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Knowledge Integration in Fact-Changing Environments

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RE – INVENTING THE WHEEL: KNOWLEDGE INTEGRATION IN FAST-CHANGING ENVIRONMENTS

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Abstract

The aim of this paper is to look at knowledge integration as an organizational capability which leaves traces in intra-organizational networks. To do so, this paper develops a methodology to identify and capture with quantitative data the key characteristics of those organizations that integrate knowledge to solve complex problems. We rely on a two year long project which has gathered extensive qualitative evidence on the micro-level processes which led to the introduction of a radical process innovation in tire manufacturing, i.e. a robotized, modular production process. On this strength, we compare the strategies of two of the world's leading firms (Michelin and Pirelli) engaged in the effort of developing this breakthrough technology in the 1990s. We look at the evolving structure of their intra-organizational co-inventors' networks in order to explain the different outcomes of their strategies.

JEL codes: O32, L23, L6

Kew Words: knowledge integration, social network analysis, tire industry.

1. Introduction

Recent research has highlighted the strategic importance of integrative capabilities in explaining firms' innovativeness and, ultimately, their profitability and survival. In knowledge intensive environments, firms need to reconcile apparently conflicting objectives. On the one hand, they need to specialize in order to be able to deepen their competencies in existing bodies of knowledge and practice. On the other, they need to be able to combine, or integrate, such specialized skills to be able to deliver new products and services. Hence, the increasing attention devoted to the analysis of knowledge integration (Grant, 1996); combinative capabilities (Kogut and Zander, 1992); architectural knowledge (Henderson, 1992); systems integration (Prencipe et al., 2000). Such emphasis on 'integration' and 'combination' highlights the fact that knowledge accumulation processes ought to be seen as a series of small (although sometimes really fast) steps in related technological competencies, rather than stochastic moves across unrelated technological areas (Teece, et al., 1994; Breschi et al., 2003). Thus, what matters is not the mere accumulation of productive knowledge by firms, but how firms manage to acquire new knowledge, integrate it with the existing knowledge base and exploit it in a productive context. The activity of combining productive competencies (we use indifferently competencies and knowledge) to develop new strategies and business models is called, in this paper, knowledge integration.

The aim of this paper is to look at knowledge integration as an organizational capability (Grant, 1996) which leaves traces in intra-organizational networks. To do so, this paper develops a methodology to identify and capture with quantitative data the key characteristics of those organizations that integrate knowledge to solve complex problems. We rely on a two-year long project which has gathered extensive qualitative evidence on the micro-level processes which led to the introduction of a radical process innovation in tire manufacturing, i.e. a robotized, modular production process (Brusoni and Prencipe, 2006). On this strength, we compare the strategies of two of the world's leading firms (Michelin and Pirelli) engaged in the effort of developing this breakthrough technology in the 1990s. We look at the evolving structure of their intra-organizational co-inventors' networks in order to explain the different outcomes of their strategies. We suggest, and empirically explore, the idea that there is a link between the structure of an innovative network and an organization's ability of framing and solving complex problems. We chose these two firms because they varied widely in terms of how they organized their development efforts, and their overall strategies. Michelin was the technological pioneer, bringing online the new technologies at a time when Pirelli had just started exploring their viability. However, Pirelli caught up and used the new process technology as the centre-piece of a new corporate strategy, which brought about new marketing tools, the entry in new segments, a revamped corporate image, new intra-organizational processes: in short, a new business model. Michelin instead stayed closer to its traditional way of doing things, and used –for the best part of the 1990s and well into the 2000s- the robotized process it pioneered to exploit its traditional niches.

In a few words, Pirelli was capable of developing an integrated strategy on the basis of the new process. Michelin was not. We posit that the observed differences in outcomes were due to the different capability-building strategies pursued by these two firms, which generated different levels of knowledge integration capabilities. Michelin, due to its history and strategy, lacked 'knowledge integration' capabilities. Our working hypothesis is that successful knowledge integration requires the presence of focal individuals that connect and integrate interdependent technological and organizational areas. More specifically, our working hypothesis, based upon the qualitative fieldwork already carried out, predicts that the presence of knowledge integration capabilities can be revealed by a few fundamental characteristics of the networks of inventors as mapped using patent data. We argue that organizations which have developed knowledge integration capabilities (relatively to organizations with less developed knowledge integration capabilities), are characterized by an intra-organizational network structure which is: (1) more connected, i.e. a larger number of nodes are in the giant component; (2) vertically structured i.e. exhibit a relatively larger number of distinct layers; and (3) such layers are partially overlapped thanks to the presence of focal individuals.

This paper is structured as follows. The next section selectively reviews the relevant literature on innovation and knowledge integration. Section 3 discusses the empirical setting, introduce the working hypotheses we intend to test and the method to do so. Section 4 presents our preliminary empirical results. Section 5 concludes.

2. Innovation and knowledge integration

Integrating knowledge has become a widespread concern, as empirical evidence shows that, in a variety of industries, large firms are more diversified in the technologies that they master than the products that they make (Granstrand, Patel and Pavitt, 1997; Gambardella and Torrisi, 1998; Von Tunzelman, 1998; Brusoni et al, 2001). Moreover, Nesta and Saviotti (2005) found that, in the pharmaceutical industry, the extent to which heterogeneous technological fields are coherent, or integrated, has a positive impact on firms' market value. That is to say, markets value not knowledge accumulation *per se*, but the abilities of firms to make specialized knowledge coherent.

Besides strengthening Rumelt's (1974) classic results about the advantages of coherent diversification, this literature touches upon fundamental theoretical issues related to the prevalent models for conceptualizing learning and innovation. Much of the capability-development literature is inspired by the seminal work by Cyert and March (1963) and Nelson and Winter (1982), which gave centre stage to incremental, cumulative processes of routine development (see also the discussion in Podolny and Stuart, 1996). Their analysis, as synthesized by Gavetti (2005), emphasize processes of local, experiential, semiautomatic search. However, local search is only one possible way to generate new information and knowledge. Goal-oriented search, cognition, forward-looking learning processes also play a key theoretical role in the seminal contributions by Simon (1976) and March and Simon (1958). However, they have received comparatively little attention. Recent research in the strategy area has begun to address this gap.

Gavetti (2005) develops a simple simulation model in which local processes of search interact with cognitive processes of goal-oriented search and experimentation. In his model, hierarchy intervenes as the organizational locus of higher level cognition. Similarly, Jacobides (2007) stresses the role played by hierarchical reframing in the context of complex problem solving: local cognition leads systems made up of many interconnected, and hierarchically nested, elements to local optima. Higher level cognitive processes are necessary to reframe the overall problem structure in order to lead local learning toward higher picks of efficiency. Cattani, Dorsch and Winter (2007) show that a search strategy which combines local search with a moderate level of non-local focus is distinctly advantageous in searching a rugged landscape. Prencipe et al. (2003) discusses a range of managerial issues related to the practice of systems integration, i.e. the ability of some firms to coordinate complex networks structures constituted of many interconnected and horizontally specialized firms. They also raise the issue of integrating local learning with goal-oriented search and direction.

In fact, the engineering and new product development literature is quite rich of empirical analysis of leadership within innovative projects, as well as on the specific issue of knowledge integration (Prencipe et al. 2003). Recently, research inspired by a network analysis perspective has enormously developed the idea that innovation and learning occur in networks, and that specific actors –often called brokers- play a strategic role within these networks (e.g. Allen, 1977; Burt, 1992, Sutton and Hargadon, 1996). On this basis, many have conceptualized firms' and industries' knowledge bases as networks of interconnected elements (Podolny and Stuart, 1996; Ahuja and Katila, 2001; Rosenkopf and Nerkar, 2001, Siggelkow, 2002).

We develop the intuition of Yayavarm and Ahuja (2005) that 'the structure of the network of knowledge elements can guide the process of recombinatory search for new inventions, and thus directly affect the utility of such inventions' (p. 4). We extend this analysis moving the locus of analysis to the intra-organizational network of individuals engaged in developing a new technology, and a new strategy around it. In doing so, we follow Tripas and Gavetti's (2000) idea that the development of new technological capabilities must be accompanied by conscious efforts to develop also consistent business models, else technological capabilities will remain unused and technological leadership may not lead to superior competitive advantage. We aim at extending this line of thought combining two streams of research: that on knowledge transfer and that on complex adaptive systems.

