

Master's Degree in Management – International Management

Final Thesis

# KNOWLEDGE SOURCING IN THE AUTOMOTIVE INDUSTRY: A PATENT-BASED ANALYSIS OF INDUSTRY 4.0 AND RELATED TECHNOLOGIES

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## Introduction

From the dawn of humankind, the most basic forms of technology have revolutionised daily lives and habits. The wheel, generally known as the architype of a primitive technology, allowed ancient civilizations to transport people and goods across long distances, affecting the socioeconomic dynamics of the time. Society gives purpose to technology, for technology is made to help man. Throughout the centuries, the symbiotic union of society and technology has made the production of food and other necessities more efficient, improved medical treatments and enabled better communication and mobility worldwide. Yet, the future still holds an untapped potential for growth, especially in the area of digital technology. Digital devices continue to permeate every area of our lives: they have become immersed in our routines, influencing the way we work, our communication, and consumer behaviours (Piccinini et al., 2015). It has even been suggested that digital technologies are defining a new industrial revolution, which is building on the Third and has been occurring since the middle of the last century. Many authors, however, are sceptical about the magnitude of the changes about to come. According to them, some components of technologies related to the so-called Industry 4.0 were already present 30 years ago. Most notably, since the Digital Revolution is being identified before it happens, all results or effects are forecasts, assumptions or projections (Klingenberg and Antunes, 2017).

Digitization has become one of the trendiest topics in businesses (Lorenz et al., 2020). The transition towards "smart" factories, and the deployment of connected objects in transport (autonomous vehicles), energy (smart grids), cities, healthcare, agriculture and many other fields, is under way, and promise to profoundly change the current organizational schemes of these sectors (EPO, 2017). Furthermore, new technologies are increasingly catering to the personalized individual needs of consumers to connect the physical with digital world, making industries worldwide experience a differentiation of quickly changing demands (Piccinini et al., 2015). To lead rather than follow these trends, leading firms must become more agile and much better attuned to customer needs, to avoid facing the same fate as failed companies in some digitally disrupted industries such as telecommunications, media, and consumer electronics.

Being at the forefront of the latest technological advances is a hard challenge. First of all, the implementation of a more dynamic, startup-like mentality is needed to be able to react rapidly to changes in the ecosystem, the infrastructure, and the resource composition (Piccinini et al., 2015). A number of companies across sectors – many of which have been on business for a century or longer - are struggling to adapt, because their business models have historically been slow to evolve (Wyman, 2017). What is more, in a digital context, knowledge is spread across heterogeneous disciplines and domains, and no longer concentrated in the hands of a few specialized firms. The exponential growth and development of Industry 4.0 technologies, as well as their variety and embedded complexities, make it extremely difficult for firms to keep abreast of all new opportunities for innovation (Lorenz et al., 2020). It is no longer feasible to own all the R&D outputs that can have a significant effect on products, services, and manufacturing processes and procedures. This implies a heavy reliance upon the external sourcing of technology over which firms have less – or no – mastery. By all means, this is not a new issue. Starting from the late 1990s, research has increasingly questioned the assumption of "local search", according to which a firm's innovative effort is closely related to its previous R&D activity, and emphasized the ability to move beyond boundaries to maintain a competitive advantage (Rosenkopf and Nerkar, 2001). In 2003 Chesbrough introduced the term "open innovation" to refer to a new model for industrial innovation, which assumes that firms use external as well internal ideas, and external and internal paths to the market, creating a more extensive, collaborative, and engaging environment with a wider variety of participants. Hence, digital trends are accentuating the need for the implementation of external knowledge sourcing practices, which, however, began to spread long before the emergence of Industry 4.0. What is more, Big Data analysis provides a great technological chance to grasp valuable information that has been hidden until now, thus sustaining most of the benefits of the open innovation paradigm. It enables organizations to access and handle big volumes of new data from multiple sources, especially sources outside the usual firm boundaries, and to select advanced analytic tools that help predict outcomes of business decisions. (Wyman, 2017). In this sense, Industry 4.0 technologies serve both as an input accentuating the need for external search, and a valuable tool to access information from diverse contexts.

This thesis focuses on the automotive industry, which is a typically complex technical environment, where the cooperation in knowledge creation is very extensive (Agostini and Caviggioli, 2015). Over the last decades, as a result of technology evolution, globalization, and sophistication of customers' preferences, a trend toward Open Innovation has taken on greater saliency in the automotive sphere (Ili et al., 2010). The enlargement of the car's technological components and the rise of new trajectories have expanded the set of

knowledge and resources involved in the innovation process of the automotive sector, often requiring the combination of technologies from other industries (Trombini and Zirpoli, 2012). The traditional mindset of generating and exploiting innovation seems to have reached its limits, and carmakers, who have historically invested in their own R&D to boost innovativeness, have turned to new sources for help in achieving innovations goals (Ili et al., 2010). In particular, carmakers established a large number of external ties with suppliers, which handle the design, purchasing, and production of all components in a complex module.

According to many, the automotive industry is now at the forefront of the Industry 4.0. Over the last years, the amount of digitalization in and around the vehicle has increased, substantially altering dynamics in markets and forcing automakers to find a balance between the digital trends and their established competences and assets that relate to the physical world (Hanelt et al., 2015). Changes are gaining speed, impacting business models, product portfolios and required employee skills. While on the supply side digitalisation is expected to generate strong productivity growth, the redefinition of the nature of the automobile from a status symbol to a device for digital experiences threaten OEMs' business models (Hanelt et al., 2015). In fact, car manufacturers have a long tradition in satisfying a basic human need, i.e. mobility, while now transportation infrastructure is facing a growing diversity of consumers' requirements, such as information, responsibility, safety and digitally enhanced mobility experiences (Piccinini et al., 2015). Old-line car manufacturers are facing pressure from many sides, not only in new expansion areas, but also in their core business. New entrants, by leveraging technological innovations and non-automotive mindset, are setting up to capture future businesses and threatening to erode incumbents' market share.

Few other industries with such a pervasive and tangible impact on our lives have gone through recent periods of similar upheaval. In the most dramatical picture, within some decades self-driving electric vehicles, organised into an Uber-style network, will be able to offer such cheap transport that people will decide they do not need a car anymore.

The impact of digital transformation on automotive organizations is difficult to assess, as its characteristics largely deviate from those that have been the focus of most investigations of Industry 4.0 so far. That is to say, unlike other industries that have experienced digitalisation, such media and music industries, the automotive sector's core product, i.e. the car, cannot be fully digitized (Piccinini et al., 2015).

In light of these considerations, the aim of this work is to investigate how OEMs are proceeding to bridge their competence gap, and to source digital knowledge. A recent series of announcements, indeed, suggests that carmakers, aware of the importance of upcoming change, are making some efforts to prepare for it. Confronted with an environment going through significant technological change, leading companies in the automotive industry are rethinking traditional forms of cooperation, and set up cross trades and sectors relationships in constantly evolving production modes (Attias and Mira-Bonnardel, 2017). To study this topic, we often draw on the concept of disruptive technological innovation, as it provides valuable frameworks to comprehend which challenges the digital trend is bringing about for automakers. However, our purpose is not to assess if 4IR technologies truly have the potential to disrupt the industry, yet to describe the direction and the extent of knowledge flows in the automotive sector, as far as Industry 4.0 is concerned.

The elaborate is structured as followed. The first chapter provides the theoretical background needed to analyse the issues introduced above. Accordingly, it deals with technological evolution at the firm and industry level. The first section is dedicated to the innovation process within organizations, which is described as complex, uncertain, somewhat disorderly, and exposed to changes in the surrounding environment (Kline and Rosenberg, 2010). Despite the unpredictability of the ways in which technological advancements occurs at a firm-level, the literature has emphasized that, at an industry-level, technology tends to follow a standard path of evolution. In particular, Foster (1986) demonstrated that the pace of performance improvement of a new technology typically conforms an s-shape curve. Utterback and Abernathy (1975), instead, proposed a framework that expands upon the s-curve and characterizes the periods of the technological cycle. The second part of the chapter fixes attention on the theme of "disruptive" technological innovations, which is crucial to grasp how emerging technologies can sometimes lead to a breakdown of industries' competitive patterns, and eventually to the dismission of established players. The last paragraph is completely centred on the paradigm of open innovation, and to the related external knowledge sourcing.

The second chapter focuses on the automotive sector, to depict the structure of the industry and the dynamics that dominate its competitive panorama. After having presented a chronological timeline of the major innovations that shaped the sector and made it what it is today, the emphasis will move on the innovation process, to explore the evolution of the knowledge base and the division of the innovative labour that took place over the last decades. The final part of the chapter directly dealt with the new technologies that are causing disturbance to the industry players, grouping them into four megatrends as proposed by a KPMG report (2017): electrification, autonomous driving, shared mobility and

digitalisation. It will be show that Industry 4.0 is part of a wider storm of changes that are bearing down on the sector.

The third chapter enters the heart of the matter. After having discussed the main questions involved in the debate about the Fourth Industrial Revolution, a comprehensive examination of the impact of Industry 4.0 will be offered, considering both the implementation of digital technologies along the automotive supply chain and its applications in the end product. The last part of the chapter aims at comprehending which challenges the digital trend is bringing about for automakers. In particular, it will be show that the emerging mobility paradigm has created a new innovation momentum, obliged car makers to approach new forms of cooperative partnerships, and, with the arrival of new entrants, led to a reorganization of the entire industry (Attias and Mira- Bonnardel, 2017).

