to generate new products?

Answers to these questions will be scattered across this project.

PART II: RESEARCH SETTING

CHAPTER 2: Alfa: a long history of success

2.1 Introduction

This chapter offers an overview of the research site investigated in the project. Paragraph 2.2 briefly illustrates the research investigation. In the paragraph 2.3 a description on the Company is offered. The paragraph 2.4 provides the research methodology and data sources. The Paragraph 2.5 shows the Conclusion.

2.2 Research investigation

This study addresses the micro-foundations of innovation through a longitudinal investigation of the product portfolio of a large food, beverage, sweet and confectionery Multinational Company[2] where I collected primary and secondary data through an in-depth two years study in order to track product portfolio's evolution over the 60 years of activity (1949-2009). For the primary data I conducted several in-depth interviews and for the secondary data I collected archival data about each Company's product. The reason of studying Alfa in order to investigate the micro-foundations of innovation is rooted in the strong interest that the Company has always demonstrated on this issue. Indeed Alfa's strengths lie in the combination of its abilities and its knowledge in developing new product where "it may take different forms, such as upgrades,

[2] This dissertation employs very sensitive data about Company's innovative capability, thus for this reason I omit the name of the Company. Following I will refer to the company with the name of Alfa.

modifications, and extensions of existing products and it may be new to the firm, the market or the world" (Li and Atuahene-Gima,2001: 1124). In the following part I will offer a description of the context and the research methodology applied.

2.3 Alfa Company: a description of the context[3]

Alfa is one of the leading confectionary manufacturing product companies in the world acknowledged for several leading brands and with a remarkable story began in the '40. Alfa's product portfolio is characterized by an inexhaustible line of unique and high-quality products, widespread on several product categories such as spread, candy aisles, bakery and beverage. Alfa's products are unique products, inimitable for taste and technology and characterized by a constant interest toward research and innovation. In fact the ongoing investment in research is one of the company's strengths aimed at developing new and original products that are unique and. Alfa has its own R&D department that supplies the entire Group with both technical and marketing research in order to invent and put on the market new products as well as to continue the process of innovation and improvement of current products. Each year around 100 million of euro are dedicated to its R&D department where around 360 among chemists, biologists, agronomists, nutritionists, engineers are engaged the several tests on the products. The constant attention to quality, together with the need to create absolutely unique confectionery products, has often required the development of special techniques and machinery. Alfa is also at the leading edge on the packaging technology by studying and developing package in order to improve the products

[3] The information of this paragraph have been gathered both on Company web site and through archival Company's documents.

preservation and their shelf-life. It designs and develops new packaging ideas with the aim of improving product protection and shelf-life, which are ensured by meticulous physical, chemical and micro-biological checks and controls.

2.4 Research methodology

The research methodology is articulated in the following steps:

- Collection of primary and secondary data gathered through semi-structured and structured interviews to Company's managers and archival data on each Company's product;
- Formalization of the issue of firm's product knowledge as it emerged from the interviews and elaboration of a model in order to capture and represent it;
- Use of network analysis in order to map product knowledge as a network of product components and model its dynamic in the period considered by utilizing insights from graph theory and network topology to identify evolutionary trajectories of product knowledge.

2.4.1 Primary data

Data gathering spanned the period 2007-2008, during which over 40 company visits were carried out. Thirty-three interviews with twenty-three key informants helped to better understand what product knowledge is and offer suggestions on how to model it. With some informants (seven informants) multiple interviews have been done. Informants' collaboration with Alfa ranged from 4 to 30 years. The interviews have been carried out in two windows of time (September – December 2007 and January – May 2008). During the first phase the team of researchers performed five unstructured interviews with Top Management; the aim of these interviews is to comprehend *what* in their opinion is the distinctive advantage of Alfa and *where* it resides and *how* they achieve it. All the interviewees agreed that *"the valuable resources of the company are marketing and distribution but that real core of this advantage resides in the product and how they do it"*. They convey that the knowledge of the product is the source of the Alfa's competitive advantage "*In our company product knowledge is a key asset and its source of a structural competitive advantage. This knowledge is stored at several levels and it is partially codified mostly following technical and functional logic of product and process. The reserve has always been a fundamental element in the choice of product and process knowledge management and to be able to simultaneously develop new knowledge instrumental to product innovation and keep it secret represents a core and distinctive competitive advantage"*. Thus, since product is the source of this advantage they suggest that *"it should be searched first of all in a particular area among the several organizational ones: the technical area[4]"*. The technical area is represented in Alfa by the R&D Department where engineers, technicians, experts of chemistry, biologists, chefs and so on, daily work to do experimentation in order to create new products and improve past ones. Thus these first five interviews with Top Management allowed understanding where exactly address the next. To identify the most knowledgeable informants in the technical area we decide to focus on the responsible of some Laboratories in the R&D Department. As a result the team of researchers conducted 19 semi-structured interviews tape-recorded and transcribed with 18 experts of several Laboratories of R&D

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[4] Platform knowledge resides in the minds of the professionals and managers who work in an organization's technical core (Ghandler, 1996; Dierickx & Gool, 1989; Grant, 1996; Nelson & Winter, 1982; Simon, 1991; Stinchcomhe, 1990).

department (with responsibility on raw materials, semi-finished goods, products, packaging, engineering). During these interviews, a similar schedule has been followed. Initially, general information about the aim of the interview has been offered[5], then questions about roles, activities, presence of best practices in the area, interaction within the Laboratory and with other Laboratories, how knowledge is generated and diffused, if the knowledge is more tacit or explicit have been asked in order to understand which are the contents that need to emerge and the characteristics that needs to be communicated to represent the heritage of Alfa's knowledge.

From these interviews come out that each Laboratory involves around 3-9 people whose daily activities may range from *"concept generation, design and testing activities of a product prototype to ensure industrial manufacturing and market viability"*. For example a responsible from semi-finished good laboratory said "*My laboratory is antecedent to all the others; we do research on raw materials rooted in Alfa's knowledge such as hazelnuts, cocoa beans, coffee, milk but even on new ones that we did not know before. In this case when little samples of these raw materials arrive in the laboratory we start working on them. This continuous experimentation can be useful both to find new inputs and discover raw materials similar to others that could be helpful in the case of price changes or out of stockiness. The research on raw materials is directly linked to the technologies because when the new beans arrive we should understand if it needs to be toasted, fried, and boiled and so on. Sometimes we do several trials that at the end are useless"*. About

[5] The principal aim is to refer what emerged from the interviews with the Top Manager which about the source of competitive advantage and distinctiveness in Alfa. According to them this advantage derives from product, so experts of technical area of R&D department, and owner of Alfa's product knowledge, may help to surface it and to construct the Alfa's knowledge heritage for the next generations.

mechanisms of knowledge storing and sharing there are several differences in the Company; some Laboratory gathered detailed information about their knowledge, one example is the "*Library for aroma*" that according to the responsible *"is the daily instrument we use to manage the huge quantity of samples we have. An aroma for a cream is different from an aroma for a candy. Our library is update each semester"*; a responsible of another Laboratory quotes *"we have some archives for the doses where we collect new experiments and new recipes; when we improve technologies or preparation we prepare a file in order to keep in mind this activity and advancing it in the future"*; other are more based on internalized routines and tacit knowledge always in the mind of few people, as a responsible from a Laboratory quotes *"I'm sure that something written exists in the Company but in my opinion it's always better not to write too much. The principal information is written and shared but we keep secret the small devices that create the difference. Everybody knows how to roast hazelnuts or coffee or cocoa beans, but it's in the details that Alfa has always won respect to the competitors"* or as another told *"The migration of knowledge between departments were impossible even among people in the same hierarchical position and company contributed in exaggerating this aspect. I remember when I entered in Alfa in 1985 that in the production line people spoke in dialect as representing the secrecy of secrets. Although several years passed each time there are some anecdotes, for example when we did some experiments on a new dose of wafer we realized that there was a severe problem during the process of cooking; only when an old employee came and saw the problem we managed it. His visual experience was related to several years spent in the area but he was unable to convey his knowledge to younger generation"* or as a responsible from another

Laboratory argued *"If I broke my leg the information will stop. I understand all the reasons to keep secret but you can be reserved but at the same time efficient. Company has a higher effectiveness in problem solving but we don't have a systematic approach to this. The different laboratories own a great amount of information but usually they do not communicate among themselves; this implies that sometimes you could repeat things that other have already done."* This different approach may vary for several reasons; a sort of revenge as someone told that *"I learnt lonely during my first years. I have worked here for 35 years. Why should I teach someone now?*" or a reason of secrecy *"In my opinion lots of principal information are reserved or kept by a few people. I understand and approve this decision because our know-how is characterized by very small details that should not be captured by competitors. Consequentially the information is more tacit and protected"*.

Nevertheless what these Laboratories showed to have in common is the consciousness of their distinctiveness that resides in what everybody called "*Alfa's advantage*". Alfa's advantage means identification with the Company and products, as someone quotes *"See the Company and the product as they were yours"* or *"create something that does not exist everywhere"* or *"The continuous play because what is good today could not be tomorrow and the use of something that you never thought about"*; or distance with competitors in *"keep the treasures we have and maintain a constant gap toward competitors"*; or attention to particular in *"at technical level there is a maniacal research of excellence in product quality that nobody in the food industry offers; we have a proper culture in the research of raw materials and technologies. This research makes the daily activity very complex because we constant search something that it is difficult to be replicated. Alfa during these years created a lot of good* *products but several have not been put on the market because they were easy imitable. Our products should be inimitable product because they are obtained after several years of activity, construction of identity and quality"*; or active participation during the phases of new product development in *"there are 10-15 people belonging to different business units and different hierarchical levels who meet Alfa and develop and start to think about a new product; this does not happen in other Companies"*. Moreover other evidences illustrate that everybody has in mind a *"knowledge structure representing all the passages they usually do in their activities of combining and recombining components, trying new linkages between components, using methods processes and techniques to create new products or improve the existing ones".* Thus using James Walsh's words they use "a mental template with form and meaning" (Walsh, 1995: 281) that are based on past experience and represent organized knowledge about a given concept.

2.4.2 Secondary data

Research team gathered secondary data from several sources: several hundred pages of documents were available through Alfa's knowledge descriptors; patents data have been retrieved from both U.S Patent and Trademark Office database and European Patent and Trademark Office[6]; information on market domains and product categorization; firm financial indicators have been assembled from Euromonitor International (data on company and products brand shares as well as competitors and products' competitors brand shares); from AIDA (performance data at firm level such as ROI, ROE, R&D investments

[6] Since some patents are present on both sources, others have been registered only on one source or on the other, thus research team preferred to use both sources of data.

etc); from Hoovers (general information about industry and competitors). Moreover research team has had access to several information about future product strategies and experimentation. All the data gathered have been used in the two empirical parts of this project.

2.4.2.1. The knowledge descriptors: repository of product knowledge

The knowledge descriptor (KD) is a repository of organizational knowledge where firm accumulates, codifies, and stores product knowledge. The function of knowledge descriptor is to systematize product's knowledge and contribute to the development of firm's knowledge base. Knowledge descriptors can be referred to raw-materials, technologies, semi-finished goods, finished goods. The information available depends on the typology of knowledge descriptor. Knowledge descriptors of raw-materials offer information about: raw materials' definition, how they are in nature, the chemical components, organoleptic characteristics, functional and nutritional aspects, in how many products they can be employed, the applied and potential applicable technology, internal value chain, subject matter expert, documents and blue-prints; knowledge descriptors of technologies offer information about: technology's definition, application in the production process, range of raw materials or semi-finished goods combined or combinable, input, output, description of the technology, level of criticality, presence of patents, competitors, internal value chain, subject matter expert, documents and blue-prints; the knowledge descriptors of semi-finished goods offer information about: semi-finished good's definition, organoleptic characteristics, in how many products they can be employed, the applied and potential applicable technology, internal value chain, subject matter expert, documents and blue-prints; the knowledge descriptors of finished-goods offer information about: product's history, the components (ingredients) of each product, technique (a part related to all components - raw materials and semi-finished goods - and technologies – transformation and combination -, information about marketing and sales, data on performance, experimentation, commercialization, communication), product evolution (technique, marketing and sales), internal value chain, subject matter expert, documents and blue prints). These knowledge descriptors include not only information about physical components and processes but even the proportions, the order and the circumstances of usage for reaching the desired aim. Thus knowledge descriptors represent the competencies maintained by the individuals into the company and they help to acquire, retain, deploy, idling and abandoning knowledge over time. As someone told "*They embody useful information about the past that may be ready to lend a hand for the future, the larger the knowledge will be the broader will be the repertoire of organizational responses it will offer*[7]".From technical point of view products are the result of a creative process of combination among several elements such as raw materials, technology of transformation of raw materials in semi-partly goods, technology of combination of raw materials and semi-partly goods; semi-partly goods, technology of combination of semi-partly goods, technology and materials for packaging. Knowledge descriptors represent the content of each knowledge cells and each knowledge cell represents a product specific knowledge chunks including the definition of the element (nature, variety,

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[7] Similarly Levinthal and March said "where situations or proper responses are numerous and shifting, it is harder to specify and realize optimal inventories of knowledge. By the time knowledge is needed, it is too late to gain it; before knowledge is needed, it is hard to specify precisely what knowledge might be required or useful. It is necessary to create inventories of competencies that might be used later without knowing precisely what future demands will be" (Levinthal and March, 1993: 103)

states), other elements and lower level structures, blue prints or documents describing the elements, organizational unit, subject matter expert, scientific literature on the elements, internal or external supplier, internal or external client.

On the knowledge descriptors research team performed a content analysis codifying all the information present in this document in order to have a structural skeleton of the products' recipe detailing how to combine ingredients, in which proportions, in what order and using what processes.

2.4.2.2 Alfa's patents

Alfa's distinctive competitive advantage is based on its continuous research of technological barrier toward the competitors. Patents activities referred to technologies, processes, whole products or part of them, packaging and design represented a constant for this Company that from the early '60 to nowadays has positioned its products and the technologies behind on the frontier of research. To give an illustration of the Alfa's patenting activities I gather data from USPTO and EPTO that are summarized in the following table.

Tab. 1 Alfa's patenting activities

	Design	Packaging	Product	Product and Technology	Technology	Total
EPTO	39	45	6	11	52	153
USPTO	25	39	12	4	35	115

By looking at the temporal patents distribution it appears that especially during the last years Alfa patented more designs and packaging respect to the other categories. This issue fits with some interviews according to *"The technological barrier respect to the past are less, now* *our products can be copied by competitors but it still remains the concept that we don't copy the others".*

2.4.3 Elaboration of the product knowledge model

Through interviews and archival data research team surfaces and formalizes the issue of product knowledge and elaborates a model in order to capture and represent it. The research team follows these steps:

- Identify cells of knowledge accordingly to the interviews with the experts;
- Structure the cells of knowledge in standardized documents (called knowledge descriptors unfolding the technical knowledge associated to all knowledge chunks);
- Define a theoretical model for product knowledge in the form of a relational tree constituted by nodes and relationships
- Use the tool of network analysis (that will be properly explained in the next paragraph) to construct adjacency matrices for each products (adjacency matrices are two-mode matrices representing the raw materials and the semi-finished goods on the rows and on the columns the technologies of transformation, the technologies of combination and the final product)
- Transform the two-mode matrices in one-mode matrices representing raw materials, semi-finished goods, technologies of transformation, technologies of combination and the final product both on the rows and on the columns;
- Validate the knowledge model and the matrices created by the research team through a second phase of interviews with nine of the informants previously interviewed.