From the former, we take the notion that effective knowledge transfer requires both connections among people and the presence of key individuals which act as 'reservoirs' or repositories of knowledge embedded in organizations (Argote and Ingram, 2000). In this paper, we look at both the evolution of connections among individuals, as well as at the emergence of focal individuals (i.e. our knowledge reservoirs) who cut across areas of specialized expertise. Uzzi (1997) and Hansen (1999) argued that a relationship exist between the strength of social ties and the effectiveness of knowledge transfer and search within organizations. Rather than tie strength, we look here at network positions within clusters of specialists. In particular, we aim at identifying those focal individuals who define the relational architecture of the firms: they may not be specialists in each field (i.e. they are not necessarily generalists competent about or directly involved in all activities and sub-tasks), but their decisions affect the patterns of relationships among other people. By knowledge integration, we mean exactly this ability of defining the relational architecture of a group. We shall argue that knowledge integration capabilities are necessary to make search less local and more goal-directed.

Building upon research on complex systems, we consider problems as made up of many interconnected elements (Kauffman 1993, Rivkin 2000, Fleming and Sorenson 2001). Problems which are characterized by complex interdependencies are less tractable than problems characterized by fewer or more predictable interdependencies. Firms' strategies can be represented as bets about the actual pattern of interdependencies (Levinthal 1997; Levinthal and Warglien, 1999). The recent upsurge of modularity research can be interpreted as an effort to understand how firms can 'simplify' problems by reducing interdependencies among interconnected components (e.g. Baldwin and Clark, 2000; Schilling, 2000). Yayavarammi and Auja (2005) also discuss the distinction between interdependency (i.e. the 'actual' degree of interconnectedness among sub-problems) and coupling (i.e. the 'hypothesized' degree of interconnectedness among sub-problems). Similarly, Sorenson (2003) looks at the fit between environmental turbulence and firm's internal design. Empirically, we measure coupling as embodied in the relationships among individuals in two different organizations competing to develop the same process technology (see next section for details and working hypotheses). In our empirical context, we study the degree of within-group coupling (or integration) in two different firms: effective problem-solving requires organizational coupling to proxy the actual interdependencies among sub-problems. Theoretically, we extend this literature searching for the sources of what Reagans and Zuckerman (2001) called the origins of network effects on groups' performance.

3. Empirical setting, data and method

3.1. The tire industry

The tire industry is often depicted as an archetypical example of a mature business (Sull et al. 1997, French, 1991). Since the early 1990s, however, it has witnessed an explosion of R&D initiatives. In the late 1990s, the trade literature described ongoing technology developments that were leading to a fully robotized and modular tire production process. Pirelli Tires, a leading player, developed a process called the Modular Integrated Robotized System (MIRS). The trade press reported that MIRS would usher in an era of customized tires. It also said that robotized, modular production had the potential to change century-old practices that emphasized the mass production of tires, the standardization of tire products, and economies of scale. Business models based on robotized processes, in contrast, emphasize economies of scope, i.e., the production of small batches of differentiated tires; flexibility, i.e., rapid responses to changes in market trends; and customization, i.e., abilities to fulfill specific engineering requirements for different car models. In other words, the diffusion of robotized production would lead to fundamental changes throughout any organization that adopted it.

In a related paper, one of us has explained in some detail how Pirelli succeeded in developing the robotized production process. In this paper, we want to answer a related, yet very different question: why did Pirelli succeed in catching up and overtaking Michelin in terms of technological leadership and market presence? Of course, Michelin has developed his own version of the robotized process (called C3M, i.e. *carcasse*, *monofil*, *moulage et mechanique*). Interestingly, in 1997 Michelin had a clear lead over Pirelli, as a number of C3M lines were already up and running in France, Sweden and US. Three years later the Swedish and US outfits were shut down though. At the same time, Pirelli was opening plants in Italy, Germany, UK and US; winning OE-contracts in the US (which had never happened before); piling up international awards for the innovativeness of its new process; and aggressively moving across the high and ultra-high performance segments in city cars (e.g. Smart and Mini Copper), moto, SUVs and, more recently, trucks. This catching up process is what we want to explain in terms of the internal organizations of the two companies (and more specifically of the groups focused on developing this specific process technology).

The trend toward more automation and flexibility in tire manufacturing dates back to the 1980s. As the automobile industry worked to improve car safety and performance and increased model variety, tire manufacturers strove to reduce average batch size and more efficiently customize tires, e.g., varying tire widths. Pirelli's internal data show that between 1996 and 2004, the number of tire market segments nearly doubled, while average batch size dropped. Most improvement efforts focused initially on the point in the manufacturing process where raw materials and components are all assembled to form a crude tire. The introduction of more flexible building machines reduced the average batch size and set-up times. Nevertheless, costs rose rapidly because material inventories serving as intermediate buffers for upstream process steps increased to accommodate the smaller batch sizes downstream. In the early 1990s, Pirelli was in a difficult situation for two reasons. First, the company specialized in the medium and high end of the market, precisely those segments in which car makers required better-performing and more customized tires, and where the trend toward segmentation was strongest. Second, Pirelli was finding it difficult to maintain its reputation as an innovative leader. Its innovative reputation was tarnished when it failed in its bid in 1992 to acquire Continental Tires, one of its main competitors. According to interviewees, some of Pirelli's key customers saw this failed bid as a signal that Pirelli wanted to turn itself into a commodity tire producer. When this acquisition did not take place, the ownership grip of the Pirelli family loosened, and there were changes in top management, and a major strategic refocus.

The first priority of Pirelli's new top management was to solve the firm's serious financial issues. They also reorganized Pirelli around core areas, exiting or downsizing unprofitable businesses, and investing to improve the efficiency and innovativeness of core businesses. Some of Pirelli's non-tire product divisions, e.g., fiber optics and real estate, began to overshadow the tire division. Archival data indicated that Pirelli's market share by tire segment was static or declining. Moreover, in the early 1990s Michelin began to develop a new robotized production process that allowed it to produce small batches of large tires. Michelin, the market leader, was explicitly targeting exactly those segments that were Pirelli's traditional strongholds. These developments characterized the context wherein Pirelli's top management decided to reinvest to rebuild Pirelli's tire-making capabilities and innovative reputation.

Innovation was emphasized in the rhetoric used to discuss the new strategy, as Pirelli built a new headquarters and research facilities, launched new marketing campaigns, and searched for new distribution channels. In September 1997, the new CEO and owner (Marco Tronchetti Provera) gave Renato Caretta the task of developing a radically new production process to be the flagship of this renewed emphasis on innovation. This project started at a time when Michelin already had at least two C3M lines already up and running.

3.2. The key features of the robotized process.

Conventional Tire Manufacturing. Unlike most processes in the chemical industry, tire manufacturing has traditionally been a discontinuous process during which the various raw materials used (polymers, chemicals and fillers for the rubber compounds) and fabrics and steel reinforcements are preprocessed in a usually continuous fashion (with eventual batch storage), then cut or shaped in discrete components which are then assembled to create each individual green tire and then cured. Various rubbery polymers are mixed with fillers –e.g., carbon black or silica- and other chemical additives to make the various rubber mixes for the different parts that constitute a tire -- sidewalls, tread, bead areas, liner, inserts, etc. -- and that are characterized by widely different physical properties. The mixing is usually carried out by Banbury mixers, after which the various rubbers are extruded to specific contours and cut to length. Textile fibers are, in the meantime, twisted and woven into fabrics that are impregnated with adhesives and then calendered and coated with rubber. The calendered fabric is cut to specific widths and angles in order to be used as reinforcement plies (carcass or breaker). High tensile steel wire is similarly treated and coated with rubber and cut to predetermined widths and angles to be used for reinforcement plies (carcass or belts) and for the bead. All the individual components are deposited sequentially onto assembly drums and pressed into shape by automatic rollers. This assembly is done either in a two-phase sequence or, more recently, on single machines. After this step, the green tire is transferred onto a curing bladder that supports the tire during the vulcanization phase, where rubber curing and molding of tread designs are simultaneously performed.

Innovative Tire Manufacturing. In the innovative process, we see that production is characterized by a flow-line system that makes all components in their final shape so that conventional batch processes are eliminated. Each building process is focused around a rigid torus, fixed in size and design. All rubber parts are directly extruded onto the rigid drum in thin rubber strips. Similarly, textile plies are knitted in situ around the tire, while bead wires, belts and all reinforcement plies are deposited onto the drum as pre-extruded tapes of rubber-coated cords. The sequence of deposition of the various parts is accomplished in a single multifunctional station (C3M, i.e. Michelin's process), or as the drum travels on a trolley on rail through various stations (BIRD, i.e. Bridgestone's process), or as is taken around by robots (MIRS, i.e. Pirelli's process). When the green tire is completed with the deposition of the rubber tapes constituting the tread, the torus is brought to the curing phase. In some of the innovative process, e.g. Michelin C3M (and maybe Bridgestone BIRD), the curing is done by electrical heating, while in others, e.g. MIRS, curing is done with internal injection of steam or nitrogen so that the molding of tread designs is accompanied by inflation as in conventional manufacturing. When the curing cycle ends, the toroidal core, which is formed of a number of separate sectors, is disassembled, thus allowing its removal from the finished tire. Table 1 reports a brief description of all known robotized process developed by the leading manufacturers. It is worth noting that Michelin's C3M and Pirelli's MIRS represent the most radical departures from the standard production process, as they cannot be integrated within traditional manufacturing plants but both require ad hoc facilities.