The chapter four intends to describe empirically the sources used by OEMs to tap into external knowledge. At this purpose, a patent-based analysis has been performed, which is structured into two areas of research. The first section focuses on focal firms' external innovative search effort as reflected in patent citations, emphasizing first the search along technological domains, and then the variety of sources used by OEMs, such as suppliers, competitors and potential new entrants of the industry. Instead, the second part of the chapter will exploit the phenomenon of patent co-assignment to detect any trend in the R&D partnering activities of automakers, our focal firms.

#### I. Technological Evolution at the Firm and Industry Level

Today's fast-changing and often chaotic business environment places a premium on innovative capabilities of firms; in many industries, technological innovation is the most powerful mean to gain, and maintain, a competitive advantage. The introduction of new and differentiated products and services helps firms to protect margins, while the investment in processes enables them to reduce costs. In the era of globalisation and with the advent of knowledge economy, these positive effects are amplified, and the pace of innovation is dramatically accelerating (Schilling, 2017).

Globalisation represents for companies both an opportunity and a threat; on the one hand it has expanded the pool of suppliers and customers, on the other it has torn down competition's borders. The lowering of international trade barriers has indeed forced organizations to confront not only with national competitors, but also with foreign ones. Customers' needs and requirements are changing, and firms need to keep up with them (Schilling, 2017).

In various industries, profitability relies substantially on products developed within the last years, as exemplified by Figure 1.<sup>1</sup>



Figure 1: Share of New Products and Imitation Innovation on the Total Revenue of the Automobile Production Industry in Germany from 2008 to 2018

<sup>&</sup>lt;sup>1</sup> The graph yields the results of The Annual German Innovation Survey, a contribution to the European Commission's Community Innovation Surveys (CIS), coordinated by the Statistical Office of the EU (Eurostat, 2018).

The figure shows the percentage of the total revenue of the German automobile production industry attributable to new products and imitation innovations (namely new products of a company which have already been offered by other companies at the time of introduction). Another confirmation of the significance of newly introduced products comes from a really different industry. Adidas, ranked on Boston Consulting Group's most innovative companies list for 2019, attributes the majority of its sales to new offers. According to the Annual Report of 2019, products launched during the course of the year accounted for 77% of adidas brand sales and for 67% of Reebok brand sales (Adidas, 2019).

However, while it provides exceptional opportunities, innovation also comes up with steep challenges. In the fierce competitive environment of the modern world, companies must run their activities with speed, skills and precision. The lack of innovation not only impedes firms to thrive, but it can also cause their business to slump. A striking example of the failure to innovate is represented by Blockbuster, one of the largest DVD rental companies ever. The company was founded in the 80s, and in some years, it managed to become the leader of the industry, enjoying a worldwide success. At the turn of the century, Internet and subscription services emerged to challenge its business model. At the time, Blockbuster made a series of poor choices and mistakes, that led it to the bankruptcy. Instead of focusing on new media and new competitors, the company started to expand into the videogame rental market and employed various programs to promote instore rentals. The decision of passing on the acquisition of Netflix provides the evidence that Blockbuster never envisioned a future for streaming and mailing platforms.

This chapter has been carried out through a review of the literature on the topic of technological innovation and it is organized as follow. The first section will focus on the patterns of technological development both at the firm and industry level. Having discussed the importance of technological innovation for organizations in the modern world, it is useful to focus on the processes through which innovation has traditionally occurred within organizations. At the same time, models explaining the evolution of a technology provide valuable tools and techniques to predict timing, performance or rate of diffusion and are used widely by organizations to manage technological changes. If managers are able to understand and harness innovation dynamics, rather than fight them, they may succeed in embracing new technological introductions (Christensen, 2003).

In the second paragraph the attention will be moved on the concept of technological discontinuities or disruptive innovations. Different perspectives about the motives beyond the failure of big firms when confronted with such changes will be introduced. Built on the

concept of "creative destruction" (Schumpeter, 1942), and expanding upon the cyclical theory of technology evolution (Utterback and Abernathy, 1975), various theories questioned which features of emerging technologies enable them to provoke such an alteration of competitive dynamics.

Lastly, the third paragraph stresses the role of knowledge in the innovation process, which serves both as an input and an output. The knowledge needed for technology development and improvement may be obtained from a variety of sources. It will be shown that in recent decades more and more organizations have moved from the traditional approach of "local search" (Nelson, and Winter, 1973), to an "open innovation" strategy (Chesbrough, 2006) by leveraging internal and external knowledge development in parallel, so as to hone their innovative capabilities.

#### **1.1 The Concept of Technological Innovation**

Over the last decades innovation has become a key concept in society. As the importance of innovation as an engine of economic and social change grows, the research on its nature, role and determinants is proliferating. However, the discipline of innovation has a much longer history. Economists have long wondered how innovation can affect the profitability of organizations, and their position in the market. Furthermore, they tried to identify the external factors that promote, or hinder, a firm's ability to innovate, as well as the macroeconomic effects of innovation on an industry, or economy. Joseph Schumpeter is often thought of as the pioneer in this field. He was fascinated by the innovative role of the firm, and by the way in which innovation was carried out under the direction of the entrepreneur. In the theories developed by the Austrian born thinker, innovation signified change, disequilibrium; he coined the term "creative destruction", to refer to the evolutionary process "that revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one" (1942, p. 83). Thus, organizations that do not innovate lose market share and are eventually driven out of business. In his writings, he did not use the word "innovation" as a synonymous of "invention", but instead defined it as the materialization of new ideas on an economic level. The distinction between the two terms is indeed a key point of the notion of innovation, and the element that the various definition in the literature have in common (Kline and Rosenberg, 2010). On the whole, innovation is described as something that adds value, and it is considered to have occurred if it has been implemented or commercialised in a way. Although it generally originates from knowledgebased activities that involve the application of existing or newly developed information, the creation of abstract knowledge is not considered innovation until it has been put in use or made available for use by others.

Industrial organizations are the primary engine of innovation. Due to the reasons stated above, firms face strong incentives to develop differentiated new products and services. What is more, they generally are equipped with instruments and a management system to marshal their resources toward an innovative purpose (Schilling, 2017). Nevertheless, it has been proved that innovation is not the sole prerogative of the business enterprise sector, but it can come from many different sources. The same definition provided by the Oslo Manual uses the generic term "unit" to refer to the actor responsible for innovations, thus including in the group any institutional entity, as households and their individual members. In particular, the source of innovation varies significantly between categories of innovation; in some fields, conventional wisdom holds and product manufacturers are indeed the innovators, but in many others, innovation users or suppliers of innovation-related components and materials are the sources (E. von Hippel, 1998). In addition, public research institutions such as universities, government laboratories and incubators, as well as private non-profit organizations, play a salient role in boosting innovative effort. The knowledge activities performed by these actors often provide companies with the information needed to develop a technology that they would not have otherwise developed.

There are different ways in which an organization can innovate. As regards this point, the Frascati Manual (2002) clarifies that technological innovations comprise new products and processes and significant technological changes of products and processes, thus establishing a basic distinction between "technological" and others innovations. Non-technological innovation applies to new or improved organisational structure, marketing method or management technique, undertaken by a firm.

Product vs process innovation is a popular dichotomy in the stream of research aimed at classifying the heterogeneity of technological changes. While product innovation is embodied in the output of an organization, process innovation concerns the way an organization conducts its business. The former type can refer to the improvement of performance, additional or different features, or the introduction of a completely new device. Though these modifications are often more visible than process innovations, especially to customers, it must be stressed that both are needed for an organization to achieve a competitive advantage. Process innovations may instead incorporate changes in techniques, equipment and software, oriented toward the improvement of the effectiveness or efficiency of production or delivery methods. For example, they can be intended to decrease unit cost or increase the quality by reducing defect rates (Shilling, 2017).

The last noteworthy dimension of the concept of innovation is novelty. According to the Oslo Manual (2018), the words "new" and "improved" are related to the uses of an innovation and are determined by the features of the new product or process compared to the alternatives or by the previous solutions. For example, a firm's implementation of a procedure being used by others still represents an innovation for that firm. Therefore, the diffusion of existing knowledge, as well as the development of new one, are both involved in the concept. Novelty is sometimes difficult to ascertain, because of its intrinsically subjective characteristics.

#### **1.2 Evolutionary Patterns of Technology Development**

The evolution of an innovation is complex, uncertain, somewhat disorderly, and exposed to changes in the surrounding environment. Thinking about technological advance as a smooth and linear process that starts with scientific discoveries and ends with a widely adopted commercial product can be misleading (Kline and Rosenberg, 2010). In its early stages, a new technology is indeed very crude and primitive, and the same inventors do not have a defined idea of its usefulness (Kline and Rosenberg, 2010). Different paths of improvement are explored, until the researchers gain a deeper understanding of the invention and its potential. The identification of a commercial use and the subsequent introduction of a product based on the technology is adopted by more and more users, who, in turn, work to further increase the performance. The subsequent improvements after its first introduction may be vastly more important than the invention itself; sometimes innovations go through rather drastic changes that partially, or totally, transform their economic significance (Shane, 2009).