2.4.4 The network of product knowledge

In order to understand and map product knowledge Social Network Analysis (SNA) may be helpful. SNA is a methodology used to analyze social networks used in several disciplines such as sociology, anthropology, psychology and management. In the last years this methodology has been also applied in physics, biochemistry and genetics and it has been directed as a way of representing of interdependent and complex phenomena. In its development SNA has used terminology and concepts of *graph theory* (Wasserman and Faust, 1994). Graph theory has been useful in social network analysis for several reasons: firstly is offers a vocabulary which can be apply to label and highlight many social structural properties; secondly it provides some mathematical operations and ideas with which many of these properties can be quantified and measured (Freeman, 1984; Seidman and Foster, 1987b). Matrices are an alternative way to represent and summarize network data where a matrix contains exactly the same information as a graph, but it is more useful for computation and analysis.

Graph theory offers a representation of a social network where nodes represent actors and lines represent ties between actors. In graph theory the nodes are also referred to as a vertices or points, and the lines are also known as edges or arcs. A graph may be *undirected*, meaning that there is no distinction in direction between the two vertices associated with the edge, or its edges may be *directed* where a line is directed from one node to another. This are also called digraph and they are used for representing directional relations, where the tie has an origin and a destination. Graph can be cyclic or acyclic; an example of acyclic graph is a tree. The tree is a graph that is connected and is acyclic, meaning that contains no cycles (Wasserman and Faust, 1994). Trees show some particularly features: firstly they are minimally connected graphs since every line in the graphs is a bridge (thus the removal of any one line causes the graph to be disconnected); secondly, the number of lines in a tree equals the number of nodes minus one (L= g-1); thirdly, there is only one path between any two nodes in a tree.

Because in this project from a technical point of view products are the result of a creative process of combination among several elements such as raw materials, semi-partly goods, technology of transformation and technology of combination and so are represented by several multiple relations, generally following a sequential order among the knowledge elements, they can be drawn as a relational tree among these knowledge elements. For this reason graph theory and network analysis can be helpful. By using adjacency matrices some knowledge chunks elements have been identified in each product and this network represents the entire Alfa's product knowledge. Alfa's product knowledge structure is here considered a co-relational structure where knowledge is represented as a network with nodes that are knowledge chunks, connected by links meaning the joint utilisation of different knowledge chunks. Using Porac and Thomas (2002) conceptualization "knowledge structures order an information environment in a way that enables subsequent interpretation and action, are built on past experience, and represent organized knowledge about a given concept or type of stimulus". This is a useful way to map product knowledge in a structured way in order to analyze its development and evolution.

This approach of mapping product knowledge toward a network perspective offers several opportunities: analyze the structural properties of network-product to stimulate the innovation process; study the past product knowledge trajectories and construct an empiric model to predict new ones; understand the architectural logic of product construction and the knowledge behind each components.

2.5 Conclusion

Since the challenge for the firm's competitiveness is based on knowledge, try to increase its value and use it to advantage is a key of success. Intellectual capital is one of the inescapable firm's resources and the codification of individual knowledge in collective one represent an important firm's asset. Most of the research the knowledge management area investigated the properties of different types of knowledge, in particular the distinction between tacit and explicit knowledge, and the relationship between individual and social knowledge (Nonaka, 1994; Spender, 1994). These characteristics have crucial strategic implications not only for innovation but also for barriers to imitation and the sustainability of competitive advantage (Kogut and Zander, 1992).

Because several research on knowledge management asserted that knowledge grows, develops and become more sophisticated with usage and that the capacity to develop and sophisticate knowledge is a primary source of value generation, a model that may make product knowledge structured and easy transferable to several levels of organization but at the same time able to preserve its reservation avoiding its dispersion, is necessary. Thus the model of product knowledge has been appositely elaborated to provide a way in order to solve these two simultaneous problems.

As the knowledge-based view of the firm refers, firms need access to different knowledge bases and capabilities to develop new knowledge, but also bundle them with internal mechanisms, structures, and cultures to exploit their resources and capabilities (Kogut and Zander, 1992; Teece et al., 1997). This project tells the way in which Alfa could capitalize its past knowledge for future generation using this Product Knowledge Model in order to share its product knowledge together with the improvement of knowledge security by transform product knowledge in a collective asset. For this reason this model may create the foundation to guarantee greater stability and longevity of innovation capabilities.

PART III: EMPIRICAL ANALYSES

CHAPTER 3: Investigation of knowledge trajectories

3.1 Introduction

Chapters 3 and 4 yield the empirical analyses of this project. In this Chapter I take on the challenge of modelling firm product knowledge and identifying its evolutionary trajectories. The paragraph 3.2 examines firm's knowledge base and knowledge recombination. The paragraph 3.3 is about knowledge recombination and innovation. Section 3.4 is a about learning trajectories taken by product knowledge and the theoretical mechanisms behind it. The paragraph 3.5 explores the method and the 3.6 describes the construction of the product knowledge networks. The paragraph 3.7 shows the analyses performed and the 3.8 provides the results. Finally 3.9 and 3.10 provide discussion and conclusion.

3.2 Firm's knowledge base and knowledge recombination

Firm's knowledge base can be defined as "sets of components, such as information, inputs, capabilities, or individual pieces of knowledge that firm creates over time and that represent the content of what the organization knows" (Jaffe, 1989; Ahuja and Katila, 2001; Fleming, 2001; Katila, 2002; Yayavaram and Ahuja, 2008). Furthermore, a component can be defined as a physically distinct portion of the product that embodies a core design concept and performs a well-defined function within a system of coupling structure among interrelated components whose collective functioning makes up the product (Clark, 1985; Sanchez and Mahoney, 1996). Components and coupling structure together shape the firm's knowledge base (Yayavaram and Chen, 2009).

The dimensions under which firm knowledge base has been investigated are several. For example it has been mapped into knowledge persistence and knowledge integration (Brusoni and Geuna, 2003); more specifically knowledge persistence was studied analysing the evolution of knowledge specialisation over time and hinting at the accumulative and path dependent nature of learning processes (Pavitt, 1992) and knowledge integration was studied by analysing the evolution of knowledge specialisation across different typologies of research (Pavitt, 1998). These two constructs have been also operationalized through the indicators of breadth and depth of knowledge (Katila and Ahuja, 2002). Moreover, the size of the knowledge base, measured as the number of elements included (Fleming, 2001; Ahuja and Katila, 2001) or its relatedness, such as the degree of overlap between different organizations, are other dimensions investigated by previous scholars.

Recently, another frontier of firm's knowledge base studies is referred to its structuration at network level. In this direction Yayavaram and Ahuja (2008) offered an original contribution exploring "how the structure by which different knowledge elements of knowledge base are coupled together or are isolated from each other in different clusters, will affect the organization's ability to combine knowledge elements for innovation" (2008: 333). These authors are the first to look a firm's knowledge base as a network where a "coupling" is a tie between two knowledge elements.

It is broadly recognized that the starting point of each invention is the firm's initial knowledge base and that a firm's inventive outcomes depends on its ability to combine and recombine knowledge (Yayavaram and Chen, 2009). Accordingly, a long tradition of studies looks at invention and innovation as a combination of components in a new way (Schumpeter, 1939; Nelson and Winter, 1982), or as a reconfiguration of existing combinations (Henderson and Clark, 1990). Innovation can surface because it embodies components that were not present earlier or it can emerge through recombination of existing components (Holland, 1975). Thus, new knowledge and its embeddedness into firm's outcome, such as new products, is often the result of a firm's combinative capability to originate new usages of existing knowledge components (Kogut and Zander, 1992). In this perspective firms innovate by searching out new resources or new ways of using existing resources because as Nelson and Winter (1982, p.88) affirm "the creation of any sort of novelty in art, science or practical life consists to a substantial extent of a recombination of conceptual and physical materials that were previously in existence".

However, the idea that breakthrough invention and innovation are characterized by a combination of knowledge components in a novel way (Gilfillan, 1935; Schumpeter, 1939; Usher, 1954; Nelson and Winter, 1982; Hargadon and Sutton, 1997) or by a reconfiguration of existing combinations (Henderson and Clark, 1990; Galunic and Rodan, 1998) has been principally examined in the context of technological invention and measured by patents and patents citations (Loasby, 2002). In fact the vast majority of studies (except Yayavaram and Ahuja, 2008) have focused on knowledge recombination using patent citations although several concerns about this measure of knowledge are acknowledged by researchers[8] (Alcacer and Gittelman, 2006). I agree that patents and

[8] In particular the underlying assumption is that citations map the flows of knowledge and the technological learning because it represent that a citation from patent B to patent A specifies that inventors on B knew about and used A in developing B (Alcacer and Gittelman, 2006). The concerns surfaced about the use of patent citations to

specifically the analysis of patent citations are a valuable source to grasp knowledge recombination and diffusion and lots of studies across several dimensions such as geographic space, technological fields, organizational boundaries, alliance partnerships, and social networks witness their utility (Almeida and Kogut, 1999; Jaffe and Trajtenberg, 2002; Gomes-Casseres, Jaffe and Hagedoorn, 2006). However, I convey that a valuable contribution in order to deeply look at the process of knowledge recombination resides in switching the level of analysis and investigating this phenomenon at product level rather than at patent level. In fact product knowledge is more complex and multi-faced and it is contemporaneously characterized by several elements such as technical and scientific knowledge and knowledge of product components such as raw materials and semi-finished goods that enabling the activities that a firm should perform in order to create and produce products. As a result, as patent citations show what knowledge elements are combined together, product knowledge evolution illustrates which knowledge elements, underlying product architecture, are re-used and recombined over time.

More specifically, this paper looks at firm's knowledge base as a cumulative function of product knowledge and more specifically on how the knowledge underlying firm's products is recombined over time to create new products. By following previous work, I assume that solutions to complex problems (such as the creation of new products) correspond to combinations or syntheses of existing knowledge (Fleming and Sorenson, 2000; Henderson and Clark, 1990). Recently, scholars have portrayed this

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measure knowledge flows are that "patent examiners, government agents who approve patent applications, are also involved in drafting the contents of patents, and their citations are unlikely to reflect knowledge flows" (Alcader and Gittelman, 2006: 774) and so their use could add some measurement errors.

variety of knowledge combinations as a landscape (Levinthal, 1997; McKelvey 1999; Gavetti and Levinthal 2000; Rivkin 2000; Ethiraj and Levinthal 2004; Rivkin and Siggelkow, 2007). This approach conceptualizes knowledge landscape in terms of the product knowledge developed by a firm.

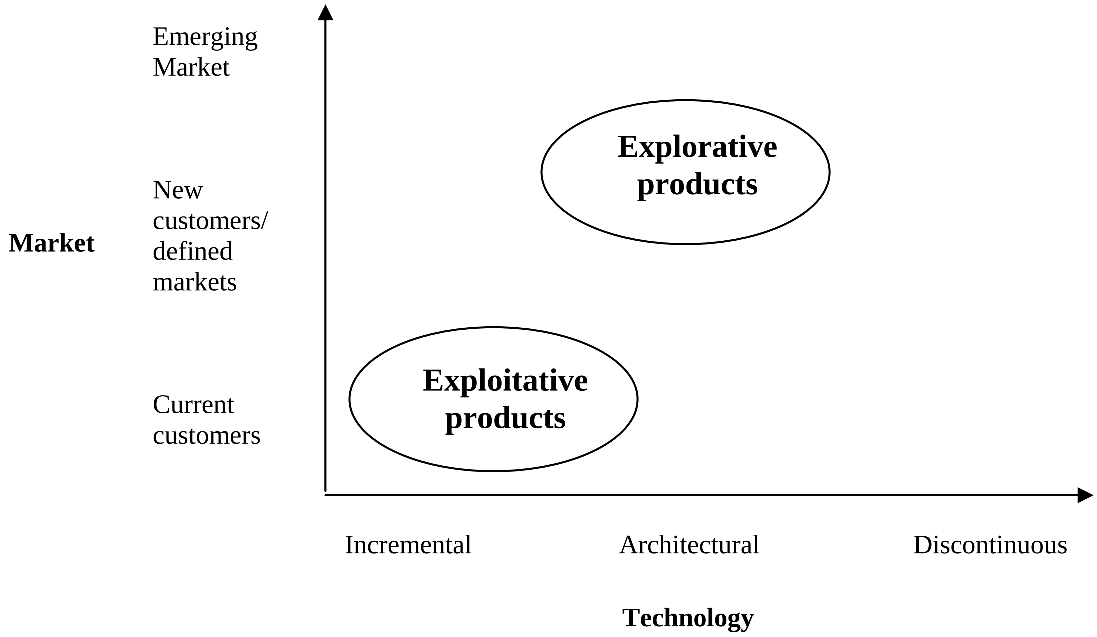
Indeed to the best of my knowledge the evolution of knowledge landscape is still an under-investigated phenomenon and more specifically product knowledge landscape has been never investigated by previous studies. This project also answers to Galunic and Rodan's (1998) call for a better framework to implement knowledge recombination. Accordingly I expanded the focus of this line of inquiry by analysing knowledge recombination at firm's product level using a network perspective.

3.3 Knowledge recombination and innovation

Innovative capability manifests itself in the firm's capacity to continuously generate new knowledge and bring it to the market in the form of new products and services where new products represent the commercialization of an invention and they may take different forms, such as upgrades, modifications, and extensions of existing products that may be new to the firm, the market or the world (Li and Atuahene-Gima, 2001). Innovative capability may be looked according to a macro or micro perspective (Garcia and Calantone, 2002). On the one side "it is the capacity to create a paradigm shift in the science and technology and/or market structure in the industry" on the other side "the capacity of a new innovation to influence the firm's existing marketing resources, technological resources, skills, knowledge, capabilities, or strategy" (Roger and Calantone, 2002: 113).

In summary innovation is about knowledge – creating new possibilities through combining different knowledge sets. These knowledge sets may be in the form of knowledge about what is technically possible or what particular configuration of this would meet some latent needs (Tidd, Bessant and Pavitt, 2004) and may regard technological as well as markets knowledge. Indeed by looking at the innovation stream of literature referring to the portfolio of products (Tushman and Smith 2002) innovation can be classified relative both to the technology and the target markets of the firm's existing products (Abernathy and Clark 1985). On the one side by comparing new products to the existing one, the firm's innovation can be classified as incremental (Christensen 1997, Dosi 1982), architectural (Henderson and Clark 1990), or discontinuous (Gatignon et al. 2002). On the other side, new products may also be targeted to existing customers, new customers in defined markets (Abernathy and Clark 1985), or emerging markets (Christensen 1997). Smith and Tushman (2005) summarized these dimensions in an innovation space where along these dimensions innovations move from more exploitative to more explorative typologies.

Fig. 1 Innovation space (Adaptation from Smith and Tushman, 2005)



Similarly in this Chapter I will consider two main dimensions according to classify new products comparing to existing ones; the first is the marketing knowledge similarity so if a new product builds or not on the same market knowledge of the previous products and the second is product knowledge similarity so whether a new product put up or not on the same product knowledge of the previous products.

3.3.1 Product knowledge and market knowledge

In order to achieve competitive advantage firms should be able to successfully adjust the strategic combination of their resource bundles, or capabilities to the unique characteristics of the marketplace (Eisenhardt and Martin 2000; Grant 1996; Pisano 1994; Teece, Pisano, and Shuen 1997). Product innovations can improve a firm's overall performance by fulfilling customer needs more effectively than actual offerings (Davidson 1976; Szymanski, Bharadwaj, and Varadarajan 1993). By creating a product innovation from the generation of new ideas through the launch of a new product the exploitation and exploration of capabilities are central (Atuahene-Gima 2005; Holmqvist 2004; Özsomer and Gençtürk 2003; Rothaermel and Deeds 2004). Thus firms need to concurrently exploit existing resources while developing new ones (March 1991).