[Table 1 about here]

One of the fundamental differences between traditional and innovative manufacturing is the sheer size of the plants: both MIRS and C3M save about 80% of floor space. Both Pirelli and Michelin have played with the idea of making 'movable' plants. Also, these small modular plants can be easily reconfigured to produce efficiently and rapidly small batches of customized tires. Scaling up can be done by basically installing a new module. More specifically, the traditional tire manufacturing process is *non-modular*: plants are characterized by many non-standardized organizational and technological interdependencies. For example, extruders produce large bands of rubberized material semi-continuously. Plant operators manually shape these materials on flat supports moved about by the operators. Interdependencies are managed by maintaining inventories of raw materials, components, and intermediate products. Changes in product characteristics require extensive human intervention to adapt or change machinery. These manual changes can cause tire imperfections. Consequently, traditional tire design and production are highly *specialized* and *disconnected* activities. Tire designers, process engineers, and plant operators worked independently: design and production processes are sequential operations. Communications among designers, engineers, and operators to fine-tune production take place through standardized organizational interfaces, e.g., paperwork exchanges. Tire designers focus on specific tire components, e.g., sidewalls, beads; or specific activities, e.g., the choice of materials, the mould design, etc. After identifying the tire's performance targets, designers work in parallel on distinct tire or process components, e.g., beads, treads, and moulds. Design data are not stored centrally and computer aided design is used only to a limited extent. Plant operators receive tire specifications from specialist designers and adapt plant machinery. They possess the skills to set up the manufacturing process and implement design specifications. Once the tires are produced, they are tested on cars. Feedback from testing is sent back to the tire designers who implement changes and start another design cycle. The organization design emphasizes decoupling with few, predetermined interfaces between units and functions. *Tacit knowledge* underlies a lot of traditional tire manufacturing and rules of thumb dominate tire design activities. Little articulated knowledge is available to predict how changes in specific tire characteristics may impact tire performance.

The robotized process, in contrast, is *modular* in nature.[1] The crude tire is built directly on to a rigid drum so that manufacturing collapses into three steps: raw materials processing (done outside MIRS), building and curing, and finishing. Textile plies are knitted *in situ* around the tire, whereas bead wires, i.e., the string of rubberized metal that holds the tire to the rim, belts, and all reinforcement plies, are deposited onto the drum as pre-extruded tapes of rubber-coated cords. Each plant consists of a self-contained assembling and curing module. Within each module, pieces of equipment perform specific functions, e.g., each extruder deposits a specific component on the tire drum. Robots position the drums before the extruders, transport them between extruders and eventually to the vulcanizer. The process is scaled up by adding modules consisting of six coordinated robots and one vulcanizer, and so the system can make six tires at a time. After vulcanization, cured tires are removed from the drums for testing and distribution. There are no material inventories maintained between the building and curing processes. Each module is a closed unit that operates continuously. Workers do not access the module unless problems emerge.

Moreover, modularity is also a property of the tire itself. Each tire component is decomposed into elementary stripes of rubberized materials that designers manipulate and optimize. The extruders operate discontinuously, as each extrudes a small amount of material on the drum. Discontinuous extrusion of small quantities of heterogeneous rubberized materials can lead to tire imperfections, e.g., materials deteriorate rapidly, and mechanical parts are subject to greater stress than in the traditional process. On the other hand, the decomposition of tire components into layers enables engineers to vary the application parameters within each layer and more exactly control tire quality. For example, designers can vary the angle of application or the thickness of certain components in different tire areas, e.g., closer to the centre or the sidewall to improve tire performance. This flexibility that is characteristic of the MIRS process makes it particularly suitable for producing high performing tires.

MIRS requires an *integrated* (non–modular!) organization of the design and production processes and tire designers gain overall control of the manufacturing process. The dedicated software that controls the robots allows engineers to simultaneously design the tires and set the process parameters that will determine how the robotized production process is implemented. MIRS shifts skills and responsibilities away from plant operators to tire designers. *Codification* and *integration* characterize the MIRS underlying knowledge base and MIRS plant control depends on an information technology infrastructure. Whereas in the traditional process plant operators set up the machinery, implement design changes, and control the process, in the MIRS process tire designers directly control the robots that produce the tires. The development of the IT infrastructure emerged as a major source of problems and also opportunities for the MIRS development team.

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[1] Here, we describe the organizational implications of MIRS only (based upon Brusoni and Principe, 2006). The organization surrounding C3M can only be inferred using patent data –see below- as Michelin traditionally refuses *any* disclosure about *any* aspect of its own technology.

Figure 1 summarizes the main differences between the phases and organization of tire design and production with the traditional process vs. MIRS.

[Figure 1 about here]

Brusoni and Prencipe (2006) analyzed how Pirelli came to develop the skills necessary to develop and run MIRS in detail. First, the key bottleneck in developing MIRS was not the assembling of the line (i.e. the hardware). The technology for extruding rubber on a rigid drum was validated quickly. The main problems were about the development of the IT infrastructure necessary to operate the robotized process. This phase required a huge capability-building investment to develop integrated (e.g. product and process parameters are set at the same time) and codified (i.e. articulated in a complex, proprietary and strictly guarded data base management system) design heuristics. Second, the traditional distinction between tire designers and process engineers collapsed. New capabilities (i.e. software engineering) had to be brought in. A new, centralized and integrated governance structure had to be developed (i.e. a single tire designer are now responsible for the entire design-production-test and redesign loop).

There is no evidence that Michelin went through the same phase of profound reorganization. Besides, while MIRS rapidly became the cornerstone of Pirelli's new strategy, Michelin appears to have been less inclined to give C3M the same strategic role. Pirelli set MIRS at the centre of a strategy which intended to gain new OE contracts in the high and ultra-high performance segments (which it succeeded in doing). Also, the so-called 'ePirelli strategy' (an effort to change how the industry traditionally approach its final customers) was explicitly linked to MIRS, presented as the symbol of Pirelli's renewed technological leadership. MIRS was used to aggressively target a range of fast growing segments (e.g. city cars, SUVs). Finally, Pirelli also targeted raw materials processing as a key development supporting the new production process: CCM (Computerized Compounding Machine) is another breakthrough brought on line in 2002 to supply MIRS with raw materials of adequate quality. Michelin never entered that specific race, considering raw materials and assembling as two decoupled phases. In 2001, the contract with BMW to supply the new Mini Cooper with MIRS-produced run flat tires was a result which gave Pirelli in general and MIRS in particular instant visibility.

To conclude, Pirelli reorganized parts of its internal structure, its capabilities, its product portfolio strategies, its marketing campaigns around MIRS. The original development group remained central during the whole phase, from exploratory R&D to marketing through full-scale industrializations. Pirelli developed knowledge integration capabilities which allowed connecting technological, software and strategic developments into a coherent whole. The new technology developed into a new business model which had major spillovers also toward the traditional business units. Michelin strategy remained much more compartmentalized. We expect this process to have specific implications in terms of the kind of intra-organizational networks we can find in these two companies.

On the basis of this summary of what happened in Pirelli and Michelin, our working hypothesis is that structure of Pirelli's network should result more integrated than Michelin's one. By 'more integrated', we mean three distinct characteristics of the network:

1. More connected, i.e. a larger number of node is reachable by the others. This hypothesis derives from a number of classic works on knowledge transfer which positively associate interconnectedness to effective knowledge transfer (e.g. Hansen,

1999). This is something which can be measured looking quite simply at the size of the giant component of each network.

2. A core-periphery structure 'vertically' centred around the MIRS development team, i.e. an increasingly cohesive groups nested inside each other, with the deepest group including MIRS' project leader (i.e. Caretta). This is something which proxies the idea of an organizational 'linking pin' which belongs to the different sub-groups which have to be called in to develop the new process (e.g. tire designers, process engineers, software engineers). As these various specialists were not used to work together, members of more than one group act as both as supervisors and mediators among different values, norms, and objects of both groups. This is the role played, in Pirelli's case, by Renato Caretta. No similar role emerges from the analysis of Michelin's data.
3. An horizontal structure which also exhibit some extent of integration, i.e. many overlaps among cohesive blocks at the same hierarchical layer. This is because the MIRS group grew by including heterogeneous specialists, but also specialized technologies. For example, the development of CCM represents a good example of horizontal diversification of the MIRS group which gave Pirelli a clear lead over Michelin.