Because of these reasons Kline and Rosenberg (1986) have recognized that the model describing innovation process that has been generally accepted since World War II distorts the reality. The so called *"linear model"*, in the attempt to impose a conceptual order, places research activity at the starting point of the process; the results then lead to development, development to production, and production to marketing. However, the framework lefts no room to feedbacks paths within the ongoing work of development. Feedbacks, and

consequent follow-on actions, are instead an inherent part of the process: they are an essential tool to assess the performance and formulate the next steps forward. Furthermore, in a world of inadequate information, uncertainty and fallible people, any learning process unavoidably involves shortcomings and failures; yet these present inconvertible opportunities to improve. On a final note, the authors argued that common wisdom, according to which innovation is initiated with research, is wrong most of the time. There are a few cases in which research sparks innovation, as happened in semiconductors, but generally the pressure to innovate is the result of direct feedbacks or perceived needs. Besides, the improvements that are applied after the first stage of invention, may involve little or no science. Thus, innovation ought to be conceived as a process of learning through cumulated experience.

The evolution of a technology depends on the process through which scientific advance occurs (Dosi, 1982). Achievements in the development of new physical devises and new techniques take place within a defined problem-solving activity; researchers have a propensity to seek answers to current technical problems, building on past attempts and past solutions. Technological "knowledge" is in fact assumed to be cumulative, since external and past contributions, feedbacks and trials, serve as building blocks for subsequent developments. Moreover, it is much less articulated than science, since large part of it is not written down and is implicit in experience and skills (Kline and Rosenberg, 2010). Thus, scientist and engineers proceed following frameworks, or paradigms, that determines the field of inquiry, the procedures and the tasks and provide a beneficial focusing effect on research. This tendency leads to the creation of technology trajectories: "the pattern of "normal" problem solving activity determined by a paradigm" (Dosi, 1982). Firm-level trajectories shape, and are shaped by, trajectories of other organizations and of the overall evolution of a technology (Rosenkopf and Nerkar, 2001). The trend toward smaller and more powerful microprocessors in the computer industry is one of the most recognizable examples of a technological trajectory. In 1965 Gordon Moore, co-founder of Intel, stated that the number of transistors in an integrated circuit doubles about every two year at the minimum cost for the component. His prediction was soon widely accepted and set targets for the industry's research and development.

According to Rosenkopf and Nerkar (2001), technological evolution of a product class might be seen as the aggregation of variation, selection, and retention trajectories undertaken by all firms working on that product class. This interdependence among firm-level trajectories, implies that the knowledge generated by a firm is assimilated by other

firms. In the personal computing area, for instance, first IBM and subsequently Microsoft had a major impact on the overall evolution of the product class, as organizations in the industry recognized the knowledge they established and build upon it. In the late 1980s, most personal computers carried the legend "IBM compatible", while during the 1990s, both software and hardware underlined compatibility via Microsoft's Windows operating systems.

Besides, knowledge may have an impact beyond its focal technological domain, too (Rosenkopf and Nerkar, 2001). Anecdotally, both Xerox PARC and Bell Laboratories are acknowledged as entities that discovered technologies with implications far beyond the traditional markets of their parent companies.

However, the conditions of concern in innovation are not purely technical; they are rather strongly intertwined combinations of the social-economic and the technical systems (Dosi, 1982). Alterations in the micro and macro environment in which innovation takes place heavily affect its development. Economic incentives allocated to boost technological progress intensify the rewards for development to go in certain directions and not in others. Similarly, the process is likely to develop in ways consistent with society's rule, that strictly depend on political forces. People, with their fears, motivations and attitudes, are at the heart of technological evolution and lead the process move toward things they are supportive and accepting of and away from things they are afraid or intolerant of (Dosi, 1982).

Paradigms imply the presence of perceptions on the directions of technical change to pursue and those to neglect. They have a powerful exclusion effect: research is focused on precise options, thus limiting the set of notionally possible solutions. Keeping organizations from identify fundamentally different, and better, alternatives is perhaps the most significant downside of technology paradigms (Dosi, 1982). Especially when a trajectory is powerful, it could be difficult to switch to another one. Paradigm shifting technologies are generally met with scepticism and reluctance, as they threaten to fundamentally alter the ways in which researchers operate. Unfortunately, innovators are often unable to realize in advance if the resistance toward a new technology is due to its intrinsically disruptive nature, or if it is just inadequate or pointless. It is typically the market that makes an ex post selection of devices and techniques which have overcome previous stages (Shane, 2009).

Notwithstanding the unpredictability of the innovation process, and the myriad of variables that comes into play shaping its dynamics, empirical studies have shown that the

pace of performance improvement of a new technology typically conforms an s-shape curve, as displayed by Figure 2 below<sup>2</sup>.



Figure 2: S-curve of Technology Performance

The innovative activity that gives birth to a technology is followed by a long phase of modifications and advancements, which characterizes the lifetime of the technology until it falls into disuse or is replaced by a newer device. In the early stages, improvements per unit of effort are small because technology and the key drivers of its performance are poorly understood by scientists and engineers. They spend many resources to explore different path of development, proceeding by trial and errors and often hitting dead ends. In the case of cutting edge-technologies, which are by definition very different from prior devices, researchers may not be provided with tools or evaluation routines to measure the ongoing progresses. Moreover, until the technology has established a degree of legitimacy, it might be hard to attract other organizations to participate in its development (Foster, 1986).

Once the key drivers of performance are identified and firms have gained a deeper understanding of the fundamentals of the technology, the pace of improvement tends to increase. In this intermediate stage, small amounts of effort yield large performance improvements. While these developments can continue to accelerate for a while, at some point the technology reaches its inherent limits, diminishing returns begin to set in, and the curve flattens. That is, the cost of each marginal improvement increases, hindering further

Source: Foster (1986)

<sup>&</sup>lt;sup>2</sup> The graphical representation is obtained by comparing some measures of performance (for instance, cost, capacity, or speed) with some measure of effort (for example, R&D expenditure, or personhours devoted to research).

advances. At this time, a new technology generally turns up to challenge the existing one. The radical, discontinuous innovation typically fulfils the same market need of the previous one but does so by building on an entirely new knowledge base. From time to time, technologies do not even get the opportunity to reach their limits; they may be rendered obsolete before the time by the advent of a radical innovation. As the new technology improves, customers shift to it. Once it surpasses the existing device on the dimensions that users value, the new technology takes off, and the old one goes into decline (Christensen, 1992).

Development process for technologies which are radical in nature diverts from the process for continuous technologies. Incremental improvements, upgrades and line extensions along an S-curve rely on prior advances and take place within established paradigms. Hence, incumbent firms are more likely to develop these types of progresses, as they have financial resources, and technical, market, and organizational capabilities to improve the technology. Conversely, new entrants tend to be the ones that bring new, gamechanging technologies into an industry, thus shifting the S-curve. Foster (1986) has stressed the tendency of leading firms to reinforce mature technologies and has cited the failure to spot successor technologies as a primary reason why they eventually lose industry dominance. In spite of the fact that experienced organizations often explore new solutions when the core technology with which they are working approaches its limit, they rarely switch to newer solutions in a timely way. In early stages, the performance of the new technology is in fact inferior to the performance of the current one, and effort invested in the existing technology still reap higher returns. Besides, to adopt a new technology, incumbent firms should write off their investments in the prior solution. This is self-defeating especially when a new technological device threatens to cannibalize existing sales. In such a case, the switch to a new technological method generates additional costs, but no extra revenue, making it financially unattractive.

In other instances, it may occur that leading firms not only are reluctant to shift, but are not even able to recognize in new technological regimes a threat. As a result of best practices and established routines within an organization, managers tend to filter out information about alternatives to their technologies, in order to keep the focus on their core activities. In doing so, they bypass, ignore, or misjudge the potential of a substitute that is raising from below at a more productive rate (Chandy, and Tellis, 2000). Furthermore, since structural changes are usually required to fit the new technology, conflict of interests may arise among managers. In other words, they deliberately resist the shift, concerned about losing their political power or influence (Chandy, and Tellis, 2000).

Utterback and Abernathy (1975) proposed a framework that expands upon the scurve and characterizes the periods of the technological cycle. They observed that each industry, during its evolution, crosses distinct stages. Early in the life of a new technology, industry expansion and redefinition results in a high rate of changes and competitive improvements. During what is called the *fluid phase*, there is a great product diversity among players, as a response to ill-defined market needs and customers' preferences. Process is extremely uncoordinated, with loose and unsettled relationships between elements. Such a system responds quickly to external stimuli and changes, but necessarily has drawbacks. In this period of uncertainty and turbulence, a high number of firms enter the industry, while the rate of firms exit remains low. This makes the fluid phase composed of a large number of players, both small new entities and older enterprises entering a completely new market.

As an industry and its product group mature, market uncertainty is gradually reduced and customers began to develop preferences. As the unit moves toward large-scale production, the emphasis is laid on process changes, which are likely to be discontinuous innovations that introduce new methods of organization. Production is increasingly designed for efficiency, with tasks that become more specialized and subject to more formal control. Such a stage of the cycle is defined *transitional* and comes to an end when producers and customers arrive at some consensus about desired product attributes and converge on a dominant design.

The establishment of a stable architecture on which firms focus their efforts provokes a shakeout of the industry structure as it consolidates around the few businesses that are able to adhere to the agreed-upon format. The period is termed *specific phase* because innovations, both in product and process, are specific to the dominant design. The overall system becomes rather rigid: production is highly specialized and tightly integrated through automation, and organization structure hierarchical and bureaucratic. This, together with high investment in specialized long-lived assets, make changes very costly, because a modification at one level works its way up and down the chain, and must be dealt with as a system. The specific phase is most favourable to large organizations, which can exploit economies of scale and pursue a cost-minimizing strategy. Experience that established firms have gained in manufacturing, selling, and customer service constitutes an entry barrier that impedes new players to enter without operating at a severe competitive disadvantage.