According to the innovation literature in the introduction of a new product firms should consider both technological and marketing capabilities (Christensen, 1997; 2000; Verona, 1999; Daneels, 2004; Henderson, 2006) where the first includes R&D and manufacturing routines, technological complementarities and design and the second market research tools, strategic marketing management, marketing mix-policies and marketing complementarities (Verona, 1999).

Similarly to this stream of research I take into consideration two main sources of product innovation: product knowledge and market knowledge. Product knowledge includes not only technical and scientific knowledge but also know-how on production processes, knowledge of product components, raw materials and semi-finished goods. Market knowledge is defined as an organized pool of knowledge about the market (or markets) in which the firm acts (or would act in the future) (Li and Calantone, 1998). Market knowledge is the capability of the firm to develop a better understanding of customer needs and their evolution and of the competitive environment in target markets (Dougherty, 1990).

The literature on new product development process emphasizes the embodying of new knowledge into new products (Rothaermel and Deeds, 2004; Madhavan and Grover, 1998). Newly acquired inputs are integrated with existing knowledge stocks following a process of knowledge accumulation. This process involves a set of search strategies reflecting the choice of knowledge elements used in recombination (Stuart and

Podolny, 1996). Consequentially, each firm shows a peculiar product sequence characterizing the paths that firm's products follow over time going through a new generation of an existing product, a product expansion or a combination of the two (Helfat and Raubitschek, 2000).

By creating a product innovation from the generation of new ideas through the launch of a new product the exploitation and exploration of capabilities are central (Atuahene-Gima 2005; Holmqvist 2004; Özsomer and Gençtürk 2003; Rothaermel and Deeds 2004). The central argument of this literature is that firms need to concurrently exploit existing resources while developing new ones (March 1991). According to search theorists these two distinct strategies depend on the kind of knowledge that firms search and recombine: the arrangements of familiar knowledge that proven their value in the past and that can be mixed and matched into new ways in the case of exploitation and the search of new knowledge elements acquired outside the existing firm's stock of knowledge in the case of exploration (Fleming, 2001; Grant, 1996; Henderson and Clark, 1990; Penrose, 1959).

The investigation of the product knowledge architectures through a network framework allow understanding in which way knowledge elements vary and are recombined over time in the creation of new products. Therefore firms may introduce new products through by deciding to explore unfamiliar area and by using components that are distant from the current knowledge base or they can opt for a local recombination of proximal and accessible knowledge components (Fleming, 2001). Exploitation and exploration may be both investigated at product and market knowledge levels. A firm exploits its product knowledge whether new products build on the same product knowledge structure of previous products; on the other side a firm explores its product knowledge if new products put up on product knowledge structure different from the past ones. Similarly a firm exploits its market knowledge if new products evidence market domain similarity with past ones and otherwise in the case of market knowledge exploration.

In the empirical part I will illustrate as Alfa positioned itself in both strategies.

3.4 Knowledge learning trajectories

Scholars interested in technological change have developed a set of concept in describing the trajectories that technology can pursue over time. By borrowing Dosi's definition of technological paradigm I define knowledge paradigm "a multidimensional construct referred to a generical task, the material selected to achieve the task and the physical, chemical and technological properties exploited". Here I theorize that the movement of knowledge paradigm follows certain trajectories that are formally investigated through the analysis product knowledge networks over time.

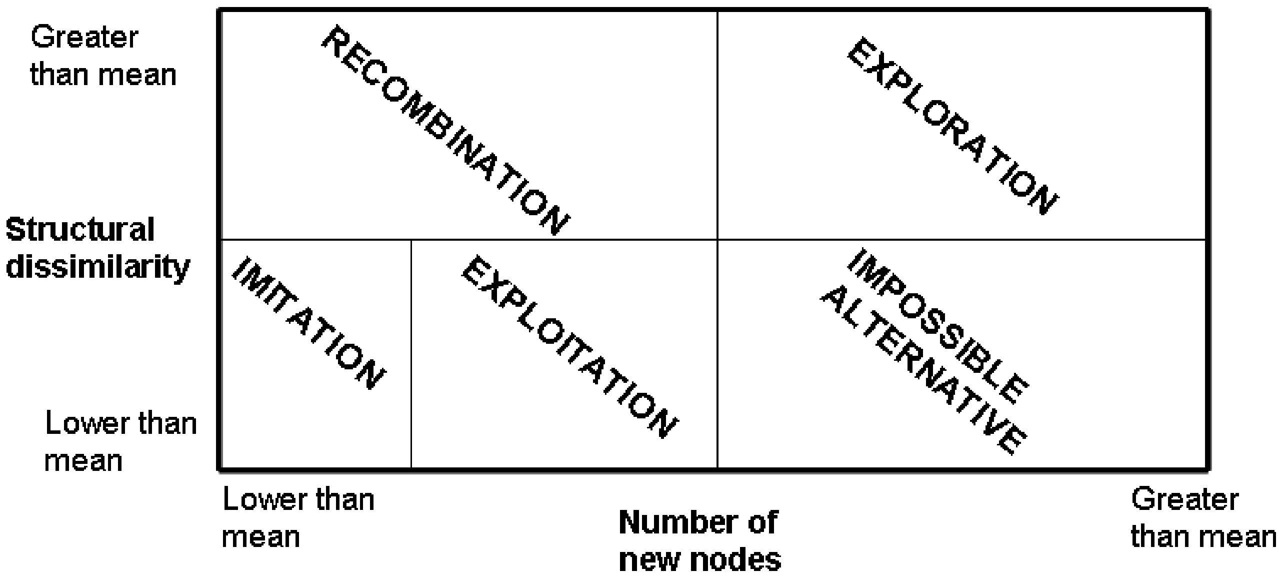
Knowledge trajectories may be distinguished according to two different sources of knowledge: on the one side the presence of new nodes and the presence of knowledge structural similarity and on the other side the typology of knowledge interested. These trajectories are not alternative or competitive but they only depend on two different sources of knowledge. So here I refer to the changes over time in the firm's product knowledge structural similarity and number of new nodes as well as in the change of the kind of knowledge interested as "knowledge learning trajectories".

By considering the new nodes and the knowledge structural similarity the knowledge trajectories can be summarized in:

- Recombination trajectory (characterized by product structure overlap greater than the mean and a number of new nodes lower than the mean);
- Imitation trajectory (characterized by product structure overlap lower than the mean and a very low number of new nodes lower);
- Exploitation trajectory (characterized by product structure overlap lower than the mean and a number of new nodes lower than the mean);
- Exploration trajectory (characterized by product structure overlap greater than the mean and a number of new nodes greater than the mean).

These trajectories are shown in the following two-by-two matrix with the number of new nodes as one dimension and the knowledge structural similarity as the other.

Fig. 2 Evolutionary trajectories



By considering the typology of nodes and so if they belong to the core or the periphery of the product knowledge network the trajectory can be distinguished in:

- Core trajectory: where firm's innovation strategy is core when it is aimed at deploying and extending core resources;
- Peripheral trajectory: where firm's innovation strategy is peripheral when it is aimed at increasing the use of peripheral resources.

3.4.1 Evolutionary trajectories

Research on exploration and exploitation since the seminal contribution of James March (1991) has shared a common dilemma. Although representing two different, seemingly incompatible organizational learning dynamics (Siggelkow and Levinthal, 2003), the maintenance of an appropriate balance between exploration of new learning trajectories and exploitation of old ones has been widely recognized as critical to succeed in the long haul (Levinthal and March, 1993; March, 1991). Highly useful innovations often come out from the interplay between deep knowledge effect of specialization and variety generated that can be reached through exploitation and exploration (Katila and Ahuja, 2002; Gupta, Smith and Shalley, 2006). More specifically, on the one hand specialization facilitates profound understanding of a specific area, due to the repeated re-usage of some elements; on the other hand exploration yields the exposure to new and innovative ideas and to new variations and combinations of a give set of elements (March, 1991; Katila and Ahuja, 2002). Although several pros of the two it is important to note that too much exploitation drives inertia and dynamic conservatism and too much exploration drives out efficiencies and prevents gaining economies of scale or learning by doing (Smith and Tushman, 2002).

Following search literature the first path is identified by March and Simon (1958) as “localized search” and “stable heuristics”; while the other is what Katila and Ahuja (2002) define “distant search” and Argyris and Schon (1978) defined double-loop learning. The process of search in organizations is a part of organizational learning activities through which firms try to find a solution to complex problems (Huber, 1991). Indeed organizations deal with several complex problems and consequentially cover a range of search activities. Among the different kinds of search, product search is “an organization’s problem-solving activities that involve the creation and recombination of technological ideas” (Katila and Ahuja, 2002: 1184) with the goal of creating new products.

Through this conceptualization by mapping the sequence of product knowledge network it is possible to understand which are the trajectories that firms follow in their innovation process and highlight the underlying mechanisms. Here I hypothesize that the presence of prior knowledge can have different effects; on the one hand prior knowledge influences organization’s propensity toward more exploitative way of new product development; on the other hand it can constitute the base to allow assimilating and discovering new knowledge that lets organization to do linkages and associations never considered before and to explore new trajectories. In my terms I want to understand the extent to which the evolutionary trajectories of product knowledge structurally mirror past product knowledge or are characterized by more variation and novelty.

More specifically I argue that the path-dependency in product knowledge network is mainly linked to the bounded rationality issue (Simon 1955). In fact because individuals can process only a partial amount of information, greatly behaviour in organizations lays on repetitive “chunks” of coordinated activity based on rules (March et al. 2000) and routines (Nelson and Winter 1982). Moreover the development of a new product is very much constrained and directed by a cognitive and learning argument that developers bring to the new situation. This means that it is economically efficient elaborate new products into which substantial resources have been invested and which is already well understood (Levinthal and March, 1993) representing a familiarity trap (Ahuja and Lampert, 2001) and the improvements in competence at existing procedures make experimentation with others less attractive (Levitt and March 1988). Thus, on the one hand in the presence of bounded rationality and cognitive issues may force past product knowledge to become a source of rigidity and competency trap (Levitt and March, 1988; Leonard-Barton, 1992) and consequentially new product knowledge will structurally reflect the past one. The reason of product knowledge network explorative trajectory is linked to: search of new market (Lee, 2003); diversification of product portfolio (Robins and Wiersema, 2003) and presence of R&D investments (Hoetker and Agarwal, 2007).

The underlying idea of this Chapter is that a firm can simultaneously pursue, during its life, trajectories of imitation, recombination, exploitation and exploration depending on how it draws upon past firm’s knowledge base distinguished in product knowledge architecture and number of new nodes. More specifically product knowledge evolution may follow each of the trajectory describe above depending on how it structures the product knowledge of new products and on how many new node are involved.

3.4.2 Core versus periphery trajectories[9]

Close to the dichotomy of exploration and exploitation is the distinction of innovation as incremental or radical (Dewar and Dutton, 1986). As Gatignon, Tushman, Smith and Anderson observed, incremental innovations involve “improving and exploiting an existing trajectory” whereas radical innovations “disrupt an existing trajectory” (Gatignon, Tushman, Smith and Anderson, 2004: 1107). Similarly, Abernathy and Clark noted that incremental innovations “build on and reinforce the applicability of existing knowledge”, while radical innovations “destroy the value of an existing knowledge base” (Abernathy and Clark, 1985: 5).

From studies on innovation, it is possible to infer how incremental and radical innovative capabilities vary in the kinds of knowledge they draw upon (Cardinal 2001); incremental innovative capabilities draw upon the reinforcement of prevailing knowledge whereas radical innovative capabilities need the transforming of prevailing knowledge (Subramaniam and Youndt, 2005). Incremental innovations are perceived congruent because they fit easily within existing schemas; on the contrary radical innovations are likely to origin incongruity because they bring in considerable changes of product attributes (Rindova and Petkova, 2007).

These distinctions on how different types of innovative capabilities draw upon knowledge that is either reinforced or transformed provide an a priori basis for systematically linking them to knowledge trajectories. Experience suggests that for radically new product generations, reuse of past knowledge is difficult so firms will bring into play peripheral components offering new insights to past knowledge product network. On

[9] A core/periphery knowledge network structure is characterized by a dense subgroup of core components and a set of peripheral components that are loosely connected to the core (Borgatti and Everett, 1999: 375).

the contrary in the case of incremental innovation firms will rather tend to deploy and extend core resources than to create and use new ones. In this direction Stuart and Podolny (1996) argue that the domains of knowledge in which organizations pursue patenting activities strongly follow and converge in the domains of knowledge of their existing patents, deepening and legitimizing their current knowledge base (Katila and Ahuja, 2002).

Past searches for knowledge are the starting point for new firm's searches, because firms rely on their own experience and established knowledge bases positioned in the neighbourhood of their current expertise and current information (Nelson and Winter, 1982; Kogut and Zander, 1992; Martin and Mitchell, 1998). In other words, organizations look for new technologies in those areas which permit them to build upon their established technological and knowledge base via a process of local search, experiential refinement, and selection and reuse of existing routines. Hence, the result of past searches is the natural starting point for initiating new one because organizational learning is a cumulative activity that is facilitated by concentrating in areas of prior knowledge accumulation (Nelson and Winter, 1982).

Consequentially, such processes create a path-dependent trajectory of knowledge reinforcement (Cohen and Levinthal, 1990; Daneels, 2002) rooted on what is the core knowledge within firms. Moreover, firm can generate new activities, knowledge or insights through processes of distant search concerted variation, planned experimentation, and play (Baum, 2000: 768). According to Nesta (2004) the emergence of new knowledge is likely to be accompanied by a growth in knowledge variety, a fall in coherence and a rise in cognitive distance. Incremental learning expands firm's current knowledge base focusing on the development of its core knowledge component and it is mainly based on internal learning for short run results (Bierly and Chakrabarti, 1996) and on capability inertia (Amit and Schoemaker, 1993; Kogut and Zander, 1992; Montgomery and Wernerfelt, 1988) and with core components (Helfat and Raubitschek, 2000; Levinthal and Myatt, 1994; Winter, 2000; Zollo and Winter, 2002) and representing a propinquity trap (Ahuja and Lampert, 2001). While radical learning questions and changes firm's basic assumptions (Argyris and Schon, 1978) and implies the exploitation of peripheral components[10] based on external learning for long run results (Bierly and Chakrabarti, 1996) and on absorptive capacity (Cohen and Levinthal, 1990) issue and boundary spanning activity (Rosenkopf and Nerkar, 2001). Thus the dichotomy of incremental and radical innovation combined with core and periphery perspective allow investigating whether over time firms tend to root incremental and radical products more on core or peripheral components and what are the fundamental reasons of this choice.

In the next section I empirically describe these trajectories to investigate how product knowledge and market knowledge evolved over time.

3.5 Method

The primary and secondary data collected have been used to perform this empirical analysis. Knowledge descriptors have been used to better understand how firm systematized its product's knowledge and how they contribute to the development of firm's knowledge base. From a

[10] Yet the decision to use peripheral components might be endogenous if that decision correlates with unobservable effects that influence radical learning. For example, if a firm has decided to undertake a radical learning before searching for peripheral components, it is more likely to change its knowledge space after this.

technical point of view here I see products as the result of a creative process of combination among several elements such as raw materials, technology of transformation of raw materials in semi-partly goods, technology of combination of raw materials and semi-partly goods; semi-partly goods, technology of combination of semi-partly goods, technology and materials for packaging.