Moreover, we expect that these features of Pirelli's network of inventors are already present before MIRS project effectively starts (September 1997). This is important particularly to defend the role of Renato Caretta as our key integrating individual. His role in the network might emerge as a mere consequence of the fact that, as leader of the group, he would co-author all patents. This is not the case as we show at the end of section 4.

3.3. Method and data

We propose to use patent data at the firm level to build the network of inventors of the two companies (Pirelli and Michelin) and to compare the evolution of their structural properties during the 1990s. Patent data are a traditional measure of innovation activity, widely used and whose advantages as well as disadvantages are known (see Griliches, 1990). Recently, patents have been increasingly used as sources of *relational* data. In particular, co-inventions data are used to build network of inventors. In these networks, each node represents an inventor and each link indicates that two inventors collaborated within the research project which led to the patent. For instance, network of inventors have been analysed to show the social determinants of knowledge flows (as captured by patent citations) between organisations (Breschi and Lissoni, 2004) and between individuals (Singh, 2005).

Our analysis focuses instead exclusively on *intra-firm* networks of inventors, as qualitative data (Brusoni and Prencipe, 2006) show that Pirelli and Michelin developed internally the new process technologies: components were bought from suppliers (robots are pretty much an off-the-shelf technology), but their customization, their arrangement in the plant, and the IT infrastructure were all developed internally. This intra-organizational focus implies specific methodological issues. Two questions in particular have to be addressed: which kind of relations these data actually measure and if they are able to capture the whole community participating in the research process we intend to analyse.

The basic assumption is that if various individuals participate in a research activity (leading to a patent), these individuals develop some kind of social and cognitive relation. The research activity is carried out by a team of researchers, each one endowed with *personal knowledge* (Polanyi, 1962) and by necessity they have to develop a common language or code (Cowan et al., 2000). In so doing, researchers develop a common understanding, i.e. know-how (which usually differs according to individual skills, knowledge and position within the network); but also a better knowledge of the competences and skills of the other members of the team (i.e. know-who). It is usually assumed (e.g. Breschi and Lissoni 2006) that the former kind of relation implies *a cognitive relation* (e.g. common understanding) and the latter implies *a social relation* (e.g. channel of collaboration). The existence of a social relation is a key assumption in order to explain knowledge flows using network analysis. However, in this paper, we are not trying to explain patterns of knowledge transfer among individuals. Rather, we focus on issues of network structure. Thus, given the aims of our analysis and differently from other studies, we assume simply that a common participation in a patent activity implies a cognitive relation among inventors.

In our analysis, we intend to refer mainly to the concept of *structural cohesion* proposed by James Moody and Douglas White (2003) and to apply the methodology they suggest. The idea of structural cohesion refers explicitly to Harary's concept of node connectivity and it is defined as *the minimum number of actors (nodes) who, if removed, would disconnect the group (network)*. For the Menger's proof (Harary, 1969), this definition can be rephrased in a completely equivalent definition: "a group's structural cohesion is equal to the minimum number of independent paths[2] linking each pair of actors in the group" (Moody and White, 2003, p. 109). Intuitively, a group of individuals is cohesive if it is resilient to the removing of nodes (i.e. it is able to hold together) and this is more likely as the number of paths connecting individuals increases.

The identification of cohesive groups can be applied recursively in order to identify subgroups nested in the original group: after having removed the nodes keeping together the group, it is possible to consider if there exist some cohesive subgroups in the new unconnected network. This recursive procedure permits to identify cohesive groups and their position related to the others, i.e. to show the hierarchical nesting of the different cohesive groups. For this reason, Moody and White call this procedure *cohesive blocking.* This is how we capture the vertical dimension of the notion of integration put forward when presenting our working hypothesis. Moreover, differently from blockmodeling techniques, individuals are not assigned to groups according a partition. Individuals are allowed to be members of different groups at the same hierarchy level: cohesive blocks can overlap. This is how we capture the horizontal dimension of the notion of integration put forward when presenting our working hypothesis.

This possibility, jointly with the previous one (i.e. the identification of the hierarchically nested structure), is the strength of the model proposed by Moody and White. Cohesive blocking technique permits to identify groups of individuals, to relate each group to the others both vertically and horizontally. Vertically because nested groups are recursively identified. Horizontally because individuals can be simultaneously member of more groups, thus causing them to overlap. In sum, cohesive blocking permits to compare different networks in terms of their cohesive blocks and considering how these are vertically and horizontally related to each other. We posit that cohesive blocking is a procedure well suited to capture different degrees of 'integration' within intra-organizational networks. As argued above, Pirelli caught up with Michelin exactly because it deployed an integrated technology, marketing and business strategy around MIRS. We want to test the idea that such an

[2] A *path* is a sequence of distinct nodes and lines, starting and ending with nodes. Two paths are said to being independent if they have in common only the staring and the ending nodes.

integrated strategy must have been supported by an underlying integrated intra-organizational network.

Our data source is the EP-CESPRI data set, which is based on all patent applications to the European Patent Office (EPO) from June 1, 1978 onwards. It includes the full set of bibliographic variables concerning each patent application. In particular, we use the following variables:

- Priority, application, and publication number
- Priority dates, application and grant date
- Title and abstract
- Main and secondary *International Patent Classification* (IPC) codes
- Applicant's name and address
- Inventors' names and addresses

The EP-CESPRI dataset is organised as a subject-oriented database: it lists all patents under either individual organizations or under inventors. The aim of this paper is to compare the structure of network of inventors of two companies operating in the same market sector and dealing with similar technological issues. However, these two firms differ in many other aspects (e.g. Michelin is to a large extent a tire-only company; Pirelli is rather diversified). Thus, first of all, we need to focus on those inventors involved in tire-related research only. However, defining the boundaries of the two populations in terms of technological classes could raise other kinds of problems. For example, we might miss important ties between inventors (as captured by co-participation in a patent).

In order to deal with these issues, we follow a procedure that takes into account both the technological content of the patents and the collaboration (i.e. links) among inventors. It is articulated in two steps. First, we select the group of inventors involved in research activity related to tire technologies in the Pirelli and Michelin.[3] For what regards the technological classes, we select the 3-digit IPC reported in Table 2. The choice of classes was validated by an engineer working for Pirelli. We consider both primary and secondary patent classes.

[Table 2 about here]

The aim of the second step is to select all inventors, employed by the firm, connected to at least one of inventors listed in the previous step. Starting from the list-output of the first step, we select their patents without any limitation in terms of technological classes. Then we select all the inventors related to these patents, i.e. the original list of inventors plus their co-inventors. Given this latter list, we restart the process. The process stops when all the connected inventors are included.[4] Thus, we obtain for each company the population of inventors who are directly or indirectly (via social relation) involved in the research activities related to tire technologies.

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[3] Given the specific object of this work, we check further the consolidation of the two companies through the dataset. We check this before the selection of individual but even after. Given the final list of inventors, we consider all the inventors' patents independently on the applicants. Thus, we obtain a list of applicants inventors works for. Given this list, we compare this list with the Michelin and Pirelli list of subsidiaries originally selected. This check allows to check that no inventors have worked for both the two firms.

[4] Of course, it could happen that all inventors of a firm are included, if all other inventors are connected to someone of the inventors dealing directly with tire technologies. But it is not our case.

We limit our analysis to the period 1978-2002. In 2002, both C3M and MIRS are operational and the related strategies are in place. For this period, Table 3 reports the results in terms of the selected patents and inventors.

[Table 3 about here]

The criteria work very differently for the two firms, both in terms of patents and of inventors. As one can expect, the relational criterion (directly or indirectly connected) matters a lot for Pirelli, because it is more diversified than Michelin. Given Pirelli's diversified technological profile, it requires an extra step in the definition of the population.

Let us consider the network of inventors built up considering all Pirelli's inventors selected according to technological content and those selected according to their direct and indirect connection to the previous group. Figure 2 displays Pirelli's giant component (349 individuals out of 522). Individuals are partitioned according to the selection (i.e. technological content or social connection). Black nodes indicate inventors selected on the basis of the technological content of the patent. Grey nodes represent inventors *directly connected* to black nodes. Finally, white nodes indicate someone *indirectly connected* to black nodes. All the white nodes are positioned at the periphery of the network. They do not affect the connectivity of the other nodes. Thus, we limit our analysis to those inventors (patents) selected according to the technological criterion and those inventors (patents) directly connected to them, i.e. black and grey nodes.