#### **1.3 Disruptive Technological Innovation**

The cited Blockbuster's case is not a one-off; the list of leading companies that failed to stay atop of their industries when confronted with new technologies is a long one.

Following Schumpeter's (1942) concept of creative destruction, the literature has characterized different kinds of innovations in terms of their impact on the established firms and on industries structure. The distinction between improving practices in use and introducing a new concept that span beyond existing boundaries has become one of the central notions in the literature on technological innovation (Christensen, 2013). While various terms have been invoked to refer to ground breaking introductions, and different bases have been uses to determine the "radicalness" of an innovation, it is generally agreed that disruptive technologies undermine the capabilities of dominant competitors and can be the premise for the entry of new firms or even the redefinition of an industry (Christensen, 2013).

Several theoretical frameworks have been developed to elucidate under what circumstances discontinuous technological change is likely to result in the demise of incumbent firms. According to Bergek et al. (2015) the diverse explanations are built upon the common assumption that leading firms are burdened with the legacy of old technological regime. When discontinuous innovations occur, the existing values, norms and structures upon which they traditionally have built a competitive advantage in the specific phase (Utterback and Abernathy, 1975), turn into rigidities that undermine their ability to innovate. Therefore, radical innovations may open up possibilities for new entrants. Traditional literature has emphasized that the creation of ground-breaking technologies is usually carried out by new firms or entrants from other industries, while the incumbents undergo the "destruction" (Bergek et al., 2015).

Theoretical models that have been employed to define the main competitive challenge for incumbents can be classified into two currents of research: some of them fall into competence-based explanations of incumbent failure, while others can be seen as market-based explanations (Bergek et al. 2015).

#### 1.3.1 Competence-based Explanations of Disruptive Technological Innovation

Competence-based explanations assume that the competitive outcomes of a discontinuous innovation depend on its impact on firms' existing resources, skills and knowledge; while some innovations improve existing technological competences and

capabilities, other make them obsolete (Bergek et al. 2015). Anderson and Tushman (1990) label these types "competence-enhancing" and "competence-destroying", respectively. The former builds on existing knowledge, skills, structure, processes, plant and equipment, and exploits the know-how underlying the technology that it displaces. That is, it does substitute the previous regime, but it does not render the embodied competences obsolete. The latter instead undermines the usefulness of the expertise developed from the technology being replaced. According to the authors, the measurement of competence enhancement and competence destruction may be referred to three factors: the amount of retraining needed to operate with a game-changing device, the number of new skills a firm would have to develop to master an innovation, or the degree to which models based on the old regime could be suitable with the new (Anderson and Tushman, 1990).

If existing firms can use their expertise as a platform for embracing a new approach, they are likely to invest in the development of the technology and propose product design based on it. On the contrary, if they must unlearn their ways of doing things and acquire a new skill base, they tend to defend the outmoded technology (Anderson and Tushman, 1990). Competence-destroying radical changes are financially very costly for incumbents and existing capabilities can actually hinder their ability to adhere to new standards. Therefore, dominant designs arising from this kind of discontinuities are typically introduced by new entrants, who are unburdened by commitments to an old technological solution. Established firms will instead defend existing modus operandi more stubbornly, and eventually will lag behind newcomers (Anderson and Tushman, 1990).

Henderson and Clark (1990) have taken a step forward in the characterization of disruptive technological innovations as they impact firm existing knowledge. Through an empirical study of the semiconductor photolithographic alignment equipment industry, they demonstrated that even apparently minor or straightforward innovations may have dramatic consequences for firms operating an industry. Starting from the acknowledged distinction between the product as a whole – the system – and the product in its part, their model gives us a richer characterization of different types of technological change. More to the point, they suggested classifying innovation along two dimensions: the horizontal attribute captures the impact on components, the vertical catches the effect on the linkages between

them. The resulting matrix (see Figure 3) places radical and incremental innovation as extreme points along both the dimensions and yields a further taxonomy of innovation: modular versus architectural.



Figure 3: Henderson and Clark's Taxonomy of Innovations

Source: Henderson and Clark, (1990).

A modular innovation is one that changes the components from which a technology is created, but not the relationships among them. To the opposite, an architectural innovation involves modifications to the product architecture, but leaves the components themselves intact. The essence of the last type of technological introduction is the reconfiguration of an established system to link components it embodies in a new way (Henderson and Clark, 1990). An architectural innovation does not destroy the usefulness of present expertise, as radical changes do. Instead, it makes some of the existing competences obsolete, while others remain valuable and need to be applied in the new product. Firms are thus presented to a subtle challenge: not only they have to acquire new knowledge, but they also must recognise which of their current skills are still useful and which are not. Henderson and Clark argued that incumbent organizations fail in this difficulty because of three reasons. The first one is related to the firm's established communication channels, information filters, and strategies. Indeed, as a product matures, its producer builds external ties that are appropriate to its tasks and develops filters that permit to identify immediately what is most crucial in the information stream with suppliers and customers. These procedures help engineers and researchers to work efficiently and cope with complexity, but, at the same time, they could discourage the exchange of information about alternatives architectures. Hence, incumbent

firms often lack the proper external interactions to gather data about an emerging technology (Henderson and Clark, 1990).

Secondly, once a dominant design has been accepted, organizations focus their efforts on the improvement of components and processes. As a result, they do not invest on alternative architectures anymore, which may prevent them from developing the background needed to absorb external knowledge concerning different approaches. Learning about modifications in the relations across components is indeed unlikely to occur naturally, as it requires specific management and attention. Firms might not be able to spot the introduction of new linkages, since the core concepts of the design remain untouched (Henderson and Clark, 1990).

Once a firm has eventually recognized the nature and the value of an architectural innovation, it faces the last major source of problems: making effective use of the new knowledge. As an organization accept the product architecture as given, expertise related to it is little by little encoded in routines and channels and becomes implicit and hard to change. It usually takes time for established competitors to root out existing practices and build new ones. As a consequence of the arguments mentioned, we might expect new entrants to be the ones who search actively to introduce architectural innovation and exploit these to gain a competitive advantage over dominant competitors (Henderson and Clark, 1990).

#### 1.3.2 Market-based Explanations of Disruptive Technological Innovation

Christensen (2013) made his contribution in the analysis of the effects that disruptive technologies have on industries and established competitors, introducing a different dichotomy of innovations: sustaining and disruptive innovations. Sustaining innovations rely upon established value networks and imply no change in the innovating firm's strategic direction. They offer existing customers in mainstream markets something more or better according to the performance attributes they value. In contrast, disruptive innovations tend to redefine the level, rate and direction of performance improvements in an industry. Hence, Christensen's analysis is not focused on the impact of discontinuous technologies on firms' existing knowledge, but on the market effect they produce (Bergek et al. 2013). He observed that the same firms who invent a radical innovation are then the ones unable to adopt it. Suggesting that the lack of technical capabilities is not always the explanation of big firms' failure, he argued that the widely accepted principles of good management are the very reason why they lose their positions of leadership. These well-managed organizations invest aggressively in new technologies that would provide their customers more and better

products and allocated resources and efforts to innovations that guarantee the best returns. Nevertheless, sometimes technological progress runs faster than market demand does: in their effort to stay ahead by enhancing value proposition, firms end up providing customers more than they require or are willing to pay. When the performance of a product has moved up-market, the basis of competitions might evolve from functionality to reliability, and, ultimately, to price. Furthermore, in the near-term radical technologies underperform existing products on some dimension that are important to customers, thus leading users to reject them. High-performing companies rely on well-developed tools for identifying improvement patterns that do not satisfy end consumers or investors and killing bad ideas. Therefore, these companies face great difficulty to invest properly in disruptive technologies that users seem not to want and are led to address their innovative activities to the improvement of existing regimes (Henderson and Clark, 1990).

While new technologies are often rejected by mainstream market, they have features that a few fringes of customers value. Incumbents, whose cost structure is generally tailored to compete in high-end markets, cannot solve their growth needs in these small, lessattractive segments, and cede niches to new companies. In the past, many large organizations calculatedly waited until new segment had become large enough to be profitable, and then eventually targeted it. However, by the time it was too late; firms that enter a market early are likely to have significant first-mover advantages over later entrants (Henderson and Clark, 1990).

Because the potential for improvement of the new technology is higher than the one of the old technology, newcomers can exploit the new device on a small scale and get it better until they are eventually able to produce products that outperform those offered by incumbents on dimensions that mainstream customers value. Established companies, on their part, in the attempt to develop competitively superior products, risk to over-satisfy the needs of their original consumers, thus creating a vacuum at lower price points into which new companies can enter. In this way, the niche serves new players as a foothold to target mainstream market in a later stage (Henderson and Clark, 1990).

#### 1.4 External Knowledge Sourcing for Technological Innovation

In 2003 Chesbrough introduced the term "open innovation" to refer to a new model for industrial innovation. Since then, the concept has attracted great interest in academic circles and it has been incorporated into the innovation practices of many, many companies. Open innovation can be defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation" (Chesbrough 2006, 1). The paradigm constitutes the antithesis of the traditional vertical integration model, where internal innovation activities drive product and service developments and improvements (i.e. closed innovation model). Under the closed model of innovation, the R&D unit of the firm launches research projects; these are driven forward through the development process, and some of them are interrupted, while others are selected for further work. Eventually, only a few successful projects make their way to the market. From the generation of ideas to development and marketing, the innovation process takes place exclusively within the company. As shown by the Figure below, projects enter from the company's internal base, and exit by going into the market (Chesbrough, 2012).