In the product knowledge system the elementary units build up the knowledge process behind the product[11]. Here the process is figured out by several multiple relations, following a sequential order, among the knowledge elements and that can be represented as a relational tree (product knowledge network) among these knowledge elements. For this reason graph theory and network analysis can be helpful. Firm's product knowledge structure is here considered a co-relational structure where knowledge is represented as a network with nodes that are knowledge chunks, connected by links meaning the joint utilisation of different knowledge chunks. This is a useful way to map product knowledge in a structured way in order to analyze its development and evolution.

Thus, through the information gathered by the interviews and by the archival data on product composition in this analysis I unpacked product knowledge in raw materials, transformation technology, combination technology, semi-finished goods and finished goods. Here firm's product knowledge is composed by a set of multiple components; each of them is characterized by a component knowledge consisting on the basic

[11] Whilst in other studies the use of patent gives a detailed description and chronology of how firms solve problems (Walker, 1995: in Katila and Ahuja, 2002) in this research knowledge descriptors are the source of all the necessary information about knowledge elements for creating new products and advance firm's knowledge base. In this vein this research moves away from the stream of research "patent and citations based" (Fleming and Sorenson, 2001; Yayavaram and Ahuja, 2008) because we use the "real" elements which compose a product.

knowledge underlying each component, and in the connections among these elements.

The restriction I provide in this paper is that only the components related to products contribute to shape the knowledge base of the firm. This is a strong assumption that excludes all the possible previous studies and experimentation behind the components and all the passages through which the knowledge components passed before being really used. Purposely for knowledge base I mean at each time the knowledge underlying each firm's product. This is a cumulative function depending on how many products have been created over time and on how the knowledge underlying each product is recombined into new one or whether it is totally new. In order to delineate the Product Knowledge Network boundaries: in each PKN are represented and linked all the knowledge elements underlying a firm's product, consequentially if a knowledge component belongs to a product it will be represented as a knowledge node in the PKN.

Thus in this research, a firm's knowledge base a time *t* is assumed to consist of all the pieces of knowledge making up a product at that time. Firm's knowledge base evolves over time as the number of firm's products increases. Specifically, the firm's knowledge base at time *t+2* consists of the product knowledge networks at time *t* summed up to the PKN at *t+1* and *t+2* and so on.

3.6 Construction of the product knowledge network

For the analysis of the dynamic of knowledge I use new product entry year to assign a knowledge component to each time window and I characterize the evolution of product knowledge networks as a time series of 62 networks (as the number of commercialized products). Formally, a product knowledge network at time *t* during the time interval t consists of a set of finite nodes and a finite set of ties between nodes. Nodes represent the knowledge underlying each components such as raw materials, semi-finished goods and technologies while the ties represent flows of knowledge among the nodes (the connection between node *i* and *j* means that the knowledge underlying the two nodes are jointly used in a specific production process).

Using network analysis carried out through UCINET VI (Borgatti, Everett and Freeman, 2002) I model over time product knowledge as a network of knowledge units (nodes). Utilizing insights from graph theory and network topology, I identify that product knowledge can be easily investigated as a network structure and that this methodology allows designing the trajectories tracked over time. More specifically I create 62 square matrices each one for each product's company. In the creation of the matrices I pursue the following routines on UCINET VI:

<u>Step 1</u>

- Use the Edgelist format (node label) in order to construct a matrix for each product. This format is used to read in data forming a matrix in which the rows and columns refer to the same kinds of objects. The one-mode matrix X is built from pairs of indices (a row and a column indicator). Pairs are typed one to a line, with indices separated by spaces or commas. The presence of a pair i,j indicates that there is a link from i to j, which is to say a non-zero value in xij;
- This procedure allows obtaining 62 one-mode matrices (with value 0-1) having different dimension *n* according to the number of knowledge components (raw materials, semi-

finished goods, technologies of transformation and combination, finished goods that are included).

Step 2

- Create a big one-mode matrix including all the small ones representing the entire Alfa's product knowledge base. The matrix obtained has *n* equal to 609.

Step 3

- Using the Union procedure on UCINET VI put together each single one-mode matrices in the big one-mode matrix;
- This procedure allows obtaining 62 one-mode matrices (with value 0-1) with dimension *609x609*

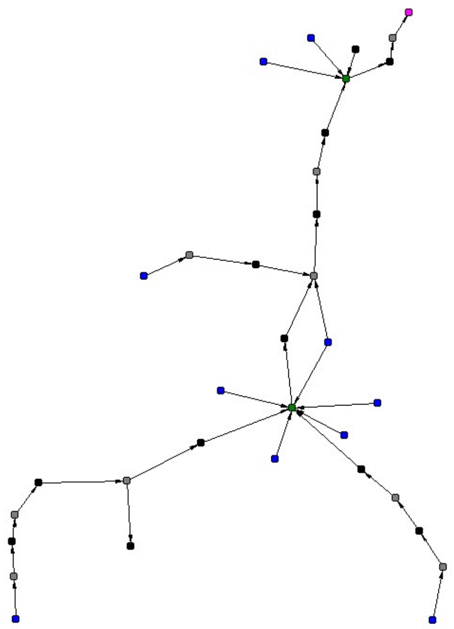
Step 4

- Using the Matrix Algebra on UCINET VI add sequentially according to the entrance on the market of each product each one-mode matrix
- This procedure allows obtaining 30 one-mode cumulative matrices[12] with dimension *609x609*.

Given that visual inspection is a methodological strategy that has been gaining increasing scientific importance in social network analysis (Moody, McFarland and Skye Bender-deMoll, 2005) I used NetDraw to show the variation of product knowledge network overtime. Each one of these matrices represents the product knowledge of each product (PKN) (in the Figure 3 there is an example of a product knowledge network).

[12] During some years more products enter simultaneously on the market

Fig.3 Product knowledge network at time t0[13]



I cumulated over time all these matrices, following the data of market entrance of each product, shaping the product knowledge network of the entire company (Figure 4-5-6-7-8).

[13] Legenda of the nodes: Pink = Finished product, Red= Combination technology, Black= Semi-finished goods, Green= Combination and transformation technology, Grey= Transformation technology, Blue= raw materials

Fig.4 Product knowledge network at time t+5

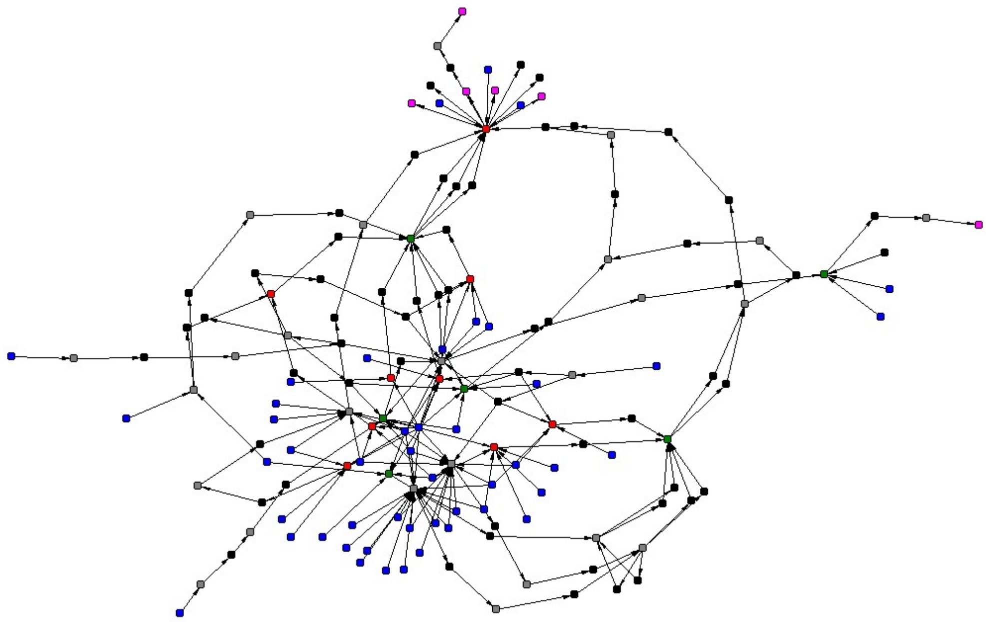


Fig.5 Product knowledge network at time t+10

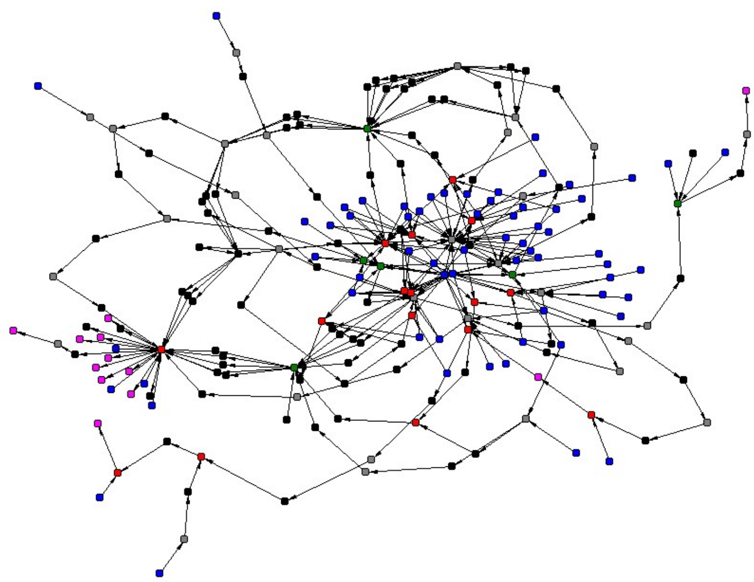


Fig. 6 Product knowledge network at time t+15

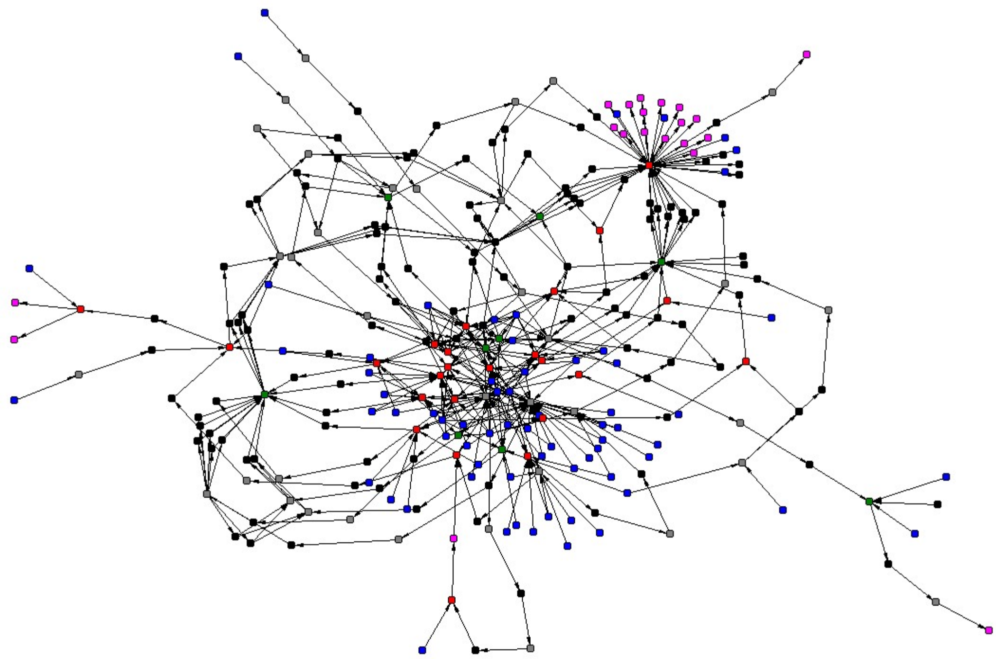


Fig. 7 Product knowledge network at time t+25

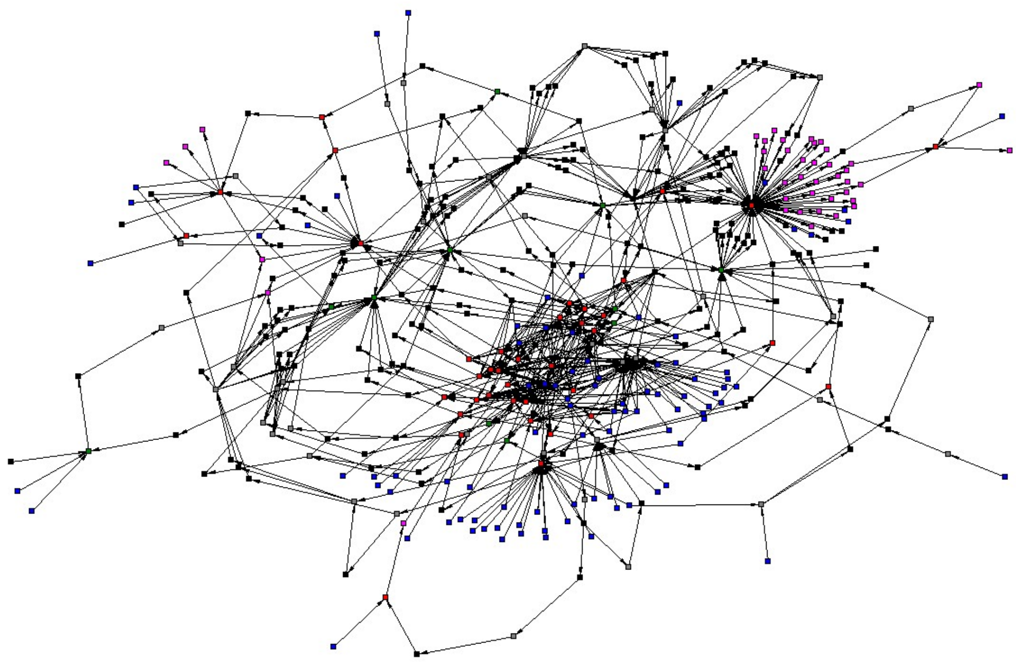
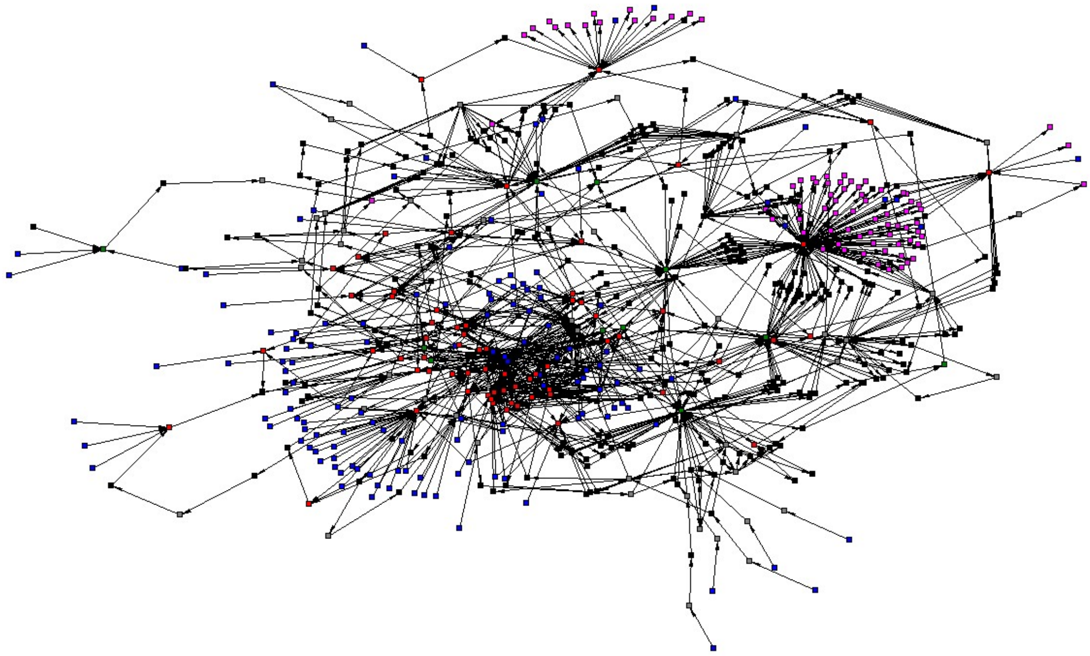


Fig. 8 Product knowledge network at time t+30



3.6.1 Construction of the market knowledge matrix

The definition of the term market is not universally in the literature: the market connotes many issues, including technical parameters users want (Von Hippel, 1986), competitors (Porter, 1991), segments defined by their industry, buying habits, or growth, or preferences, features, and prices (Dougherty, 1990). Here the presence of a product in a specific category, satisfying particular consumer habits or having certain features implies the existence of an inherent knowledge. In the creation of the matrix I pursue the following routines on UCINET VI:

Step 1

- Definition the market knowledge according to 20 attributes[14] (product categories, consumption occasion, product segmentation);
- Construction of a two-mode matrix product by market knowledge (62x20) where the value is 1 if a product corresponds to them or 0 otherwise;
- Sequential cumulation of each row of this two-mode matrix in order to have information on the market knowledge evolution over time.