[Figure 2 about here]

Therefore, our final selection lead to the identification of two populations as reported in Table 4.

[Table 4 about here]

Relative to Pirelli patents and inventors it has been possible to gather more information. First, we read carefully the patent document and we classify them as MIRS or not. Second, given the list of patent, we produce a list of inventors, labelling them as MIRS inventors. We validate both of them discussing with MIRS project leader. So doing, we identify MIRS patent and the MIRS development team, that results to be composed by 15 individuals. We intend to do similarly for Michelin, in order to identify C3M inventors and patents. However, as already told, it will be not possible to validate in the same way.

4. Preliminary results

One first striking difference between the two firms is the level of connectivity as captured by the size of the *giant component*.[5] As Moody and White stress, being connected is a necessary condition for cohesion, however defined. Figure 3 displays the size of the *normalised* giant

[5] A *component* is a subpart of a network where exists at least one path linking all its nodes. In other terms, all nodes belonging to a component have to be reachable at least in one way. The *size* of a component is given by the number of its nodes. The component reporting the greatest size is called *giant component*.

components[6] for Pirelli and Michelin over the 1990s. Till 93, Pirelli and Michelin have giant component of similar size (in relative terms), starting from 1994 the two patterns diverges
In 1997, when Pirelli decidedly moves into robotized processes, it is almost three times greater: Pirelli's giant component is formed by 57 inventors, i.e. 23.9 % of its overall network. Michelin's giant component captures instead 17 inventors, i.e. 6.5 %.

[Figure 3 about here]

In the 1999, when the first MIRS pilot plant is operational, Pirelli's giant component increases of more than 100 % in size. Two years later, Michelin displays the same pattern and it reports a striking growth rate. By the end of the period considered, there is still a gap between the two: Pirelli's giant component is above 50 % greater than Michelin's.

We now compare the two firms in terms of structural cohesion at the end of the period analysed (i.e. the cumulated network of inventors 1978-2002). We apply the algorithm for calculating cohesive blocking[7] to the two giant components in 2002: Pirelli's giant component is made up of 265 inventors (58.4 %). Michelin's is 202 inventors (38.3 %). The results are displayed in Figure 4 for Michelin and Figure 5 for Pirelli. Both the figures report how the giant component is recursively broken down in more and more cohesive blocks.

Let us go through Figure 4. First, each node represents a group of individuals (the number displayed is simply an identity code). For instance: node 1, at the top of the figure, represents the original giant component. Except for node 1, the size of a node depends on the size of the group represented.[8] Secondly, nodes are displayed at different layers. An arrow linking two nodes means that the node below derives from the node above: the former is a subgroup nested in the latter. Third, at each level, for each node the algorithm identifies its level of connectivity[9] (i.e. the minimum number of inventors which, if removed, would disconnect the network). In the following stage, the algorithm breaks down each group (node), removing the inventors holding it together and it identifies the resulting subgroups (node) nested in it. For instance, in Figure 4 the original giant component is broken down in 24 subgroups (from node 2 to node 25). It is worth noting that each group is nested in all the groups preceding it. For instance, group 27 is a subgroup nested into 25, and the latter is nested into the giant component (i.e. node 1). The higher the layer to which a group belongs to, the deeper the nesting of the group into the network: "as weakly connected nodes are removed first, leaving stronger and stronger connected sets" (Moody and White 2002, p.109).

Figure 5 shows the results for Pirelli. It emerged from our preliminary analysis (which confirms the results of the qualitative study already mentioned) that one key individual appears strongly within Pirellis' network: Renato Caretta, i.e. the R&D manager who in 1997 was put in charge of developing MIRS. The black nodes indicate those groups which include Caretta. We report in red those groups which do not include Caretta.

[Figure 4 about here]

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[6] For reasons of comparability, the graph reports the size of the giant component normalised to the corresponding random network (i.e. same number of nodes and density) giant component.
[7] SAS IML programme for identifying the cohesive blocking of a network is provided by Moody himself (1999).
[8] Each node's size depends on the percent of giant components belongs to. Node 1 is not represented for figure readability.
[9] The level of connectivity of each group is not reported for figure readability.

Figures 4 and 5 present some similarities and many differences. Both giant components are broken down in many different subgroups, one of which dramatically larger than the others. Michelin's giant component (202 inventors) results to be composed by 24 cohesive blocks. However, the majority of them are cliques of few inventors, except node 25 that is a group of 94 inventors (46.5 % of the giant component). Pirelli is quite similar. The giant component (265 inventors) is broken down in 23 cohesive groups, many of which result to be cliques of a few individuals. However, Pirelli's nodes size is greater than Michelin's. Two nodes only are of remarkable size though: node 14 (which include 19 inventors, i.e. 7.2 %); and node 24 (composed by 144 inventors (54.3 %). In sum, at the second layer, both firms are characterized by a large group of inventors: it means their structure is organised around a cohesive group (the core) with other smaller groups spread around it. Yet, Pirelli's node 14 contains nested cohesive groups in it.

[Figure 5 about here]

The core of each firm can be further broken down. First, it becomes smaller and smaller removing recursively inventors on its periphery. Second, it breaks down in cohesive subgroups. However, there are many differences worth noting. The elimination of fringe inventors requires a greater number of steps in Pirelli: it takes longer to break down Pirelli's core group in non-cohesive subgroups, than Michelin's. This happens at layer 7. As for Michelin, it happens at layer 4. Moreover, Pirelli's core, which include 41.1 % of Pirelli's inventors, is formed by nine cohesive blocks. Two of them are quite large: node 45 and node 49 include 45 inventors each. That is equal to something more than 40 % of the generating node (i.e. node 42). Michelin's core (node 27), which counts for 38.1 %, is composed by seven cohesive blocks, three of which quite numerous: node 31 (18 inventors), node 33 (14 inventors) and node 34 (18 inventors). However, the most numerous cohesive block of Michelin's layer 4 counts of 23.4 of the generating node (i.e. node 27).

Finally, Pirelli's structure presents a greater number of layers. Pirelli has 19 layers while Michelin has 9. Moreover, Pirelli's node 45 and 49 result to be strongly cohesive with increasingly cohesive groups nested inside each other. Node 45, as well as the following ones, represents the core of MIRS project. At layer 7, 10 inventors out of 15 researchers composing the main group of MIRS project are present: 6 of them are members of node 45, others are members of nodes 50 and 51, both with 4 inventors. Please note that we validated the list of MIRS-related patents interviewing Pirelli's engineers.

So far, we have considered only the vertical relations among cohesive blocks. Figure 6 and Figure 7 display the horizontal relations among cohesive blocks. We focus our attention on a specific layer of the cohesive blocking of the two firms. In particular, we propose to consider the layer in which the core of each firm is broken down, respectively layer 4 for Michelin and layer 7 for Pirelli. Each figure represents the cohesive block belonging to the layer: seven node for Michelin (from node 28 to node 34), nine nodes for Pirelli (from node 43 to node 51). The size of the nodes still indicates the size of the group, while the links between nodes imply that there is at least one individual belonging to both groups. Indeed, the thickness of the line indicates how many individuals are participating in the two groups: the thin one means one inventor. The wide one means two inventors. In sum, the two figures represent how cohesive blocks overlap among each other.

[Figure 6 about here]

[Figure 7 about here]

The difference is remarkable. In Michelin's overlap network, three out seven cohesive blocks are isolated: they have no inventors in common with any other group. The other four are distributed along a path. It is worth noting that there are no overlaps among cohesive blocks at layer 6. In Pirelli's overlap network, every node is connected, directly or indirectly, with each other. The two greatest groups, nodes 45 and 49, have both the greatest degree centrality with 4 links. These two nodes are directly connected and other smaller nodes are positioned around one of the two. The overlap between 45 and 49 persists further till layer 15, since nodes 81 and 82 overlap.

We have compared the cohesive blocking of the two firms at the end of the period analysed, showing the difference in terms of integration, i.e. vertical and horizontal overlaps. In particular, we have showed the difference in terms of vertical and horizontal integration among the cohesive blocks forming Pirelli's and Michelin's giant component. The working hypothesis driving our exercise is that these differences depend mainly on the strategies of research characterizing Pirelli and Michelin in the second half of the 90s. The different capability-building strategies pursued by these two firms generated different levels knowledge integration capabilities, as captured by our data. In order to highlight these differences, we analyse carefully the giant component of Pirelli in 1997, when Pirelli has started its main effort to fill the gap with Michelin.