Figure 4: Closed Innovation Model

Source: Chesbrough, 2012

Instead, the notion of open innovation assumes that firms use external as well internal ideas, and external and internal paths to the market, creating a more extensive, collaborative, and engaging environment with a wider variety of participants. Ideas can enter the process at various stages and can achieve the market in ways other than the company's own sales channels, such as through outlicensing or via a spin-off venture company (Chesbrough, 2012).





Source: Chesbrough, 2012

More and more, the credits for technological innovations belong to networks of innovators, that can be conceived as complex systems wherein units of different nature collaborate on the development, distribution, and application of knowledge. By providing member entities access to a wider range of information (and other resources) that they possess individually, networks make it possible for firms to achieve much more than they could do one by one (Rosenkopf, and Almeida, 2003). Networks are developed both horizontally - between institutions from the same or different sectors, between firms and research centres, or between competing firms - and vertically - between clients and suppliers (Schilling, 2017). There are several studies about the influence of network structure on the exchange of information and other resources among the participants. Intuitively, in a dense network there are many potential paths through which knowledge can flow, making its diffusion rapid and widespread. Furthermore, geographical proximity appears to be beneficial in collaborative research. Local and regional networks find much of their strength in the exchange of complex and tacit knowledge, which requires frequent and close interactions (Hansen, 1999). The existence of regional technology clusters, among which

Silicon Valley's semiconductor firms is the best-known, seems to confirm the role played by proximity in the creation and diffusion of knowledge. Even though advances in information technology has allowed the formation of *"virtual community"* and made the phenomenon of global networks more and more popular, these have not still undertaken the importance of physical closeness (Schilling, 2017).

Open innovation embeds two parts: the *outside-in* side requires to open up a firm's innovation process to many kinds of external inputs and contributions; the *inside-out* commands organizations to allow unused and underutilized ideas to exit company's boundaries for others to use in their businesses (Chesbrough, 2012). Besides, some companies embrace both *outside-in* and *inside-out* strategies by developing relationships with complementary partners in which give and take is equally crucial for success; this procedure is called *coupled process* (Gassmann and Enkel, 2004).

In the literature, inbound OI, namely external knowledge acquisition, has attracted more attention than outbound OI, namely internal knowledge exploitation (Caputo et al., 2016). Starting from the late 1990s, research has increasingly questioned the assumption of "local search", according to which a firm's innovative effort is closely related to its previous R&D activity, and emphasized the ability to move beyond boundaries to maintain a competitive advantage (Rosenkopf and Nerkar, 2001). By searching for solutions in closely related technological domains, organizations develop incremental innovations, and become experts in specific areas. This focus enables them to build the so called "first-order competence", but, in the meanwhile, it creates a risk of establishing "core rigidities" (Rosenkopf and Nerkar, 2001), which are recognized as the main cause of big firms' incapacity to adapt to technological discontinuities (Bergek et al., 2013). Little by little, the necessity of developing "second-order competence", namely the ability to generate new knowledge through recombination of sources across organizational and technological boundaries, has grown in importance. In contrast with local search, which builds upon similar technology situated within the organization, boundaries-spanning exploration load to distant technology that resides outside the firm (Rosenkopf and Nerkar, 2001).

By making intensive use of diverse channels, firms reach out to knowledge and ideas from beyond their boundaries, thus invigorating their innovation efforts (Asimakopoulos et al., 2020). More and more, organizations jointly work on innovative projects, or exchange information with universities, customers, suppliers, competitors and complementors. An important source of innovation comes from public research institutions; governments often actively invest in research, not only by granting for private entities, but also through their own laboratories or the formation of science parks and institutions. Moreover, collaborations with universities are among the most frequent relationships that firms set up, together with those with suppliers and customers. Cooperative partnerships with higher education institutions ensure firms access to early stage discoveries and advances in basic science, of which universities are top performer (Asimakopoulos et al., 2020). Firms also seek cooperation with suppliers, as this allows them to improve input quality and reduce production processes. In recent decades, globalization and technology, by increasing the complexity related to new product development (NPD), have further deepened the need for lead firms to build long-term partnerships with suppliers. Other organizations benefit from involving customers in new product development process (NPD). Customers participation can occur as crowdsourcing or through the lead-user approach. In both the cases, needs- and solutions-related knowledge that firm lack internally is integrated and exploited to evaluate new product concepts and first-hand user experience (Chang and Taylor, 2016). Sharing R&D costs, benefiting from resource pooling, and accelerating market penetrations efforts are instead important reasons to collaborate with competitors (Van Beers and Zand, 2014). Many organizations are involved in multiple collaboration schemes. For example, they cooperate with foreign suppliers and with domestic universities in the meanwhile.

Collaboration might occur in various forms, such as alliances, licensing agreements, joint ventures, participation in research consortia, contract research and development, or the acquisition of new entrants or strategic firms. R&D alliances allow incumbent firms to approach to their partner's specialized knowledge and to explore new technological opportunities. Alternatively, R&D acquisitions, by means of outright buying smaller, research-intensive firms, permits to integrate, reconfigure, and gain new resource configurations (Hagedoorn and Wang, 2012). Coupled with these formal arrangements, firms might also catch up external generated competences through indirect means of spill overs; for instance, they could organize informal meetings of scientists and engineers across firms, share common buyers and suppliers, and even hire competitors' employees (Chung and Yeaple, 2008).

According to Zobel (2017), it is not external resources access per se that enable organizations to capture value from OI, but the transformation into firm-specific technology related capabilities. The ability of an organization to recognize, assimilate and exploit new knowledge is defined as *absorptive capacity*. Recognition is about explore, identify, and value external knowledge, and it materializes into organizational processes that scan the surrounding context for new technologies and assess the strategic fit of external resources

with the firm's core business. The quantity, quality and diversity of knowledge that can be accessed are contingent to recognition ability (Zobel, 2017). However, recognizing external inputs of innovation is not sufficient to profit from them. Assimilation, namely the capacity to analyse, process, and diffuse external skills and expertise, is nontrivial to translate this access into technologies-related capabilities. Assimilation is captured in terms of coordination (e.g. via gatekeepers), integration (e.g. via legitimizing and promoting the use of external resources), and knowledge management practices (infrastructures that codify and disseminate external knowledge) (Zobel, 2017). Exploitation capacity enables an organization to determine applications for the assimilated know-how, as well as leverage existing competences. It is defined in terms of recombining processes that aim at bundling external and internal competences in novel configurations. In fact, some acquired and assimilated competences can be low performing in a certain field, but still create a competitive advantage if restructured in diverse ways (Zobel, 2017).

Absorptive capacity is strongly associated with firms' past R&D activities. During development process an organization explore various techniques and meet unsuccessful results before getting to an appropriate solution. This experimentation phase builds a base of knowledge which enable scientists and researchers to assess the value of related components, technologies, and methods more rapidly (Schilling, 2017). Hence, prior learning investment has a crucial role in fostering the complementarity between internal and external R&D strategies. Complementarity is herein understood as that undertaking more of one strategy increases the marginal return to the other, while substitutability implies than an increase in one strategy reduces the marginal benefit of investing in the other (Hagedoorn and Wang, 2012). Since investments in innovation activities tend to be path dependent, firms are likely to leverage the innovation procedure in which they have accumulated sufficient skills and capabilities. This would lead to switching costs between diverse modes of innovation (Hagedoorn and Wang, 2012). Besides, using different innovation mechanisms concurrently could result in similar outcomes of innovation and thus exhibit diseconomies of scope (Hagedoorn and Wang, 2012). Higher levels of in-house R&D investments increase a firm's synergic benefits between internal and external R&D activities and decrease the costs and risks associated with pursuing external R&D in the presence of internal R&D efforts. On the contrary at lowers levels of in-house innovative investments, a substitutive relationship may arise in which the costs and risks would outweigh the benefits (Hagedoorn and Wang, 2012).

The degree of complementarity between external and internal sources of knowledge does not depend exclusively by absorptive capacity; other factors, such as intellectual property circumstances, the type of research and development conducted and differences in capabilities across vertical value chain segments also influence boundary choices (Grigoriou and Rothaermel, 2015).

#### 1.4.1 Costs and Benefits of External Knowledge Sourcing

There are different reasons that lead firms to increasingly rely on external knowledge sourcing. First of all, in today fast-changing business environment, firms across industries, especially in high-tech sectors, face scientific and technical challenges that extend beyond the expertise of any single organization (Asimakopoulos, 2020). Increasing development costs are another reason that lead firms to source skills and expertise outside their own boundaries, for instance by setting up R&D alliances to share the initial costs for the development of a new technology (Chung and Yaple, 2008). Knowledge sourcing is also used as an "R&D springboard", namely, to reduce R&D fixed costs. Since future technological improvement often implies substantial incremental R&D expenditure, organizations might integrate skills and expertise sourced externally to their internal innovative effort. In this case, companies do not seek out knowledge that they do not possess internally, but they source knowledge more similar to its own upon which they then could more readily build (Chung and Yeaple, 2008). Lastly, the increased mobility of knowledge workers makes it hard for firms to appropriate and control their own R&D investments (Laursen and Salter, 2006). For the purposes of this study, is important to note that, while each innovation process relies on the extension of a firm's competences, external knowledge is of specific importance when dealing with discontinuous technologies (Hildebrand et al. 2015).