3.7 Analyses

I performed several analyses in order to explore product knowledge learning trajectories (both evolutionary and core/periphery) and to illustrate how Alfa exploit product and market knowledge. I performed Quadratic Assignment Procedure (QAP) among product knowledge networks (PKN) in order to look at the patterns of evolution that PKN have pursued over time. I performed Core/Periphery analyses in order to determine the distribution of core knowledge components and peripheral knowledge components in the Alfa's products. I performed some descriptive analysis, as well as correlation and Newey-West time series regression to examine the joint interaction between product knowledge and market knowledge.

[14] The attributes considered have been extrapolated by the interviews, information on the web site and internal documents.

3.7.1 Quadratic Assignment Procedure (QAP)

QAP is a test of fit for structural data (Krackhardt, 1992). It is method that has been used in social network analysis that computes correlation or regression between two or more square matrices and it is principally used in the first case to test the association between networks and in the second to model a social relation (matrix) using values of other relations.

The QAP correlation compute correlation and other similarity measures between entries of two square matrices, and assess the frequency of random measures as large as actually observed. The algorithm proceeds in two steps[15]:

- In the first step, it computes Pearson's correlation coefficient between corresponding cells of the two data matrices;
- In the second step, it randomly permutes rows and columns (synchronously) of one matrix (the observed matrix, if the distinction is relevant) and re-computes the correlation and other measures. This second step is carried out hundreds of times in order to compute the proportion of times that a random measure is larger than or equal to the observed measure calculated in step 1. In fact the larger the number of permutations, the better the estimates of standard error and significance. A low proportion (< 0.05) suggests a strong relationship between the matrices that is unlikely to have occurred by chance.

[15]The procedure is explained in Borgatti, S.P., Everett, M.G. and Freeman, L.C. 2002. Ucinet 6 for Windows. Harvard: Analytic Technologies.

In this analysis I performed the QAP correlations both on the cumulative Product Knowledge Networks and on all together the single Product Knowledge Networks. In the first case I did 30 QAP correlations among each cumulative PKNt+x on the PKNx+1. The coefficients of these correlations show if the recombinant process between new product knowledge networks and the cumulative past product knowledge networks lead to more exploitative or explorative trajectories. In the second case I did a single QAP correlation among all the PKNsx+1 where the coefficients of this correlation show a sort of knowledge absorption capacity of a product and high or low values mean that a product has been constructed or not on the same knowledge base of other products. Both results are presented in the paragraph 3.8.1.

3.7.2 QAP – Number of new nodes analysis

The Pearson correlation coefficient of the QAP (structural similarity) is a kind of pattern similarity – i.e. same way of cooking, but using new knowledge and new technologies. QAP correlation coefficient tells that PKNt+x and PKNx+1 are similar because they have same nodes and same links among nodes; otherwise low QAP correlation coefficient may be determined by: new links connecting existing nodes and the appearance of new nodes. However it is possible to have case in which the low QAP correlation is associated to the same nodes and the high QAP correlation is associated with some new nodes. How to manage these cases? What do they represent in terms of product knowledge?

In order to deal with these cases and to fill the two-by-two matrix presented above, having as dimensions the structure dissimilarity and the number of new nodes, I pursued the following steps.

Step 1

- Create an indicator equal to (1- QAP correlation) in order to have a measure between 0 and 1 called "structural dissimilarity" where high values represent dissimilar structure and low value represent similar structure;
- Computation of the mean value of the structural dissimilarity;
- According to the mean value of structural dissimilarity divide the products in two parts: those having a value greater than mean and otherwise.

Step 2

- Computation of the number of new nodes among product knowledge networks (a node is defined as new whether it has been used for the first time)
- Computation of the mean value of new nodes
- According to the mean value of new nodes divide the products in two parts: those having a value greater than mean and otherwise

Step 3

- Aggregate the results of the previous steps and complete the two-by-two matrix with the number of products belonging to each trajectory
    - Product knowledge imitation (Structural dissimilarity lower than the mean and Number of new nodes lower than the mean – in the 1st deciles)

- Product knowledge exploitation (Structural dissimilarity lower than the mean and Number of new nodes lower than the mean – excluding the 1st deciles)
- Product knowledge recombination (Structural dissimilarity greater than the mean and Number of new nodes lower than the mean)
- Product knowledge exploration (Structural dissimilarity greater than the mean and Number of new nodes greater than the mean)

3.7.3 Core/Periphery analysis

One of the familiar notions in social network analysis is that of core/periphery structure (Borgatti and Everett, 1999). The idea underlying this kind of structure is the presence of a dense and cohesive core and a sparse and unconnected periphery. The software UCINET VI uses an algorithm to fit a core/periphery model to the data[16]*:*

- It simultaneously fits a core/periphery model to the data network, and identifies which actors belong to the core and which belong to the periphery;
- The fit function is the correlation between the permuted data matrix and an ideal structure matrix consisting of ones in the core block interactions and zeros in the peripheral block interactions.

To test the robustness of the solution the algorithm has been run a number of times from different starting configurations. In this analysis I

[16] The procedure is explained in Borgatti, S.P., Everett, M.G. and Freeman, L.C. 2002. Ucinet 6 for Windows. Harvard: Analytic Technologies.

performed the Core/Periphery analysis both on the cumulative (one-mode) PKNs and on the two-mode matrices (Components-Products). In the first case the model fits the product knowledge network components in the core or in the periphery on the PKNs while in the second case the model fits both the product knowledge network components and the final products in the core or periphery.

3.7.4 Market knowledge similarity

I used UCINET VI similarity procedure to measure the correlation between each new product and the cumulated two-mode matrix product by market knowledge.

3.7.5 Analyses on product and market knowledge

I performed some descriptive analysis, as well as correlation and Newey-West time series regression to examine the joint interaction between product knowledge and market knowledge.

3.8 Results

In the following sections I will describe the results of the analyses performed.

3.8.1 Quadratic Assignment Procedure (QAP)

The results in the table 2 highlight the presence of both high and low QAP Pearson correlation coefficients. These results signify higher and lower structural overlaps among the product knowledge network of new products and the past one. Coefficients equal to zero imply that, structurally, the product knowledge network of a new product and the past one are completely divergent. This means that firm proposed explorative new products representing a disruption with the past product knowledge base. Similarly higher coefficients suggest that firm offered exploitative new products representing a continuity with the past product knowledge base. By looking at the evolutionary dynamics of these strategies it is evident that exploration and exploitation activities follow a temporal cycle along a continuum but they are characterized by a different variance. In fact by examining the Fig 9 it is visible that in the period 6-15 there is less variance between exploitative and explorative strategies respect to the period 20-26. Furthermore by observing at the simultaneous entrance on the market of some products during certain years it is clear that these strategies may be also pursued concurrently by the firm. Thus exploitation and exploration are even orthogonal.

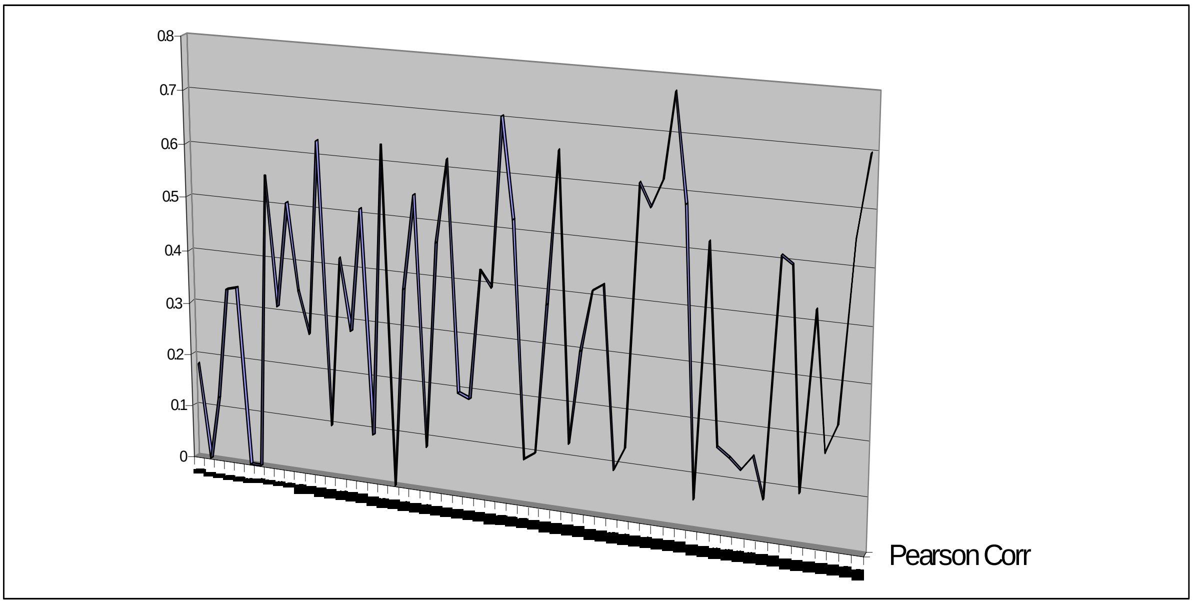
Tab. 2 Overtime QAP correlation[17]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	15
Pearson Correlation	0.181	0.000	0.122	0.336	0.000	0.000	0.554	0.312	0.508	0.345	0.267	0.097	0.283	0.092	0.632	0.000
				0.331								0.415		0.512		
												0.628				
P-value	0.000	0.994	0.000	0.000	0.994	0.994	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.994

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Pearson Correlation	0.373	0.464	0.191	0.182	0.394	0.704	0.374	0.652	0.299	0.409	0.131	0.056	0.158	0.509	0.549
	0.547	0.618		0.424		0.522		0.125		0.423	0.61	0.519	0.14	0.495	0.697
	0.082					0.084				0.088	0.568		0.122	0.094	
						0.098					0.619		0.149	0.423	
											0.773		0.074	0.173	
											0.581			0.225	
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

[17] Multiple coefficients for the Pearson Correlation in some periods indicate the simultaneous entrance of more products.

Fig. 9 Overtime QAP correlation



3.8.2 QAP – Number of new nodes analysis

Since Pearson correlation coefficient of the QAP indicates the structural similarity among the product knowledge networks – i.e. high QAP correlation coefficient may happen because PKN have same nodes and same links among nodes and low QAP correlation coefficient may be determined by new links among existing nodes and by the appearance of new nodes – it is clear that it does not distinguish between cases in which the low QAP correlation is associated to the same number nodes but different patterns of relationship and the high QAP correlation is associated with some new nodes and the same patterns of relationship.

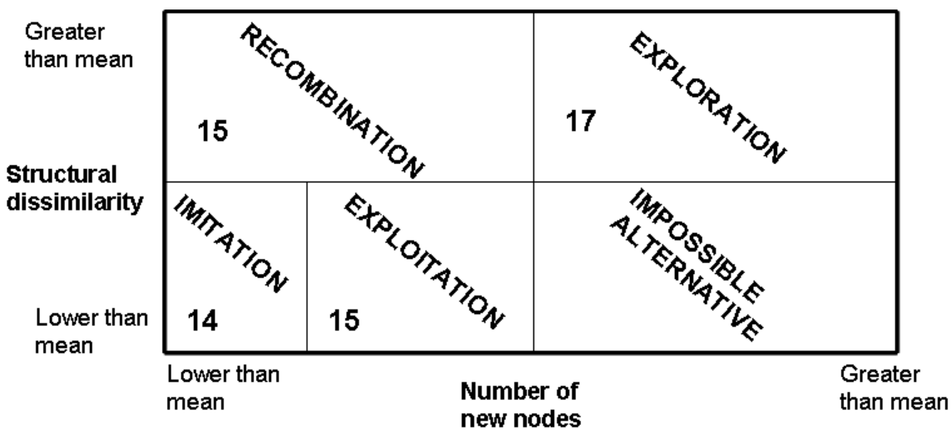
In fact by looking simultaneously at the values of QAP correlation coefficients and at the number of new nodes it is possible to place the products in the four areas of the two-by-two matrix presented above rather than only in the dichotomy high QAP (exploitation) and low QAP (exploration). In order to do this I computed some descriptive statistics for structural dissimilarity and number of new nodes (Tab 3) and I split the products in the two-by-two matrix (Fig. 10).

The picture shows that products are equally distributed in the four categories; in fact imitative products are 14 (products where the structural dissimilarity is lower than the mean and number of new nodes is lower than the mean – in the 1st deciles); exploitative products are 15 (where structural dissimilarity is lower than the mean and number of new nodes is lower than the mean – excluding the 1st deciles); recombinative products are 15 (where structural dissimilarity is greater than the mean and number of new nodes is lower than the mean); explorative products are 17 (where structural dissimilarity is greater than the mean and number of new nodes is greater than the mean).

Tab. 3 Descriptive statistics for structural dissimilarity and number of new nodes

Variable	Mean	Standard deviation	Min	Max
Structural dissimilarity	.6666721	.2189496	.227	1
Number of new nodes	7.540984	8.64595	1	49

Fig. 10 Evolutionary trajectories



3.8.3 Core/periphery analysis

The core/periphery analysis computed on the cumulative matrices identifies over time which knowledge components belong to the core and which belong to the periphery. While the QAP analysis gives an explanation on the structural similarity among product knowledge networks, the core/periphery analysis say the typology of knowledge components that are included according to their pattern of relationships (so core knowledge components if they belong to the core and peripheral knowledge components if they belong to the periphery). Tab 4 shows the distribution of this percentage according to the total number of product's knowledge components.