Figure 8 displays the cohesive blocking of the giant component of Pirelli. In 1997 it was composed of 57 inventors, i.e. 23.9 % of its overall network.[10]

[Figure 8 about here]

Similarly to Figure 5 above (which looked at 2002), at the second layer the giant component is broken down in several cohesive blocks, one of which is widely greater than the other: node 10 represents a group of 10 inventors while the other groups are cliques formed by three or four individuals. Node 10 generates recursively other 3 nodes, one inside the other until joining the deepest layer, i.e. five.

It is possible to keep this information and to report it on the network of inventors. Figure 9 represents the giant component of Pirelli's network of inventors in 1997. Each node represents an inventor (labelled with its numerical identity) and links are given by a common participation in a patent. The size (and colour) of the node is proportional to the deepest layer each inventor belongs to. For instance, nodes 160 and 15 are the greatest (and clearest in the scale of gray) nodes since they belong to the cohesive block 14 of the previous figure, while the black nodes, the smallest ones, are the most peripherical (i.e. not more than layer 1).

[Figure 9 about here]

At the centre of the figure, there are clearly four nodes composing the core of the structure: 17, 25, 15 and 160. All of them belong to layer 4 of the cohesive blocks (Figure 7), but the latter two belong also to layer 5. Two of these four individuals are particularly important, as the case study carried out by one of us has highlighted: 17 that is Renato Caretta and 160

[10] In 1997, Michelin giant component has 17 inventors, that it is equal to 6.5 %.

Maurizio Boiocchi. Starting from 1997, these two inventors follow a different career within Pirelli. The former is appointed MIRS project leader and the latter quit his technical career to acquire a leading strategic role at the corporate level, becoming the Caretta's counterpart in the top management. It is important to note the central role played by Caretta in 1997. This was before he became leader of the MIRS project.

To sum up our (very preliminary) results, relative to our working hypothesis, we get the following results:

1. Pirelli's network results more connected than Michelin's: the giant component of the former is widely greater than the latter's one. And this is clearly true from 1994 onwards. Moreover the core group within Pirelli's giant component is relatively greater than Michelin's one and it results to be more cohesive. Also, this is true from the beginning of the period, as in 1997 Pirelli's giant component is already almost three times larger than Michelin's and its structure is already organized around a cohesive core, of which Caretta is one of the members. We interpret this result as supporting the idea that Pirelli's network was, from the outset, relatively more favourable to effective knowledge transfer.
2. Both firms display a vertical core-periphery structure, but Pirelli' s is organized along more hierarchical layers than Michelin's, showing a greater number of increasingly cohesive groups nested inside each other. In this sense, Pirelli is more vertically integrated than Michelin. Moreover, as expected, one of the set of nested cohesive blocks is developed around MIRS inventors' team. MIRS' project leader (Caretta) participates in all these groups. We interpret this result as supporting the idea that Pirelli's firmly put MIRS at the centre of its new corporate strategy, and that it operated to build connections among groups of specialists traditionally used to work in isolation.
3. Pirelli is also more horizontally integrated than Michelin. Unlike Michelin, the subgroups composing the Pirelli's core have inventors in common and each of these groups overlaps with some of the others. Moreover, the overlap between the two main groups is persistent for all the level of hierarchy. We interpret this result as evidence of the fact that Pirelli developed a monitoring structure which would enable MIRS group to search in different and unrelated areas, in order to exploit, if necessary, emerging overlaps (e.g. the MIRS-CCM coupling mentioned in section 3).

5. Discussion and conclusions

To conclude, we wish to stress the limitations of this preliminary draft. First of all, we need to proceed with the cleaning of the data. While Pirelli's data have been validated down to identifying the individuals engaged in developing MIRS, their career paths, their entry and exit in the company and the specific project which developed MIRS. Michelin's data need much more attention. For example, we are still in the process of validating the identification of all core C3M patents and the related inventors. Also, we are looking for better data about the performance effects which can be attributed to MIRS and C3M. However, we believe that a few results can be put forward.

First of all, this paper has identified two related dimensions of knowledge integration: a vertical one and a horizontal one. The former hints at the need to coordinate the development of heterogeneous areas of specialized expertise through the presence of focal actors (e.g. Renato Caretta). The latter hints at the need to monitor external developments in a more decentralized manner (e.g. Renato Caretta never overlaps horizontally within the same layer).

Also, we believe we have found empirical, quantitative evidence of the processes of coupling and decoupling of interconnected elements which make up firms' non-imitable characteristics (e.g. Rivkin, 2000). While much has been said about this using simulation models, field-generated evidence is still in relatively short supply. We believe that these two firms have been caught in the effort to frame the same problem (i.e. introduce a breakthrough process innovation) in different ways, i.e. betting of very different intensity of 'coupling' among elements: Michelin bet on a rather modular and disconnected frame; Pirelli actively sought instead interconnections and coupling. Our preliminary evidence points to the fact that Pirelli's choice of coupling appears to have gone closer to the real interdependencies than Michelin's. In this respect, the role of Renato Caretta appears to stress the importance of agents bearing an overall vision of the new business model, and in so doing reorganize accordingly organizational and technological interdependencies. Goal-oriented search (i.e. Pirelli) manifests itself in a structure which is connected and both horizontally and vertically cohesive. Local search (i.e. Michelin) leaves instead traces in a network which is less connected and less cohesive.

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Tables and figures

Table 1. Major new process developments in the international tire industry.

Process	*First line open*	*Product segment*	*Integrability with existing plants*
MMP (Continental)	1997	All	Yes
IMPACT (Goodyear)	1998	All	Yes
TAIYO (Sumitomo)	2002	All	Yes
BIRD (Bridgestone)	2002	Special/All	Yes
C3M (Michelin)	1992	Special	No
MIRS (Pirelli)	2000	Special	No

Source: adapted from Brusoni and Sgalari (2006)

Table 2. The IPC groups selected

IPC	Description
B29	Working of plastics; working of substances in a plastic state in general
B60	Vehicles in general
C08	Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon
D07	Ropes; cables other than electric
F16	Engineering elements or units; general measures for producing and maintaining effective functioning of machines or installations; thermal insulation in general
G01	Measuring; testing

Table 3. Patents and inventors by selection criteria

Selection criterion	**Michelin**		**Pirelli**	
	Patent	Inventors	Patent	Inventors
Technological Content	700 (93.7)	510 (92.4)	415 (48.9)	326 (46.4)
Directly connected	27 (3.6)	17 (3.6)	186 (22.4)	128 (18.2)
Indirectly connected	-	-	93 (11.2)	68 (9.7)
Not connected	20 (2.7)	25 (4.5)	137 (16.5)	180 (25.6)
Total	747 (100)	552 (100)	831 (100)	702 (100)

Table 4. Inventors and patents selected

	Michelin		**Pirelli**	
	Patent	Inventors	Patent	Inventors
Selected	727 (97.3)	527 (95.5)	601 (72.3)	454 (64.7)
Excluded	20 (2.7)	25 (4.5)	230 (27.7)	248 (35.3)
Total	747 (100)	552 (100)	831 (100)	702 (100)

Figure 1. The 'organization' of MIRS vs. traditional tire manufacturing

Traditional process			MIRS		
Activities	**Responsible**	**Duration**	**Activities**	**Responsible**	**Duration**
Initial tire design	Product engineer	One day	Initial tire design	Tire designer (single point of responsibility) + specialists (e.g. mould designers)	One day
Initial design of components (e.g. sidewall)	Product engineer				
Choice of materials	Product engineer		Choice of materials		
Tire design: sizing, tread, etc.	Product engineer		Tire design: size, tread, etc. Definition of building process. Final design of components		
Definition of building process	Process engineer	One week			
Final design of components	Process engineer				
Building, phase 1	Plant operator	Two/three days	Building	Plant operator	Half a day
Building, phase 2	Plant operator				
Vulcanization	Vulcanizer operator	One day	Vulcanization		

Figure 2. Pirelli - Giant Component 2002. Inventors partitioned according the selection criteria