The motives behind tapping into external knowledge constitute a central theme of inquiry in several studies. However, growing attention has also been paid to the question of partner selections, i.e. with whom to collaborate (Van Beers and Zand, 2014).

The extent to which firms use external knowledge is measured in terms of variety of external knowledge sources exploited by focal firms and strength of the relationship between focal firms and external partners. Laursen and Salter (2006) defined the external search *breadth* as the numerosity of search channels that firms rely upon in their innovative activities, and external search *depth* as the extent to which firms draw deeply from the different channels. The two concepts together delineate the openness of organizations' external search procedures. According to the authors, radical innovation requires for external search depth. As widely discussed above, in the early stages of a development process, the

state of technology is in flux and only a few actors have the knowledge underlying its evolution. Organizations need to cling to these sources, such as lead users, suppliers, or universities, to learn deeply from their experience. As the technology mature, and the network supporting innovation expands, innovators need to scan across a wider number of sources to find new combinations of existing competences and make significant improvement in the technologies. Incremental innovations are inspired by many different entities, so that firms would draw more broadly, but less intensively, on external environment (Laursen and Salter, 2006).

Research on innovation practices has traditionally underscored a positive relationship between external knowledge sourcing and a firm-level innovative output. Nevertheless, recent researchers in the field of firms' openness offer mixed results regarding the outcomes, suggesting positive, curvilinear, or even negative association with innovation performance. In particular, it has been detected that this relationship may exhibit diminishing returns or be contextually specific. In other words, opening up firm's boundaries empowers innovation performance but only up to a point, as costs and complexity of OI system have to be taken into account (Caputo et al., 2016). Asimakopoulos et al. (2020) underscored an inverted Ushaped relationship between the level of external knowledge sourcing and firm innovation efficiency. More precisely, when the organization's stock of external knowledge increases from low to moderate, the innovative performance is expected to improve. However, as the level of external knowledge sourcing exceeds a certain threshold, the complexity inherent in the learning mechanism and escalating costs are likely to outweigh the benefits.

Over-relying on multiple external channels, indeed, deviates firm learning processes from their current paths and routines, and diverts R&D resources away from the organization core business. When dealing with a variety of partners, organizations need to undergo substantial partner-specific investments and face a high degree of complexity, which may be aggravated by information overload (Caputo et al., 2016). Furthermore, external knowledge sourcing is typically associated with high coordination costs: firms need to identify partners, work jointly with them, commit resources, actively transfer knowledge, supervise progresses, execute adjustments, and so on. This aspect is in line with what highlighted by the literature about the advantages related to the reduction of coordination costs ensured by a centralized R&D structure (Grigoriou and Rothaermel, 2017). Combining internal and external sourcing also places additional pressures on decision makers' limited attention capability (Grigoriou and Rothaermel, 2017). External sourcing is bound to be less effective for new knowledge creation for organizations that already possess strong internal development capabilities (Grigoriou and Rothaermel, 2017). In fact, if the firm already owns the capability to internally recombine existing knowledge and generate new one, then the marginal effect of any external technology sourcing diminishes to some extent. In such a situation, external sourcing becomes a substitute for internal knowledge sourcing (Grigoriou and Rothaermel, 2017). Besides, from a behavioural point of view, the replacement of internal knowledge with external one may lead to the presence of not-invented-here (NHI) syndrome, where internal knowledge producers are biased against external sources of knowledge (Laursen and Salter, 2006).

The effect of the use of external knowledge on technological innovation performance also varies depending on the external sourcing method. Kang and Kang (2009) evaluated the effectiveness of diverse knowledge sourcing methods by incorporating various methods into three models: information transfer from informal networks, R&D collaborations, and technology acquisitions. They classified informal information network as a weak tie, since it aims at information sharing, it does not require formal agreements or contracts, and does not involve any organisational interaction or critical capability sharing. Accordingly, it requires very low transactional and maintenance costs or no cost at all. Thus, the extent of using informal information network has a positive relationship with technology innovation performance (Kang and Kang, 2009). R&D collaboration network constitutes instead a strong tie, because it is built on a specified agreement and necessitates organisational interactions and capability sharing. While it allows to share resources and to split the risk of failure, R&D collaboration implies large maintenance costs, thereby make it difficult for firms to create wide and various networks. This, together with the possibility of opportunistic behaviours of partners or technology leakages, means that R&D collaboration can have a negative impact of firm's innovative performance (Kang and Kang, 2009). Lastly, technology acquisition is constructed by a contract, yet has the properties of a weak tie because it only causes a short-term organisational interaction for transferring knowledge, and do not need to maintain the network once the contract is over. Therefore, technology acquisition does have a positive relationship with the firm's technology innovation (Kang and Kang, 2009).

Tapping into external sources has differential effects in high-tech and non-high-tech industries. The formers are featured by rapid and unpredictable changes in technologies, which quickly renders existing knowledge obsolete, and makes new knowledge exploration needed for firms to keep competitive in the marketplace. In such turbulent environments, learning by doing and existing competences exploitation is less likely to ensure competitive advantage (Asimakopoulos et al., 2020). Because high-tech firms typically face scientific and technical challenges that extend beyond the expertise of any single organization, they tend to engage in inter organizational collaborations frequently and regularly. Hence, it is reasonable to believe that these organizations develop routines in selecting and managing multiple linkages with external partners, thus mitigating the risks triggered by an excessive use of external knowledge. By contrast, low-tech industries are relatively stable, and knowledge is typically accumulated in a path-dependent way. Sourcing external knowledge is an exception, rather than a norm (Asimakopoulos et al., 2020).

Heterogeneity of external partners also plays its role in boosting – or hamper – knowledge sourcing activity's outcome. Martinez et al. (2017) suggests that R&D alliance portfolio diversity enables firms to access diverse markets and technological domains and enhance innovativeness. However, too much diversity of external sources could adversely impact firm innovation performance, due to greater coordination and integration costs. Again, the result is context specific. In high-tech industries a broader business ecosystem is needed to maximise radical innovation performance. As far as incremental innovations are concerned, instead, there are not significant industry differences in the optimal level of alliance portfolio diversity. Product complexity and market uncertainty, as well as the divergent skills sets related to discontinues technologies and emphasized by the fast-paced business environment in high-tech sectors, intuitively demand for higher partners' heterogeneity (Martinez et al., 2017).

#### 1.4.2 Cross-countries Knowledge Sourcing Practices

A separate discussion is deserved by knowledge sourcing practices that span across countries. Indeed, cooperation arrangements with firms situated abroad provide companies with opportunities that domestic partners might be unable to deliver. According to Van Beers and Zand (2014), involving foreign customers in NPD is thought to produce efficient innovations as it facilitates the adaptation to specific market conditions and user preferences. In more general terms, collaborating with foreign partners ensures access to immobile assets that are either firm or location specific. Technology indeed differs across places because it depends on location specific factors, such as innovation previously developed, intellectual properties and trade policies, the education system, and the linkages between public institutions and firms (Chung and Yaple, 2008). Thus, through R&D collaboration firms can

enter country-specific knowledge, including institutional community in a certain high technological field. Partner company can be part of a cluster where they may benefit from the supply of specialized suppliers or the availability of specialized workforce. For instance, United States are deemed to be the at the forefront in biotechnology and microelectronics, which implies that European firms in these sectors are more inclined to choose U.S. rather than EU partners (Almeida and Phene, 2004).

Firms can also supplement their existing technological base by expanding internationally. In his empirical analysis, Frost (2001) found evidence that foreign direct investment may be driven, at least in part, by the purpose of tapping into the knowledge of diverse institutional contexts, by linking distinctive technical competences of foreign subsidiaries to local sources of knowledge. To gain access to the knowledge developed in an another country, an organization may establish a foreign affiliate there to facilitate information flow. In this way, useful knowledge of one nation might be combined with useful knowledge of another nation to obtain "technical diversity" (Chung and Yaple, 2008). In addition, because of the trend of globalization, the importance of competition coming from abroad has grown exponentially. As a result, acquiring, allying with, or setting up facilities foreign competitors is more and more appealing (Chung and Yaple, 2008). The role of subsidiaries in the innovation system of multinational corporations (MNCs) has been a common focus of research in the field of international business over the last decades. Initially, the process by which an MNC creates value from knowledge was conceived as a linear sequence: knowledge was generated at the headquarters and then diffused to subsidiaries worldwide in the form of new products or processes. In a second moment however, it was recognized that skills and expertise are sourced from various locations and developed incessantly in all parts of a company. Accordingly, subsidiaries are provided with both an exploitation mandate (i.e. they perform R&D to exploit existing MNC knowledge), and an exploration mandate (i.e. perform R&D to expand existing MNC knowledge) (Almeida and Phene, 2004). This is consistent with the perspective of MNCs as globally distributed innovation networks, whose success is due to the capacity to generate and integrate knowledge on a worldwide basis (Phene and Almeida, 2008). In such a network, subsidiaries firms assimilate knowledge either internally, sourcing it from headquarters and other subsidiaries or investing in their own R&D, and externally, catching up technical capabilities of foreign firms located in the neighbourhood (Frost, 2001). Since each unit of the MNC structure integrates external knowledge, at an MNC level the overall process of acquiring or assimilating competences from outside firm boundaries is amplified. Moreover, given the differentiated nature of subsidiaries, the whole knowledge base is expected to encompass a rich diversity (Phene and Almeida, 2008). Notwithstanding the undeniable advantages coming from the establishment of a research-oriented affiliate abroad, R&D cooperation are in general more beneficial as they not have high start-up and time costs, especially when prior experience in the host country is limited (Van Beers and Zand, 2014).