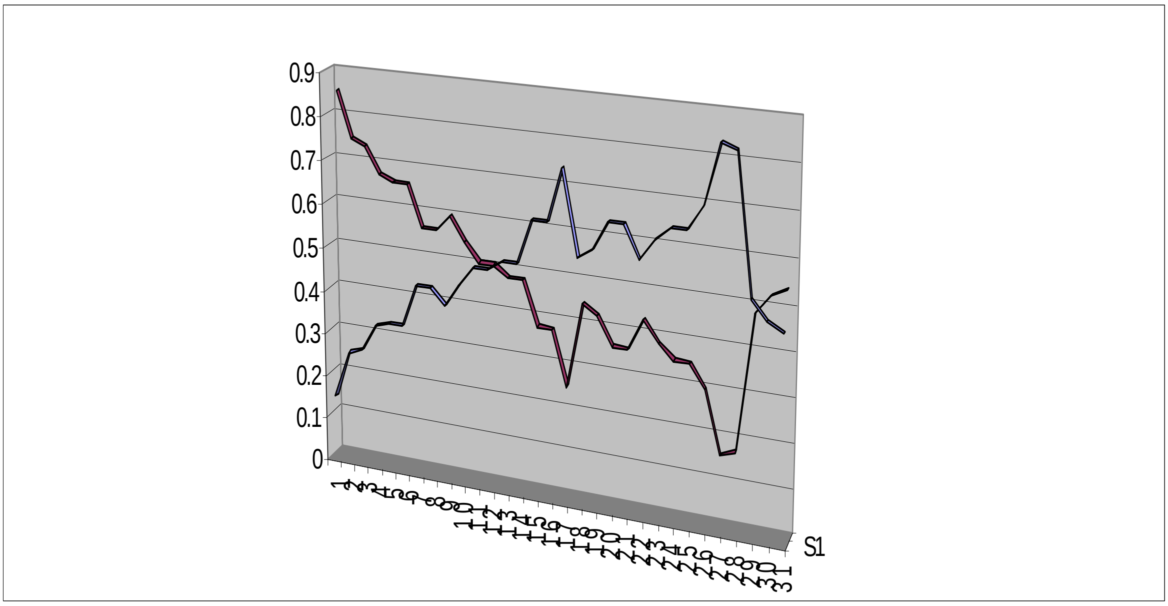
By examining the evolution in the distribution of the core and peripheral knowledge components it is evincible that firm alternates moments of re-usage of core knowledge components and periods of re-usage of peripheral knowledge components as well, as moment in which these components are equally distributed in a product.

Tab. 4 Evolution of Core / peripheral structure

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
%Core components	15.11%	25.78%	26.93%	33.17%	34.32%	34.32%	44.01%	44.01%	40.39%	45.65%	50.08%	50.08%	52.55%	52.55%	62.56%	62.56%
%Peripheral components	84.89%	74.22%	73.07%	66.83%	65.68%	65.68%	55.99%	55.99%	59.61%	54.35%	49.92%	49.92%	47.45%	47.45%	37.44%	37.44%

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
%Core components	75.04%	55.67%	57.80%	64.37%	64.37%	57.14%	62.07%	65.19%	65.19%	70.44%	84.40%	83.09%	52.22%	47.95%	45.98%
%Peripheral components	24.96%	44.33%	42.20%	35.63%	35.63%	42.86%	37.93%	34.81%	34.81%	29.56%	15.60%	16.91%	47.78%	52.05%	54.02%

Fig. 11 Evolution of Core / peripheral structure[18]

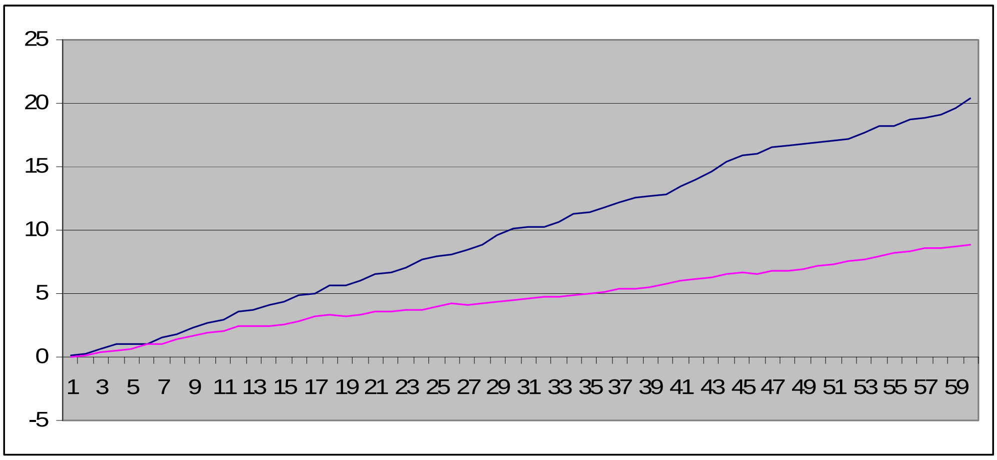


3.8.4 Product and market knowledge interaction

By examining the firm’s capitalization of product and market knowledge computed as the cumulation over time of their correlation coefficients it is visible that Alfa has capitalized more the product knowledge than the market knowledge. This means that it has re-used in new products the product knowledge more than the market knowledge. Putting differently, it explored and developed new market knowledge associated with new domains by using the accumulated product knowledge (Fig 12).

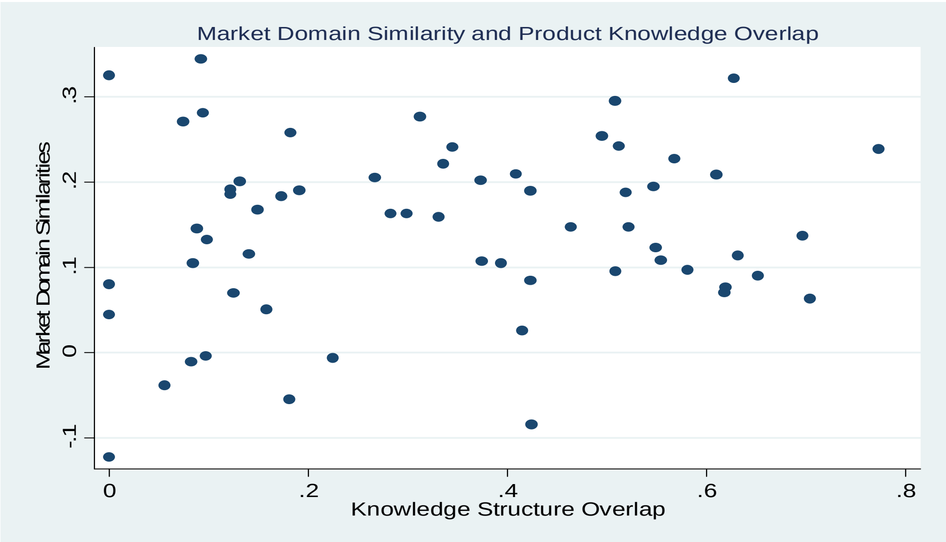
[18] Peripheral is the red line while core is the blue one.

Fig. 12 Product knowledge and market knowledge capitalization[19]



By correlating product knowledge overlap and market knowledge similarity it is evident in the Fig. 13 that the two variables are not correlated. In fact even if the product knowledge between products may overlap, market domains may be different.

Fig. 13 Scatter-plot between market knowledge similarity and product knowledge overlap

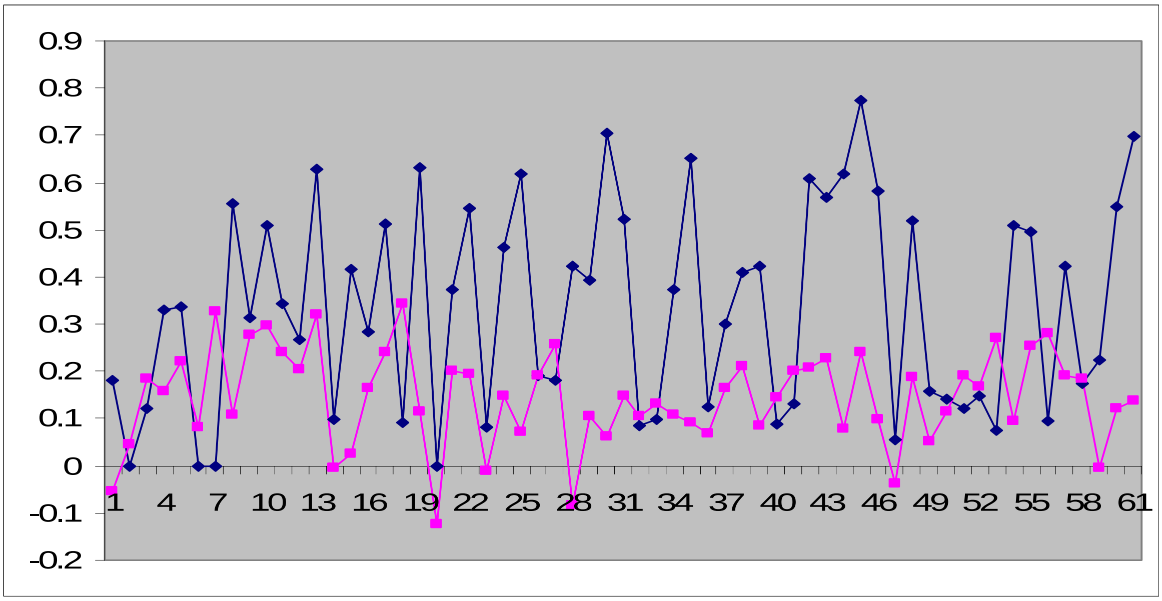


[19] The blue line represents the product knowledge capitalization and the red line the market knowledge capitalization.

By regressing through Newey-West time series product knowledge overlap on market knowledge similarity the result is not significant even the test is not very robust (p-value=.366 and Beta .0593).

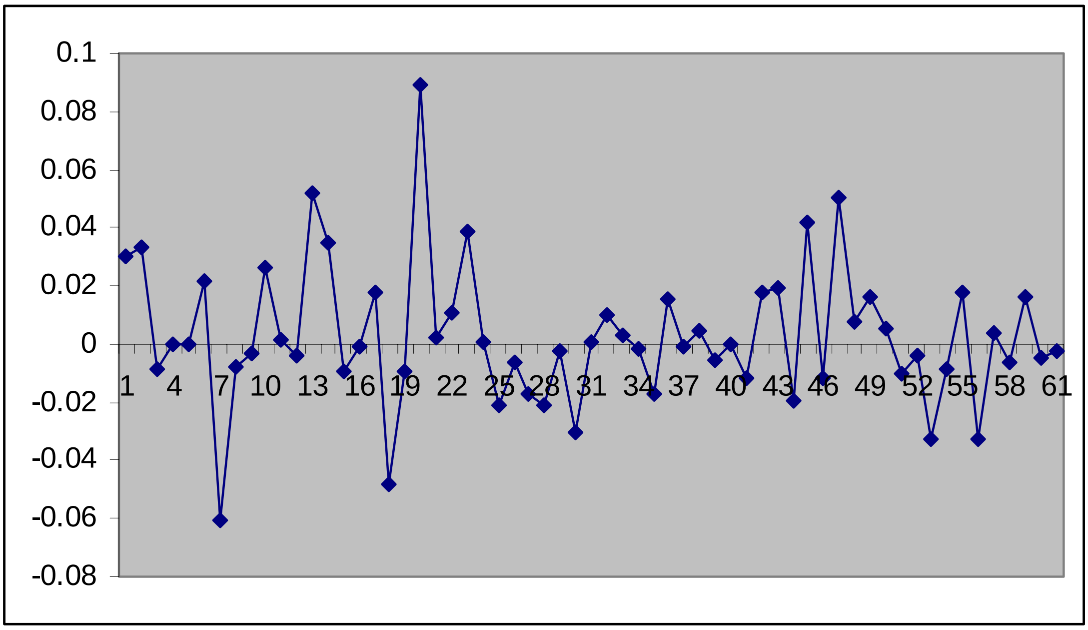
Furthermore by examining simultaneously the evolution of the QAP correlation coefficients and the market knowledge similarity it is evident that the dynamic of the two variables is independent. Indeed this tendency is highlighted in the Fig. 14.

Fig. 14 Dynamics of product knowledge overlap (QAP) and market knowledge similarity (MDS)



Finally by interacting product knowledge overlap and market knowledge similarity (Fig. 15) it is possible to say that low numbers may distinguish more radical innovation (lower in product knowledge overlap and market knowledge similarity) and high number more incremental innovation (higher in product knowledge overlap and market knowledge similarity).

Fig. 15 Interaction between product knowledge overlap (QAP) and market knowledge similarity (MDS)



3.9 Discussion

This Chapter addresses two main blocks of questions, on the one hand because to the best of no one has empirically studied, yet, how knowledge recombination actually takes place at the firm level, how this transforms a firm's product portfolio and how product accrues and cumulates over time consequently I mainly ask: "Which are the structural patterns of product knowledge evolution?" in order to understand whether firm's product knowledge build or not on previous product knowledge foundation. Moreover among these patterns I want to explore how they lead to product innovation, so I ask "Which kind of longitudinal structural patterns of knowledge evolution lead to product innovation?"

Thus, contrarily to the previous research that has predominantly focused on the technological invention to analyze the process of knowledge recombination the focus of this paper is explicitly on firm's product knowledge. Adopting a network analytic approach I model in a novel and original way firm's knowledge, and in particular firm's product knowledge. This methodology helps to investigate and deeply understand the process of knowledge recombination through which firm re-uses knowledge elements and builds incremental innovations or use new knowledge to create radical products. More specifically, looking at firm's knowledge's and in particular at firm's product knowledge toward a network perspective this work investigates whether product knowledge trajectories are more path-dependent and follow predictable and exploitative patterns (Patel and Pavitt, 1997) or whether they pursue an explorative and unexpected path. For this reason the issue of knowledge components recombination is helpful to trace the evolving knowledge network through which knowledge diffuses within firm and gets creatively recombined among firm's products. Thus, I formalize product knowledge structure as co-relational structure where knowledge is represented as a network with nodes that are knowledge chunks, connected by links meaning the joint utilisation of different knowledge chunks in performing specific activities of the product's production processes. This product knowledge representation allows to visually investigating patterns of product knowledge network evolution and consequentially highlights the trajectories that firm's product knowledge followed over time.

The analysis of product knowledge trajectories relies on the investigation of QAP and Core-Periphery examinations. The preliminary findings of these analyses suggest that the base of product knowledge developed over time frequently built on the past foundation so following exploitative trajectories (as the higher and positive correlation in the QAP shows), however firm also pursues pathways previously unexplored in history so following explorative trajectories (as the negative correlation in the QAP shows). These results represent that exploration and exploitation activities follow a temporal cycle along a continuum. Furthermore looking at the simultaneous exit of some products in some years it is evident that these strategies can be also pursued concurrently in the firm. Thus exploitation and exploration are even orthogonal. Moreover, by looking at a more micro-level of knowledge recombination we can see that firm alternates moments of re-usage of core knowledge components and periods of re-usage of peripheral knowledge components as well, as moment in which these components are equally distributed in a product.

These results show that on the one hand firms' new search can fall within the domain of the firm's past activities and on the other hand fall outside. Indeed, Helfat and Raubitschek (2000) argued that firms' product history constrains firms' options for future product sequences and in the same direction Martin and Mitchell (1998) show that new product introductions are heavily influenced by the designs of existing products. These empirical findings reinforce the population ecology argument of the presence of inertia in the firm's knowledge search and of the mechanism of legitimation of previous product's success. Moreover, according to previous studies I delineate a pattern of incremental learning that relies on local search for new knowledge in the neighbourhood of existing knowledge (Cohen and Levinthal, 1990). This cumulative learning creates path dependence in the re-use of knowledge and in organizational learning (Nelson and Winter, 1982; Helfat, 1994). Furthermore, concerning the issue of incremental and radical learning processes I can say that in the period considered firm takes turns between these two kinds of processes supported by the positive and negative results of QAP analysis and by the alternation of core knowledge components and peripheral one. Thus, the re-use of core knowledge resources is more present in incremental learning processes while for radical learning processes firm will more bring into play peripheral knowledge components.