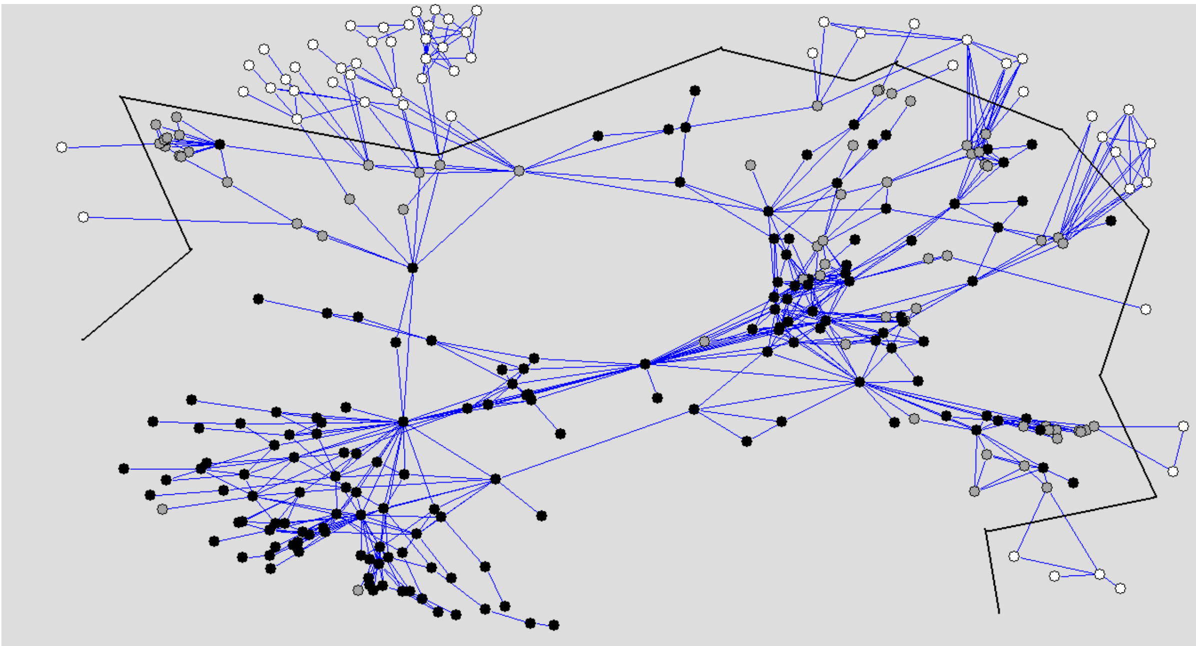
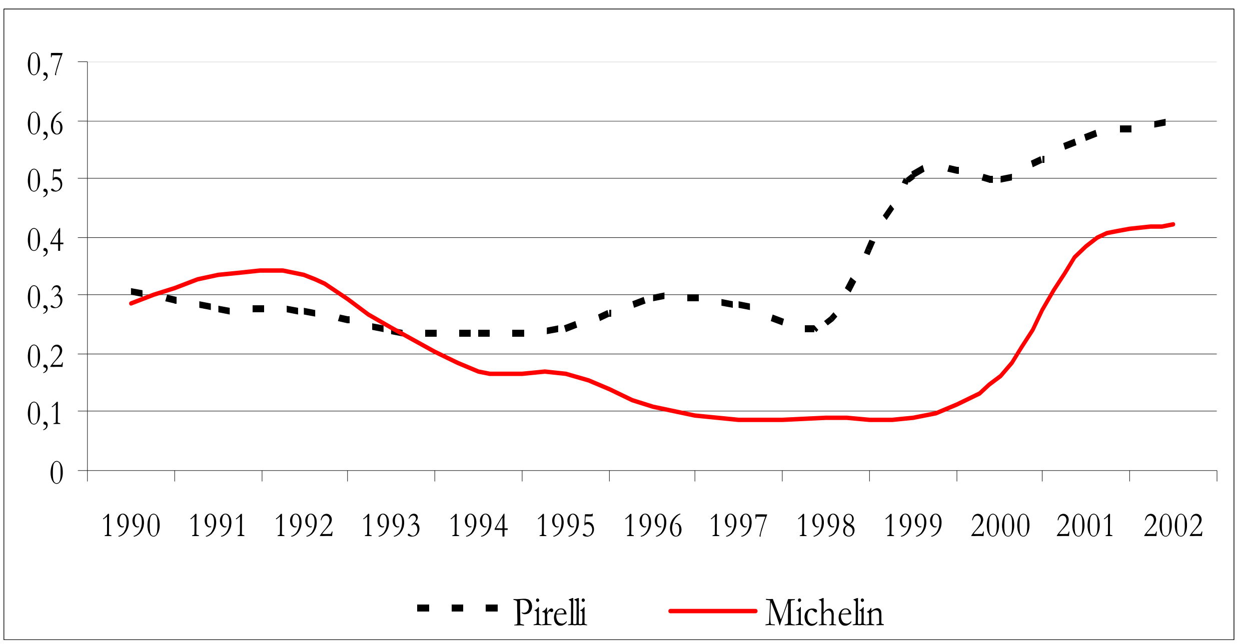


Figure 3. Michelin's and Pirelli's giant component size (percent of inventors)