## **II** The Automotive Industry

The previous chapter casted light on the dynamics related to the advent of disruptive innovations. Various models have been considered, that analyse the way in which emerging technologies tend to evolve, and their consequences for the dominant strategies and structures of incumbents, and the nature of competition. Henceforward, the attention will be focused on one of the major industries worldwide which, according to many, is in the middle of a disruptive change process: the automotive industry. The industry includes a wide range of companies and organizations involved in the design, development, manufacturing, and distribution of motor vehicles. Its significant share of GDP in G7 countries (Jacobides et al., 2016), large scale employment, powerful lead firms and industry associations, as well as the iconic status of cars in the minds of consumers in many countries, boost the visibility and the political clout of the sector (Sturgeon et al. 2008).

As much as any industry, the automotive sector has been impacted on by globalization and consolidation during the last decades, which induced many changes in its structure and sourcing operations (Trautrims et al., 2017). As a result of outsourcing strategies starting from the late 1990s, manufacturing, design and engineering are no longer performed in vertical integrated organizations but instead in highly fragmented networks (Trombini and Zirpoli, 2013). This has raised competitive tensions within the value chain and complicated the coordination among a high number of actors. In the new business ecosystem, exploiting scale efficiencies, a traditional driver of competitive success in the industry, plays a less relevant role, while the key challenge for carmakers seems to be the ability to handle such a high level of organizational complexity (Trombini and Zirpoli, 2013). What is more, car manufacturers today need to master a wider range of competences than they did in the past to stay at the forefront of technological developments. Accordingly, innovation has turned out to be a collaborative activity, as firms rely extensively on their environment to cope with the increased complexity.

Over the years, technological innovation has been the driving force for evolution in the sector. The emergence of a dominant design in the first decades of the twentieth century triggered the consolidation of the industry around the few firms that were able to adapt to the dominant technological regime. Since it has been established, the paradigm of gasoline engine has reduced alternative techniques to only marginal roles (Chanaron, 2001). Much of
the subsequent innovation, indeed, has focused predominantly on the adoption of technology to support incremental improvement of the gasoline-powered vehicles. Throughout the decades lead firms pioneered concepts such as mass production and lean manufacture and rationalized the supply chain into supplying systems (first tier) and components (second tier). Nowadays, the automotive industry appears to be arrived at a tipping point, with new trajectories and emerging technologies that threat to disrupt the sector in almost every aspect of its traditional ways of working, including R&D processes, vehicle design and manufacturing, supply chain integration, and distribution.

The remainder of the chapter seeks to depict the structure of the industry and to pinpoint the dynamics that dominate its competitive panorama. The first section will provide a chronological timeline of the major innovations that shaped the sector and made it what it is today. Then, the focus will move on the innovation process, to explore the evolution of the knowledge base. In fact, the increasing sophistication of the design of cars, has caused the division of innovative labour, assigning a significant role to suppliers and affecting problem-solving procedures. Lastly, final pages are focused on the new technological trends that are challenging industry's incumbents, seeking to assess their disruptive potential.

# 2.1 The Dawn of the Automotive Industry

Unlike many others major inventions, the original idea of the automobile cannot be attributed to a single individual. It certainly occurred long before the 1830s, when the appearance of the first steam engines boosted the manufacture and the use of steam road carriages. Albeit being revolutionary for the time, steam-powered vehicles had considerable disadvantages: they were slow to start, used coal and put out dirty smoke. In 1886, Carl Benz applied for a patent for his "vehicle powered by a gas engine." In the same period, an English electrical engineer invented the world's first electric car. Thus, in the end of the 19<sup>th</sup> century, many alternatives designs raised to satisfy the emerging market of personal transportation. The technologies underpinning diverse prototypes came from other industries, mainly bicycle, wagon and locomotive manufacturing, or electrical sector.

What triggered the onset of consolidation in the newly born car industry was the arrival of the Model T. Introduced by Henry Ford in 1908 at a price of around \$1,000, it established the architecture of product and process and represents an early example of a dominant design in the automotive sector (Abernathy and Clark, 1985). Throughout the lifetime of the car, Ford added only a few incremental innovations, which constituted mostly

a creative synthesis of the existing technologies. These allowed him to break out of the confines of established industries while opening up new linkages to markets and customers (Abernathy and Clark, 1985). The application of vanadium steel alloy in engines and chassis components, for instance, enabled the development of a lightweight vehicle, and released the automobile manufacturing from many constraints that had been adopted from carriage makers, who sought durability through rigidity. Ford was able to devise a utilitarian vehicle durable and reliable, that fitted the need of basic transportation, and that was sufficiently low cost to permit the creation of a mass market (Abernathy and Clark, 1985). Down the years, the American entrepreneur took steps to gradually render the process more specific and rigid, in order to achieve high-volume production. Eventually, his adamant determination to pursue standardization led him to introduce the moving assembly line in his factory of Highland Park near Detroit. The innovation involved team scheduling with stationary product and roving team and permitted to decrease the process of assembling an automobile from 12 hours and 8 minutes to just 90 minutes (Amatori and Colli, 2011). By 1926 more than 15 million Model Ts had been sold, and the price had been driven as low as \$290 on some models (Abernathy and Clark, 1985).

The mid-1920s ushered a revolutionary phase of innovation for the industry as a whole. The period marked the beginning of the competitive duel between Ford and General Motors, which ended with a complete inversion of the market shares and a redefinition of the nature of the automobile (Amatori and Colli, 2011). Ford's model of standardization, denoted by the notorious motto "any colour as long as it's black", was challenges by GM's philosophy "a car for every pursue and purpose". The latter company was indeed subdivided into five divisions, each of which geared towards different levels of consumer income. Alfred Sloan, GM's executive manager, understood that cars marketing had changed: no longer was the purpose to sell a customer his first car, yet getting drivers to think about the purchase of a replacement automobile. Automotive market was not dominated by rural buyers merely interested in durability anymore. Instead, the emphasis was moving toward urban customers who looked for comfort and convenience, as well as easier operation. Thus, Ford started to lose hold of some of his vantage points as first mover (Amatori and Colli, 2011). While it continued to persecute volume production and lower cost, General Motors, Chrysler and other producers began developing new designs in suspensions, bodies and transmissions. The increasing investments in new concepts shifted the competitive and technical emphasis on new variables, and redefined the nature of the automobile (Abernathy and Clark, 1985). The innovation that contributed more than any other to this change was the closed steel body. First marketed by Hudson in its 1921 Essex, Chevrolet and GM introduced then a series of process modifications that made it an affordable feature in mass production. Its impact on manufacturing was disruptive: the new technology rendered craft skills of the wooden body makers obsolete, and required new machinery, new competences in labour and management, and new relationships with suppliers. What is more, since giant presses and expensive dies were utilized to form the metal part, the emerging technique increased minimum economies of scale, thus weakening dramatically the position of small firms (Abernathy and Clark, 1985). The fluid phase of the automotive industry, that had seen the number of manufacturers increase from 0 to 75, came to an end (Shane, 2009). The closed steel body got to dominate the competitive panorama, giving rise to the consolidation of the sector around those firms which were able to adapt to the new technology. By the 1940 Ford only covered the 18.9 percent of the US market, as opposed to the 55.7 percent of the 1921. GM held almost half of the market with its 47.5 percent, while Chrysler had 23.7 percent.

It can be stated that for the better part of the twentieth century the automotive industry was dominated by American manufacturers. This notwithstanding, around the 1970s a firm emerged from overseas to question the existing production system. Probably the most outstanding example of the Japanese keiretsu, Toyota Motors promoted a new manufacturing and assembling model, known as lean production. The company relied on a vast network of connected firms that were joined together in an association of suppliers. Toyota Motors bought from other manufacturers (components, automobile parts, and various services) about 80 percent of the final value of its vehicles (Amatori and Colli, 2011). Power was not evenly balanced in the corporation: producers and sub assemblers had invested huge amounts to locate their factories nearby the main company, and to set up plants and machinery to produce what Toyota would need, so that they could not risk to lose it as a client. This was at the backbone of the Japanese manufacturer's success: Toyota did not need to inspect the component it purchased and it could adopt its famous "just-in-time" production system that allowed for small stock of components in its warehouses (Amatori and Colli, 2011). Another important element of the philosophy behind the model was to operate intelligently and eliminate waste to further reduce inventory levels and increase output.

The rise of the Toyota Production System (TPS) proposed an alternative approach to mass production, and a different logic for organizing the sector, from product development and process engineering to purchasing and manufacturing. Japanese automobile manufacturers quickly learned to master lean production, and, via the globalization, diffused it to other firms worldwide (Jacobides et al., 2016). Soon after, performance gaps in both

productivity and quality measures for manufacturing and for product development between TPS and U.S. and European's systems manifested themselves. Leading occidental companies were pressured to shorten working-hours per vehicle, to diminish defect rate and to strengthen the coordination with their largest supplier, in an attempt to mitigate the competitive advantage that Toyota threated to gain with its flexible and agile organizational structure (Jacobides et al., 2016).

## 2.2 GVC Analysis of the Automotive Industry

The onset of the automotive industry saw many competing firms and product concepts arise. Once a dominant design emerged, tremendous consolidation took place during the 1930s, which left a few OEMs amassing system-integration capabilities and massive scale (Jacobides et al., 2016). To this day, the industry presents a distinctive concentrated structure: only a small number of giant companies control the market and exert power over smaller firms (Sturgeon et al., 2009).