3.10 Conclusion

The principal aim of this study is to bridge new knowledge creation with network perspective. I use the conceptual tools of network theory to better understand product knowledge architectures and dynamics and its consequences on product management and innovation. In fact the core imagery that underlies this work is the conception of knowledge base of a firm as an evolving network. Several studies investigate networks as an important determinant of new knowledge creation because they are considered as conduits of information, channels of relationships, and sources of knowledge. In this paper networks are not an antecedent of knowledge but an original way through which the process of knowledge creation and, more specifically the process of knowledge recombination, could be investigated.

In particular developing a methodology to tackle quantitatively the issue of knowledge recombination this paper provides a contribution to capture the trajectories of firm's knowledge base. Specifically, this approach allows tackling how the knowledge underlying firm's products is recombined over time to create new products and the extent to which the knowledge structure of products builds or not on the same product knowledge foundations by conceptualizing firm's knowledge as a network of components and by studying its properties. In fact the measurement of knowledge is an under investigated topic in strategy and organizational literature. In fact the issue of structuring organizational knowledge represents an important frontier for organizational research with growing and stimulating possibilities (Yayavaram and Ahuja, 2008). In our opinion viewing firm's product knowledge as a network structure can offer a new theoretical and methodological approach which can prove to be useful for a better understanding of product knowledge dynamics. In this way, the study helps scholars open up the "black box" of knowledge of firm's product knowledge design and evolution. Moreover, using a path-dependent evolutionary framework, I develop the argument that both current knowledge and historical knowledge matter for future creation of new knowledge. By examining the temporal dimension, it explores the recombinant process of knowledge creation and evolution creating an agenda for future empirical research. This framework has managerial implications since it can be used to assess the current status and potential evolution of a firm's product knowledge base and contributes to knowledge management research by proposing a new methodological approach applying network analysis to product knowledge mapping.

This study is not lacking of some limitations. First I assume that the existing knowledge is embedded in the company products (in its present and past products). Hence firm's knowledge base at time *t* is represented by the knowledge underlying its existing product at that specific time (and chiefly by its physical components and processes). Therefore I may be missing the previous research and developments studies which have been performed by the firm prior to *t* and may have not resulted in a new product but still may well be considered part of the firm knowledge base and may have helped to create other products.

Second I take into account only internal knowledge (the knowledge stock accumulated within the company) lacking any other external sources. I'm exploring further improvements of this research gathering additional longitudinal data on firm's patents.

Third, I consider in the same way different nodes that are conceptually different, such as raw materials and semi-finished goods and technologies. I am working on this concern creating some forms of higher-order systems or clusters of resources, for example if components share the same technological areas, functional group and so on (Teece et al., 1997).

Fourth, given that all product knowledge networks are investigated over time (summing the single product knowledge network for each new product for the year of appearance) the elements and the connections between the elements (components) remain stable over time or they increase. This means that old ties never dissolve in the subject firm given that the combinations between components do not change over time; established elements can be employed into a novel architecture but without varying the existing one.

Further avenue for future improvements of this study could be at different levels of analysis, such as node level, identifying the mechanisms through which knowledge is selected for recombination. Such improvement may be represented by the investigation of knowledge positioning within the firm’s product knowledge network examining how characteristics of nodes knowledge may impact on the likelihood of knowledge recombination through an analysis of key indicators such as centrality, brokerage and coreness. Another stream of research lies in the analysis at product level by decomposing the product in product module and by following the modularity literature on mixing and matching.

CHAPTER 4: What's behind product modularity? Beyond mixing and matching paradigm

4.1 Introduction

This Chapter presents the second empirical analysis of this project. By developing the concept of "knowledge modularity" it provides a micro-foundation of the modularity issue by offering a fine-grained view of product modularity. Section 4.2 examines the issue of innovation and how it is relate to modularity literature. In part 4.3 I describe the literature of modularity and product architecture, while in 4.4 I forge the concept of knowledge modularity. Section 4.5 provides discussion and conclusion.

4.2 Innovation and the modularity issue

A large body of research and empirical evidence supports the idea that innovation is a key lever in creating and maintaining sustainable competitive advantages (Damanpour, 1991; Brown and Eisenhardt, 1995; Wind and Mahajan 1997). Researchers in this area generally converge that sustainable competitive advantage hinges on a firm's ability to move beyond existing knowledge and apply new one in the creation of new products (Dougherty 1992, Kogut and Zander, 1992; Stuart and Podolny, 1995; McGrath et al. 1996; Mowery et al., 1996). Indeed, innovative capability manifests itself in the firm's capacity to continuously generate new knowledge and bring it to the market in the form of new products and services where new products may take different forms, such as upgrades, modifications, and extensions of existing products that may be new to the firm, the market or the world (Li and Atuahene-Gima, 2001).

In synthesis, innovative products may consist of new combinations of existing components (mix and match of modules within a given architecture) rather than the creation of a non existing product (integral product) (Baldwin and Clark, 1997). In the first case the result of refining, recombining, replicating with little variation existing modules creates innovation that may be classified as incremental; while integral products may more refer to radical innovation[20]. Indeed modularity theory contrasts modular and integral products (Ulrich, 1995; Baldwin and Clark, 1997), arguing that diverse product architectures, modular or integral, may be beneficial to innovation, though along different dimensions and that there is a trade-off between them. Purposely modularization may offer a positive effect with generalized gains (Sanchez and Mahoney, 1996; Baldwin and Clark, 1997; Fine, 1998; Sturgeon, 2002; Langlois, 2003; MacCormack et al., 2008) because it is possible to focus separately and concurrently on innovating specific product components. However, product modularization is always partial, because it is limited to a few product components and even imperfect, so that inter-organizational interdependencies remain ubiquitous and continually emerge in spite of efforts to limit them (Staudenmayer, Tripsas and Tucci, 2005). And even in the hypothetical and extreme situation of complete product modularization and open standard interfaces among components, all competing buyers and suppliers would share common product architecture and obey the same design rules, which therefore could not represent *per se* a source of performance differential.

The controversial or unpredictable effect of modularization on innovation was first highlighted by Fleming and Sorenson (2001), who found support for a long-suspected trade-off between the predictability of advances and their ultimate importance. Product modularity favors

[20] However there cases in which modular products may represent a radical innovation if new technologies are incorporated in components or modules.

avenues of improvement within a given architecture because different suppliers can focus independently and concurrently on a specific module (Chesbrough and Teece, 1996). However, it hinders architectural improvements and offers few opportunities for architectural and radical innovations. Again, in the hypothetical case of completely modular products, since the innovation focus and potential benefits are component-specific, while component interfaces are fixed, opportunities to improve the way modules interact with each other are likely to be lost or delayed. Furthermore, modular structures are more imitable (Ethiraj, Levinthal and Roi, 2008). Designing and producing modular products may generate performance gains, but reduces imitation deterrence because, due to cross-firm knowledge spillovers, performance differences between innovators and imitators are less easily preserved. Overall, modularity theory suggests that separability and recombinability (Schilling, 2000) of product components may foster innovation increasing the variety of products a firm can design and produce out of a given product knowledge base and accelerating the product creation process.

In this paragraph I addressed the relationship between innovation and modularity from a general point of view; in the next paragraph I will focus on what modularity is, with specific regard to product architecture.

4.3 Disentangling product architecture

Because many products are becoming increasingly complex systems, and consequently made of multiple subsystems, the idea of product modularization is becoming increasingly strategically important (Langlois and Robertson, 1992; Garud and Kumaraswamy, 1995; Baldwin and Clark, 1997; Sanchez, 1995; Tushman and Murmann, 1998; Schilling, 2000). Research at the crossroads of management and engineering proposes a variety of definitions of product modularity, highlighting what features may characterize a product's component as "a module" (Ulrich, 1995; Gershenson, Prasad and Zhang, 2004; Mikkola, 2006; Fixson, 2007; Salvador, 2007; Campagnolo and Camuffo, 2009). While authors vary in their definitions of modularity, they tend to agree on the concepts that lie at its heart; that is the notion of interdependence within modules and independence between modules, that Weick and Orton (1990) defined as "loose-coupling". Modular designs are loosely-coupled in that changes made to one module have little impact on the others. Just as there are degrees of coupling, hence there are also degrees of modularity. Baldwin and Clark (2000), as well as Sosa, Eppinger and Rowles (2004) argue that "modules" are characterized by independence across and interdependence within their defined boundaries. This independence is achievable through the adoption of interfaces that decouple the development and the inner working principles of a product's components. Moreover, if a component fully and exclusively implements few functions, it should be easier to isolate its development from the rest of the system, and to evaluate and ensure certain performance levels (Salvador, 2007).

There are different types of modularity-in-design as well. Ulrich and Tung (1991) propose a classification based on how the final product configuration is built. Their typology distinguishes between component-swapping, fabricate-to-fit, bus and sectional modularity, and captures different possible approaches to combining modules. Ulrich's (1995) typology relies on the nature of the interfaces among components as the classification criterion and distinguishes between slot, sectional and bus modularity. Salvador, Forza and Rungtusanatham (2002) complement these typologies introducing the notion of combinatorial modularity as a sub-type of slot modularity and contrasting it with component swapping modularity. In combinatorial modularity each product component is a variant within a component family and each component family interacts with a subset of other component families. The interactions are ensured by standardized interfaces that may differ depending on the combination of families they connect but are independent of the component variant chosen, so that “all component families are allowed to vary while the interface between specific pairs of component families is standardized” (Salvador et al., 2002: 571).

There is a lively debate about product modularity and three issues of interest for this research are outstanding:

1. The possibility to evaluate the effects of modularity on product innovation (Fleming and Sorenson, 2001; Pil and Cohen, 2006);
2. The possibility to measure and capture the degree of modularity of products (Fixson, 2007; Salvador, 2007; Cabigiosu, Camuffo and Schilling, 2008);
3. The possibility to modularize complex products at all (Staudenmayer et al., 2005; Brusoni, Prencipe and Pavitt, 2005).

As explained in the previous paragraph there is still an open debate on the positive effects of product modularization because the net effect of loosely coupled product architectures on innovation and, more generally, on performance, is uncertain both in terms of rate and magnitude not only because advantages and disadvantages may offset each other, but also because such effects are typically mediated by a number of other variables *(*Salvador, Forza and Rungtusanatham, 2002: McCormack et al., 2008).

While modularity’s multi-dimensionality is one of the sources of its broad-based appeal, it has also created some obstacles to precise definition and measurement. Numerous definitions have been put forth

(Ulrich and Tung, 1991; Schilling, 2000; Fixson, 2003; Gershenson, Prasad, Zhang, 2003; Salvador, 2007; Fixson, 2007; Campagnolo and Camuffo, 2009) and empirical measures have been extremely diverse, and often quite coarse. Ethiraj and Levinthal (2004) pose the fundamental question of how, given that hierarchy and near-decomposability may be desirable attributes of a complex system (a product, a technology, an organization), bounded rational managers will be able to identify and uncover some true, latent structure of hierarchy and near-decomposability. From this standpoint, measuring product modularity and, more generally, the degree of modularity of complex systems, is extremely important for the design and management of organizations and economic activities. This aspect is particularly worth investigating because the modularity literature, and more specifically the literature on modularity measures, "has left largely unaddressed the question of the feasibility of boundedly rational actors identifying more or less appropriate modular architectures" (Ethiraj and Levinthal, 2004, p.404). From this standpoint, the investigation of what measures of modularity (in the sense of system's architecture properties) better allow to cope with bounded rationality in the design of complex systems, is crucial in improving management theory and practice (Cabigiosu, Camuffo and Schilling, 2009).

An even more fundamental concern regards the possibility to modularize at all complex products. Several studies show that the average degree of product modularity is significantly different contingent on the industry analyzed (Fixson and Park, 2008; Galvin and Morkel, 2001; Sturgeon, 2002; Fixson, Ro, Likert, 2005) and that there are industries characterized by persistent integrality (MacDuffie, 2008). Besides, products are complex systems that typically comprise a mix of components, some of which are tightly coupled to others and some of which are relatively independent (Salvador, 2007; Fixson, 2007; MacCormack et al., 2008). Finally, the one to one mapping of components to functions and the standardization of interfaces (be it a closed or open standard) remains problematic, especially for products characterized by intangible attributes and ambiguous features. This implies that the recombinability of modules (the possibility to mix and match them taking advantage of the economies of replication) is more a theoretical option.

These issues ask for a new conceptualization and a move from the static controversy about the pros and cons of modular product design towards a more realistic conception of how new products come to life. Since research on product modularity needs micro-foundations that capture more accurately the cognitive and social processes behind product creation, this work tries to make a step forward from the current debate around product modularity toward a broader concept of knowledge modularity. By inductively deriving the knowledge modularity construct from the in-depth multiple cross-products analysis of the Alfa's product portfolio this Chapter tackles the issue of what is beyond the typical mix and match paradigm applied by modularity literature and the static controversy about its advantages and disadvantages. While modularity paradigm is split into two contrasting streams of literature, on the one hand who affirms that mix and match is a source of innovation and on the other hand who argues the opposite, an extensive exploration of the product portfolio of the Company reveals a non investigated aspect offering insight for theory development. Here, a new product neither is the result of a mix and match procedure nor shows the characteristics of an integral product, but it derives each time from something that is simultaneously invariant (what I define knowledge module) that gets recombined in different artefacts.

4.4 An exploration of the knowledge modularity issue

The application of the modularity paradigm at confectionary products might seem counterintuitive. Indeed how can a chocolate bar be modular following the traditional definition of modularity offered above? In general confectionary products look like integral rather than modular following Ulrich's definition of product architecture (1995, 420) as "the arrangement of functional elements, the mapping from functional elements to physical components, the specification of the interfaces between interacting physical components" where a modular architecture includes a one-to-one mapping from functional elements in the function structure to the physical components of the product and specifies de-coupled interfaces between components while an integral architecture includes a complex (non one-to-one) mapping from functional elements to physical components and/or coupled interfaces between components (Ulrich, 1995). In fact a chocolate bar is integral because some functions may be shared by several product components and the interfaces among product components are not standard.

However the creation of integral product implies every time a systemic innovation (Mikkola, 2003) and the redefinition of a component implies a redefinition of the other component. This hints that whenever a company designs integral products it should start from scratch in defining both components and interfaces. Consequentially, since Alfa's products seem to be integral does it imply that they are invented and created each time departing from zero or there is a common base from which the Company departs before building a new product?

By moving on a higher level of exploration and by looking at the entire Alfa’s product portfolio rather than at each single product, it is feasible to discern that Company continuously blends templates translating them in different products. Hence products even if integral by nature reveal patterns of modularity in their knowledge architecture. Indeed the overarching knowledge architecture that different products may share may be articulated in some components that are invariant (knowledge modules) and get applied in product components that are diverse. Thus knowledge modules shape what in this Chapter I define “product knowledge architecture”.

More specifically by analogical extending Ulrich’s (1995) definition of product architecture I define “product knowledge architecture” as the arrangement of knowledge elements, the mapping from knowledge elements to physical product’s components and the specification of the interfaces between interacting physical product’s components”. Consequently, product knowledge architecture is a common, stable and recursive pattern framing the overarching cognitive structure of products. Product knowledge architecture incorporates knowledge modules including a bundle of information, inputs and capabilities dynamically shaped by the firm over time and strictly inherent to product components and that put up the “product knowledge architecture”.

Knowledge, though invariant, may be characterized by different degree of ambiguity and potentially product components variety. They may also have different potential in terms of the number, variety and characteristics (technical and physical nature) of the product components - physical and recognizable entities performing a well defined function and behind which specific knowledge modules have been developed – without any changes in the cognitive and architectural one. Knowledge modules simultaneously are “static” and “stable” but even “malleable” and “multi-purposive” and these characteristics represent may open up a huge variety of product components. Thus, while the knowledge modules are intrinsically equal every time they are used in different products, they may take different shapes contingent on the product in which they are included.