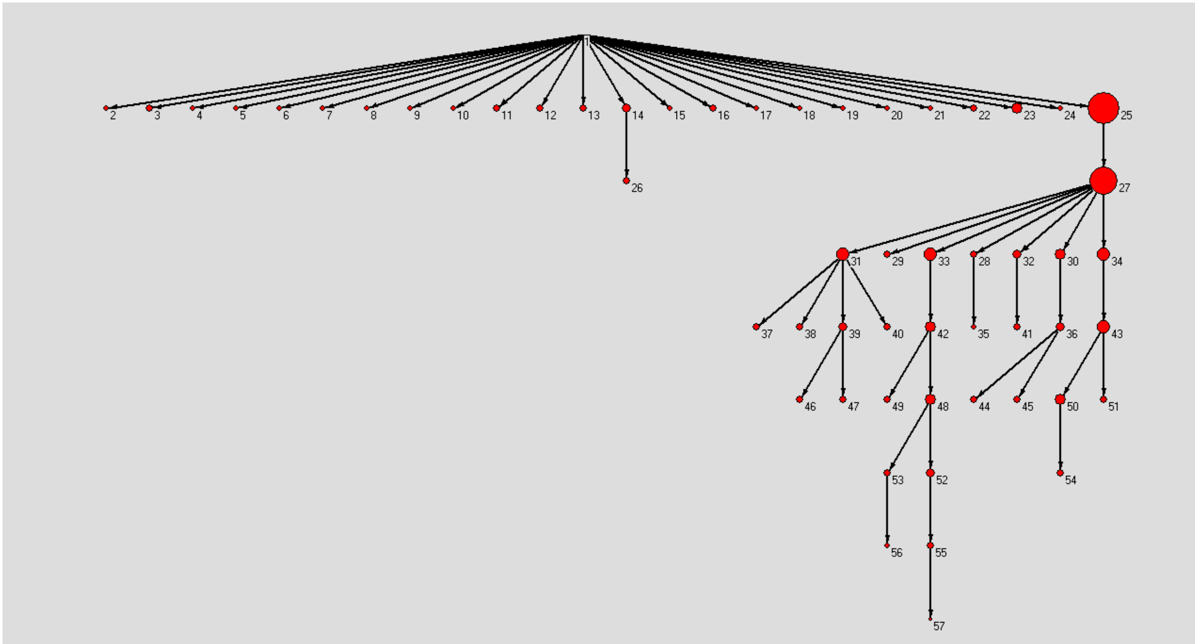


Figure 5. Cohesive Blocking for Pirelli's giant component 2002

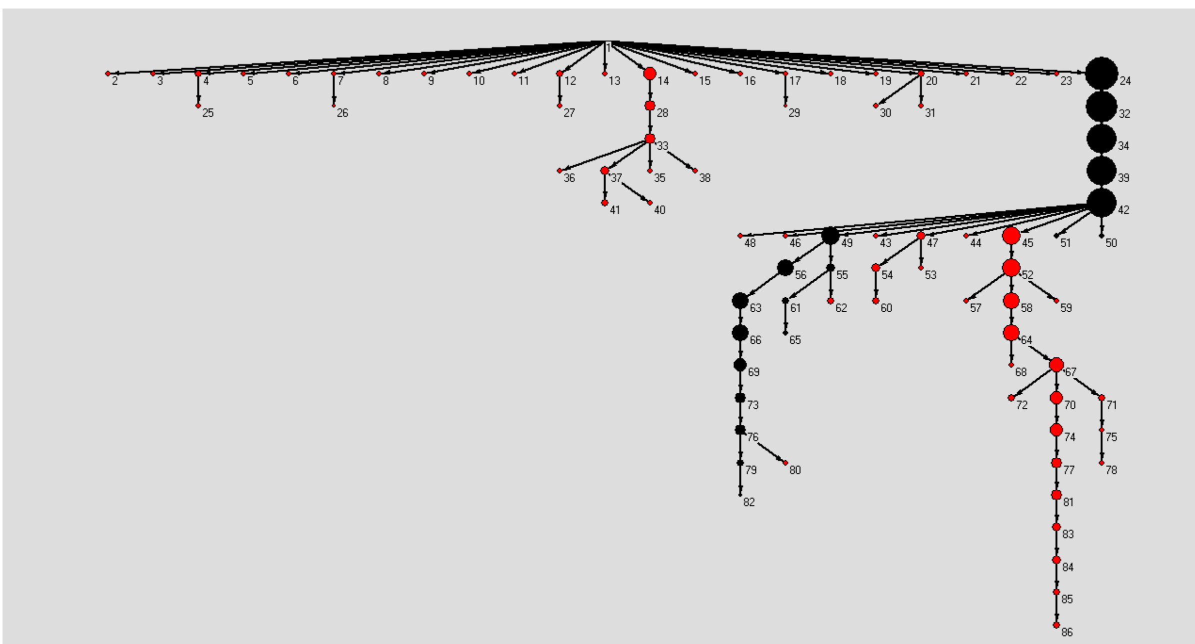


Figure 6. Overlap among blocks within Michelin's layer 4

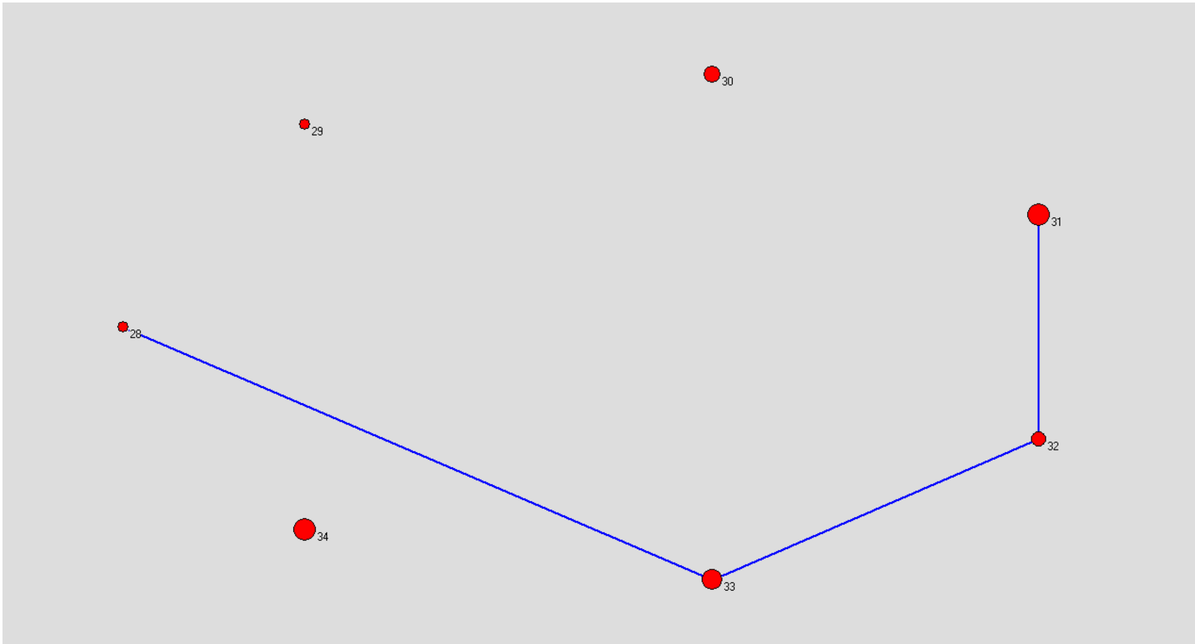


Figure 7. Overlap among blocks within Pirelli's layer 7

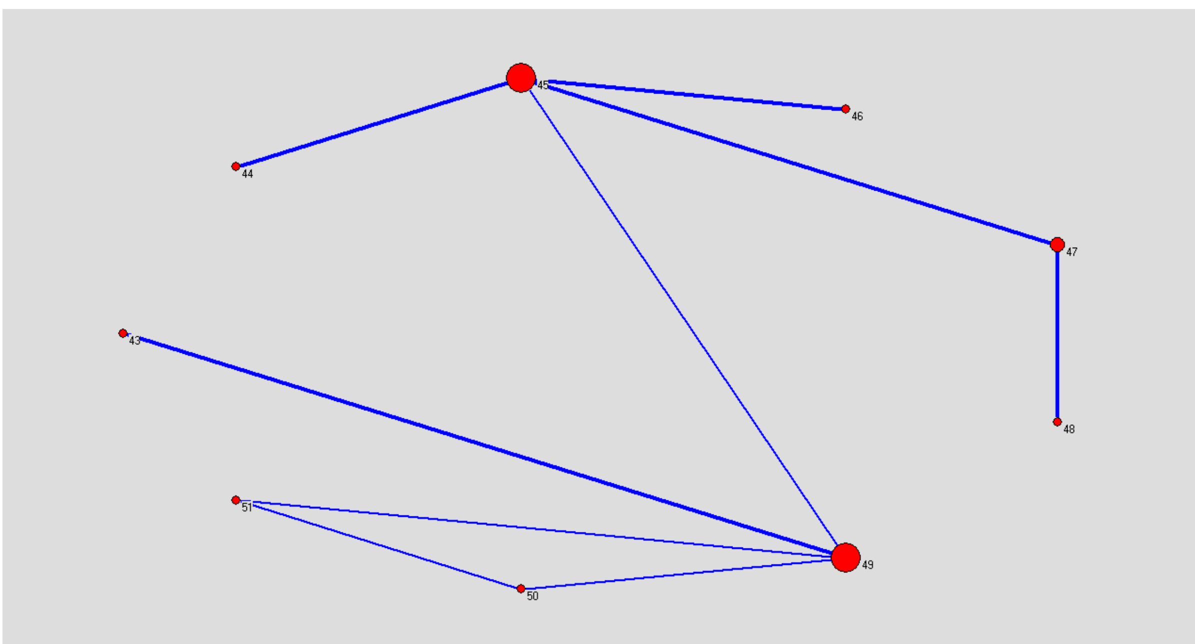


Figure 8. Cohesive Blocking for Pirelli Giant Component 1997

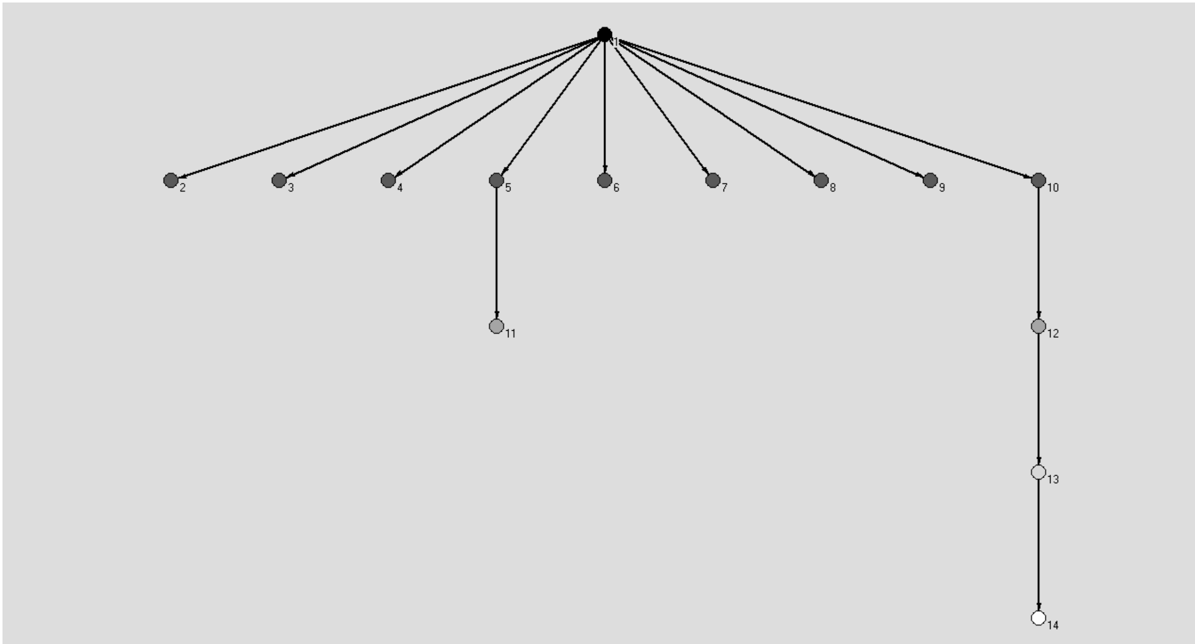


Figure 9. Pirelli - Giant component 1997.
Size and colour corresponding to the layer level as displayed in Figure X.