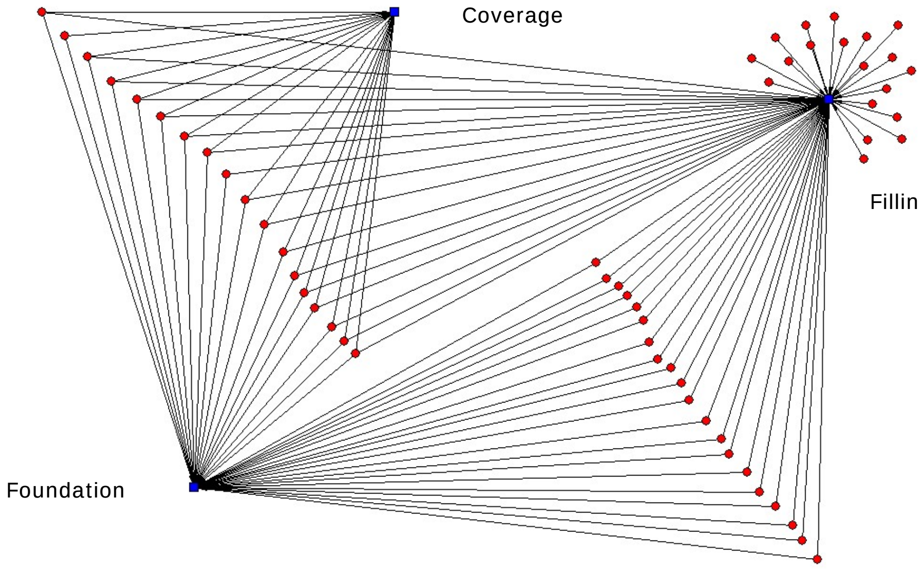
In this Chapter I argue that despite their integral nature Alfa’s products share an overarching product knowledge architecture. I used data on the 62 products belonging to company’s product portfolio. In Alfa’s Company products enclose a modular knowledge structure characterized by the sharing of an overarching cognitive architecture characterized by three knowledge modules that may be defined after a depth exploration of the data and corroborated by the interviews to the managers as a “Foundation”, a “Filling” and a “Coverage”. In fact according to the interviews Company retrieves, refines, replicates and recombines each time for each product are not the product components per se but the knowledge the each component encapsulates. As a consequence, new product is never or almost never the outcome of a plain mix and match practice but it derives from something that is at the same time variant and invariant that is “knowledge modularity”.

By doing some descriptive analysis carried out through UCINET VI (Borgatti, Everett and Freeman, 2006) it emerges that the “overarching” product architecture including the knowledge module “Filling” persists in 31% of the products; the knowledge modules “Foundation” and “Filling” persist in 35% of products; and the knowledge modules “Foundation”, “Filling” and “Coverage” persist in 26% of products[21]. Thus each product

[21] A residual part is represented by the knowledge modules “Foundation” and “Coverage” (0,01% of the products).

may be the combination of these three knowledge modules. The figure 16 is the representation of the two-mode matrices Products-Knowledge modules (with dimension *62x3*).

Fig. 16 The map of Alfa's product onto the product knowledge architecture[22]



Tab. 5 The map of Alfa's product onto the product knowledge architecture

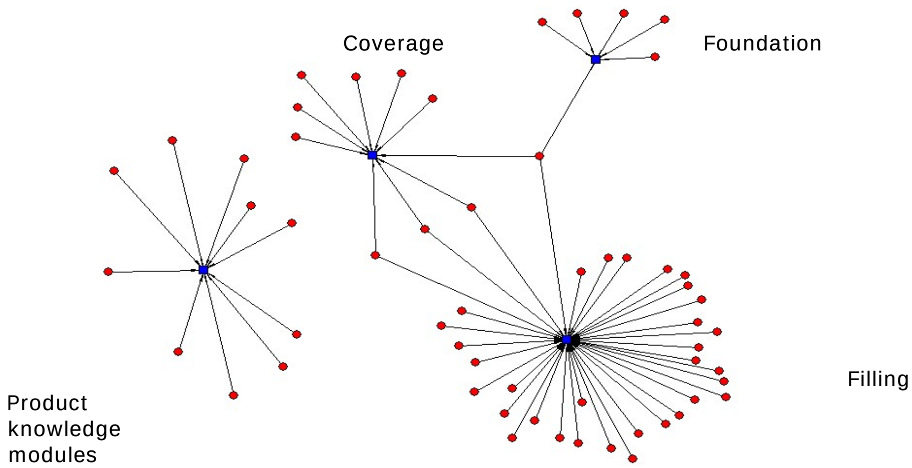
	Filling	**Foundation Filling**	**Foundation Coverage**	**Foundation Filling Coverage**
Number of products	19	22	1	15
Percentage of products	31%	35%	0,08%	26%

Furthermore the three knowledge modules according to their properties of stability and malleability may open up a huge variety of

[22] In the figure the blue squares represent the knowledge modules while the red circle represent the products sharing the knowledge architecture.

product components getting different shapes according to the product components they reflect. Thus each knowledge modules can be declined in diverse range of product components and also different kinds of knowledge modules. Moreover products themselves may become a knowledge module when they are combined in new products and this happens in the 0,08% of the products. Figure 17 is the representation of the two-mode matrix Product Components-Knowledge modules (with dimensions *57x4*).

Fig. 17 A map of knowledge modules onto product components[23]



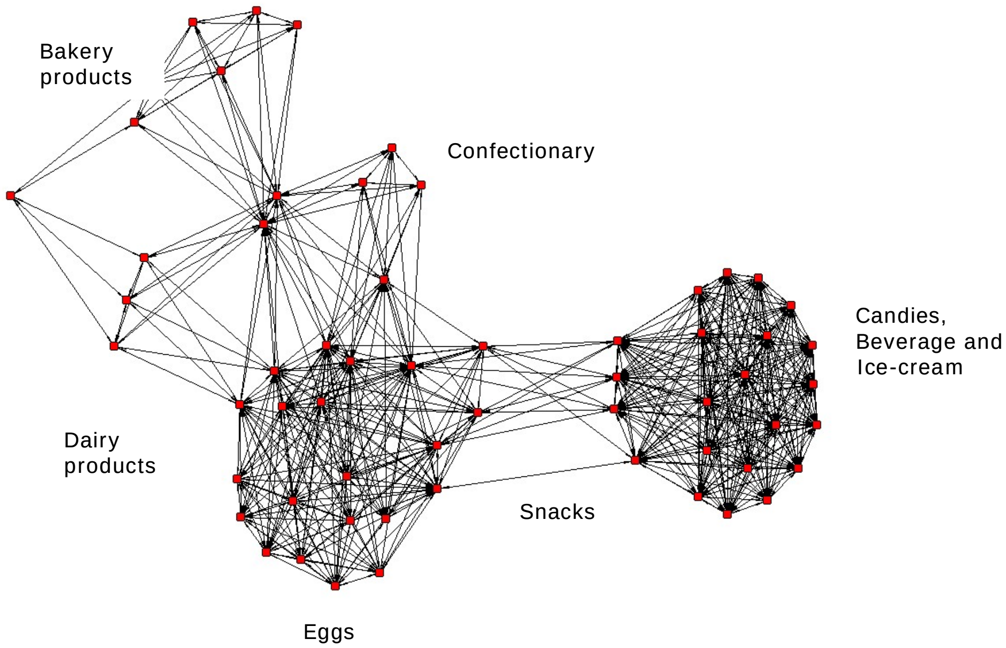
Tab. 6 A map of knowledge modules onto product components

	Foundation	Filling	Coverage	Foundation Filling Coverage	Filling Coverage	Product knowledge modules
Number of product components	6	36	10	1	3	10

[23] In the figure the blue squares represent the knowledge modules while the red circles represent the range of product components underlining them.

Moreover these product components may be used in different products (Fig. XXX). This figure represent the result of the transformation of the two-mode matrix Products-Product components (*62x57*) in a one-mode matrix Products-Products (62x62) indicating the number of product components that each product shares. Thus, the knowledge module underlying a product module is malleable in the sense that is used, adapted, improved to several purposes and products.

Fig. 18 The sharing of knowledge modules[24]



4.5 Discussion and conclusion

This chapter gives a contribution at breaching the black box of firm's product knowledge architecture design and evolution and at extending current micro-foundations of modularity research by answering to these three questions: "Given the integral nature of sweets and confectionery

[24] In the figure the red circles represent the final products and the ties represent the product components they share.

products, what are the mechanisms that allow innovating while leveraging on existing products and resources?"; "Since for integral products innovation can not be the result of components' recombination (mixing and matching of existing components), what mechanisms allow to innovate leveraging on existing products?"; "Does product knowledge have a hierarchical and quasi-decomposable structure? Do these properties allow recombining product knowledge components in order to generate new products?"

By following the modularity paradigm and its partition in modular and integral product it is arguable that the creation of integral product implies each time a systemic innovation while modular products entail more incremental and components innovation (Mikkola, 2003). Consequentially this means that when a company designs integral products it should depart from zero in defining both components and interfaces. However it is reasonable that in order to exploit synergies and economies of scale Companies, even if creating integral products do not depart each time from scratch. The case of Alfa's Company exactly gives an idea about this issue. Indeed even Alfa's products look like as integral products it dose not imply that among products do not exist any kind of analogies.

In fact, although the application of the modularity paradigm at confectionary products might sound counterintuitive because they do not present the conventional properties of Ulrich's definition by exploring the whole Alfa's product portfolio it is reasonable to recognize that product's, even if integral for nature, disclose patterns of modularity in their architecture. Indeed the overarching architecture that each product shares may be disentangled in some components being simultaneously variant and invariant that are here defined as knowledge modules representing a bundle of information, inputs and capabilities shaped by the firm and intrinsic to product components that set up the product knowledge architecture. From this study it emerges that product knowledge architecture is a common, stable and recursive pattern framing the overarching cognitive structure of products.

Thus products are both concurrently characterized by product components representing their technical and physical nature and knowledge modules representing their cognitive architecture. From this study it is evincible that Alfa mix and match product components by following an overarching cognitive structure of three main knowledge modules. Through the analysis of the 62 products belonging to company's product portfolio I demonstrate that Alfa's Company product's components are not a static and persistent entity that can be only mix and match into different products but they are a dynamic entity encapsulating information. In my opinion this concept could offer a strong contribution in enhancing the modularity literature moving from the classic debate on advantages and disadvantages of modularization toward a more in-depth exploration of what is behind product modularity. For this reason the aim of this Chapter is to surface the issue of knowledge modularity as something invariant but malleable warranting to the Company the possibility to be replicated in several products in order to obtain synergies and economies but at the same time preserving its innovative capabilities.

CONCLUSION

The debate on organizational theory and strategy has moved in the last decades from the sustainability of competitive advantage to the firm's capability to manage innovation and change. In this area scholars have underlined the importance of product development because the continuous introduction of new product is considered an important element of a firm's prolonged success. For this reason a growing number of studies have been investigated and theorized the strategies that might facilitate firms in getting the capacity to innovate through the introduction of new products.

Many of these studies indicate in resource, competencies and knowledge the key factors in understanding continuous innovation. Indeed new product development process not only leads to the design of new products, but it also generates new knowledge base nurturing firm's ability to sustain innovation over time. However, though several scholars agree that knowledge is a key resource for product innovation, limited progress has been made so far in understanding how knowledge is generated, selected and diffused across firm's products over time as well as in considering product knowledge dynamics and in measuring its evolutionary trajectories. Similarly, studies that conceptualize knowledge as underlying a firm's capabilities, that conceive it as a complex system, that analyze its architecture and structural properties and that explain its dynamics as the result of design and evolutionary processes are scarce and much needed.

Thus, the focus of this work was explicitly on product knowledge, its elements, architecture and dynamics. Product knowledge is here explored as a logical construct, a conceptualization of data, information, language and meanings, shared within an organization that underlies one or more products and that co-evolves with product portfolio.

This dissertation offers a micro investigation on how the knowledge underlying a products portfolio of a large food, beverage, sweet and confectionery Multinational Company (called Alfa) is recombined over time to create new products. Through the construction of a longitudinal and original dataset of Alfa's product portfolio this study focuses on a particular kind of knowledge defined as product knowledge. Product knowledge is here conceived as the repertoire of knowledge a firm has developed over time which is embodied in its existing products. Thus the innovation capacity of a firm may be observed in the way its product knowledge is structured over time. For this reason this dissertation is a path-breaking analysis of product knowledge architecture and investigation of its evolutionary dynamics.

This dissertation gives a contribution at breaching the black box of firm's product knowledge architecture design and evolution both on methodological and theoretical sides. On the former by envisioning product knowledge as a complex system helps its decomposition into knowledge chunks and in the analysis of its cross-product replication and/or variation over time. In this direction the methodological tool of network analysis is helpful to decompose product knowledge in nodes of knowledge and knowledge relationships and map the 'combinatorial capabilities' that underpin new product development in a large company as Alfa. The ground-breaking application of a network perspective to something not "strictly social" as the firm's product knowledge, helps to investigate and deeply understand knowledge recombination processes and how they lead to new products development as well as to map and study their evolution over time. By modelling and analyzing the patterns of structural evolution of product knowledge networks over time this work grasps the ability of a firm in making product innovations and offers an unexplored view of firm's product knowledge architecture evolution. This approach is noteworthy in producing a visual representation of the patterns of knowledge evolution in the product portfolio and identifying products with unique and not re-used knowledge and other more characterized by a strong cognitive proximity and cross-knowledge absorption.

On the latter this work moves from the classic dichotomy exploration-exploitation investigated in organizational learning and search literature toward a wider model of evolutionary knowledge trajectories. Evolutionary knowledge trajectories are here distinguished according to two different sources of knowledge: on the one side the presence of new nodes and the presence of knowledge structural similarity (recombinative, imitative, exploitative and explorative trajectories) and on the other side the typology of knowledge interested (core/periphery trajectories). The results highlight how the firm's product knowledge moves over time across these learning trajectories through the evolution of firm's product portfolio. By using the metaphor of the pastry chef who has written in the mind the exact combination of several knowledge chunks in order to obtain the desired product, on the on hand by mixing and matching what he has previously used and on the other hand by searching for new knowledge chunks, this study offers an original way to more deeply comprehend the knowledge recombination processes. To date knowledge recombination framework has always studied how firm's knowledge evolves over time, at technological level through the use of patent data and not at product level. This study explores this issue in an innovative research setting, Alfa’s product portfolio, by analyzing knowledge recombination at product level through a cross-multiple products longitudinal analysis.

Furthermore on the theoretical side this work even aims to move the debate on product modularity on product innovation at a different level showing that, thanks to the hierarchical and quasi-decomposable nature of product knowledge, Alfa can innovate its product portfolio adding new integral products by recombining (mixing and matching) existing knowledge modules. Knowledge modules provide the underlying cognitive structures on which product innovation is based and are used as templates for product innovation. By inductively deriving the knowledge modularity construct from the in-depth multiple cross-products analysis of the Alfa’s product portfolio this work tackles the issue of what is beyond the typical mix and match paradigm applied by modularity literature and the static controversy about its advantages and disadvantages offering a theoretical development on this debate.

To conclude this work allows understanding the foundations of product innovation processes, interpreting product innovation strategies and predicting innovations outcomes. The method used may have wide generalizability across a range of products and industries. This work represents a unique and powerful lens through which view what is taking place within a firm, and how knowledge is being created and shared among its various products. Such detailed information should enable managers and researchers to better understand the evolution of firm’s capabilities, and the role of knowledge in creating competitive advantage.

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