Initially, components building up the automobile were manufactured within automakers, which in U.S. were highly vertically integrated from Henry Ford onwards. Throughout the years, however, the development of a car has become a complex activity requiring OEMs to master a wide variety of skills and technological competences. Leading firms thus started establishing a large number of external ties with suppliers, and, as a result of global competitive pressures in 1980s and 1990s, they began to outsource part of the manufacturing and design activities. The process originated a pyramid of manufacturers, in which first tier suppliers supply sub-systems directly to OEMs, while second and third tier suppliers produce components or provide raw materials, but have no direct contact with lead automotive firms. Although the industry has become more globally integrated than it was in its dawn, regional patterns at the operational level remain strong.

In the following paragraph, we will perform a Global Value Chain (GVC) analysis to assess the features of the overall industry architecture, and to examine the social and economic factors that have led the sector to the current setting. It will be pointed out that the economic geography has progressed from cluster-centred to a global-scale network of interlinked clusters. Then, the focus will move to the distribution and exertion of power among actors and the role that they have in shaping industrial location and structuring business relationships.

#### 2.2.1 The Economic Geography of the Automotive Industry

Since the late 1980s, the automotive industry has been marked by a dramatic acceleration of Foreign Direct Investment (FDI), global production and cross-border trade. Automakers, attracted by real and potential market growth and by the presence of low-cost but skilled labour, have spent large amounts on investments in countries like Brazil, China and India, to supply local markets and to export back to developed nations. In the automotive, as in many other industries, the emergence of such global sourcing patterns has been promoted and supported by trade and investment liberalisation through World Trade Organization (WTO) agreements (Sturgeon et al., 2009).

The trend of globalisation led the structure of the industry to a shift from a series of national industries to a more integrated global market. The opening of new markets in Asia (mainly China, Korea and India), Latin America (mainly Mexico and Brazil) and Eastern Europe (mainly Russia), has significantly contributed to the growth of the global vehicle production, which has more than doubled since 1975. Sales for companies in Europe and North America continue to be concentrated in their home countries, even if, over the last decades leading vehicle producers have extended their reach (Sturgeon et al., 2009). In 1997, VK, GM, Ford, and Fiat sold respectively 59%, 63%, 64% and 66% of their final products in their home markets (on average 63%). In 2006, the average was 55%, which demonstrates that the concentration of sales in home regions is decreasing, although very slowly. Japanese producers constitute the exceptions to this tendency; as a consequence of their successful market penetration in Europe and North America, they experienced the largest fall in concentration in the home regions. Honda, for instance, generated 36% of its sales in Japan, and 20% in 2006 (OICA, various years).

Furthermore, increasing worldwide levels of motorization, market saturation, and political pressures for local production have foster the dispersion of the value chain, which now is distributed in many more sites than it did 30 years ago (Sturgeon et al., 2009). In 1975 about 80% of world production was concentrated in the hands of seven countries, while in 2005 eleven nations accounted for the same share (see Figure 1 below). Although it still accounts for the lion's share of global production, the portion of the Triad (USA and Canada, Japan and European Union) decreased over the period 1999-2013, from 76% to 45% (Sturgeon et al., 2009).



Figure 2: The geographic dispersal of vehicle production, 1975–2005

Source: Sturgeon et al., (2009).

On a final note, starting from the 1990s, both lead firms and their major suppliers extended in a wave of offshore investments, mergers, acquisitions and equity-based alliances. Giant firms have arisen in many vertical segments of the system and have built relationships with one another at the global level (Sturgeon et al., 2009).

Some distinctive characteristic, however, set the automotive industry apart from other volume good producing industries, such as electronics and apparel. While in these businesses worldwide demand for finished products is satisfied by a handful of giant production clusters that rely on global sourcing, in the automobile sector regional and national production structures remain strong (Sturgeon et al., 2008). What distinguishes automotive products, especially passenger vehicles, from those of other manufacturing industries is their high cost and visibility among the general population. This explains the sensitivity to high levels of imports, in particular of finished cars, in places where local firms are present and the willingness of governments to protect local automotive firms by encouraging local production (Sturgeon et al., 2008). Thus, political pressures, along with technical necessity, have driven automakers to restrict exports and set up final assembly plants in many diverse market areas. By extension, the production of heavy and modelspecific parts tends to be organized regionally or nationally and is concentrated in the vicinity of final assembling to ensure timely delivery (Sturgeon et al., 2008). The automotive production is typically clustered in one or a few industrial areas, each of which is specialized in a precise aspect of the business, such as final assembly or manufacture of electronic parts. Owing to the huge investment in capital equipment and skills, clusters tend to be very longlived.

While regional production enables just-in-time and adjustments to local content, cost reduction and economies of scale demand for centralized sourcing. Hence, lighter and more

generic parts are normally produced at distance to take full advantage of scale effects and low labour costs. On the whole, the global automotive supply base is not unified: it involves regional integration of production for some components, and global sourcing for others (Sturgeon et al., 2008).

As a consequence of the increased outsourcing and the shift of some more activities in supplier firms, suppliers have in turn strengthened their international footprint. Indeed, as automakers established their plants in different countries, they pressured existing supplier to move abroad with them. Increasingly, lead firms consider the ability to produce in all major market areas a precondition for their largest suppliers to be selected. The global presence, in fact, allows suppliers to concentrate volume production of specific parts in one or two locations and ship them to plants close to their clients' final assembly sites (Sturgeon et al., 2008). Thus, producers based in developed countries, by rising their own involvement in FDI and trade, have become more and more "global", with multinational activities and an ability to provide parts and components to a wide range of lead firms. Developing countries suppliers, for their part, have got the chance to improve their capabilities by feeding automakers plants in their regions (Sturgeon et al., 2008).

In some instances, customer preferences and purchasing power, as well as driving conditions and public policy, require automotive companies to alter the design of their vehicles to fit the characteristic of specific markets. For example, car buyers in high-income countries are more demanding, compared to those of poorest nations. Also, in developing countries roads and fuel are frequently of poorer quality, so that the body, suspension, steering etc. need to be strengthened. In the effort of leveraging common platforms in multiple markets, lead firms have settled a series of affiliated design centres in places as China and Southern California, in order to ensure conceptual designers access to lead users' information (Sturgeon et al., 2009). Nevertheless, engineering activities of products development, namely the translation of a conceptual design into parts and sub-system that can be assembled into a derivable vehicle, has been kept near the headquarters and centralized in existing clusters (Sturgeon et al., 2009). A classic example of agglomeration dynamics is illustrated by the Detroit's case. The Michigan area has been a centre of vehicle design and engineering for nearly 100 years, and boasts specialized labour markets and a host of institutions to support the field of automotive. Accordingly, the regional headquarters of foreign automakers have gravitated to the region. As the lead firms locate their design facilities in the Detroit area, European and Asian suppliers in turn establish engineering centres in Michigan to support interactions with American, and increasingly, Japanese automakers. By 2005, 55% of the largest suppliers were situated in that metropolitan region, up to 43% in 1995 (Sturgeon et al., 2008).

The world automotive industry is therefore neither fully global, nor is it tied to specific localities, as the economic geography is playing out differently in diverse segment of the value chain. In all instances, however, it is automakers that drive locational patterns, by virtue of their enormous buying power (Sturgeon et al., 2008).

## 2.2.2 Modularity and Outsourcing

The car is a multi-technology product, namely an artefact composed of components which incorporate a variety of technologies. Each component constitutes a distinct part of the final product and performs a specific function. The architecture then defines a set of interfaces through which all the elements are linked one another (Trombini and Zirpoli, 2013). Over time, the range of disciplines relative to the design, development and manufacturing of a car has widely broadened in both breadth – the number of relevant fields – and depth – their specialization and sophistication (Trombini and Zirpoli, 2013). Starting from the late 1980s, given the complexity and coordination costs rising from product proliferation, inter-organizational alliances, and global expansion, OEMs began to promote models of modular and deverticalized industry structure, in which interdependence would be reduced and suppliers would take on significant responsibilities. Increasing global competitive pressure and the existing system weaknesses brought to light by the emergence of lean production, contributed to made the possibility of charging supplier of new roles very appealing (Jacobides et al., 2016).

Literature outlines that modular architecture, by reducing complexity, provides automakers with a number of benefits that, ultimately, positively impact their performance. Responsibilities for capital investment, quality verification, logistics, and product liability are shifted to suppliers and the heavy load of assets of OEMs is reduced, which result in a more agile company structure and improved ROA (Jacobides et al., 2016). In principle, involving suppliers in the innovation process grant access to specialized and tacit knowledge that for lead firms would be troublesome to replicate in house (Tromnbini and Zirpoli, 2013). The whole innovative activity is speeded up by the standardization of module specifications and interface standards. What is more, by allowing modules to be mixed and matched, modularity permit to deliver customer-specific functionalities and pursue customization (Jacobides et al., 2016).

The shift toward modularity, however, was not immediate as it grabbed the attention of auto industry managers and engineers. In fact, they began to consider modular concepts in the 1990s, after having followed a logic of unbundling production activities to be carried out by suppliers. The analogy influencing the automotive sector was the mutation of the vertically integrated computer industry to a vertical unbundled and modular architecture (Jacobides et al., 2016). The first step in separating tasks to obtain more modular production was to relocate work from the assembly line to subassembly lines in the same plants. Thereby, each task could be performed on a physically separated and optimized subassembly line, where subassemblies were tested for quality defects before being installed in the vehicle. Greater flexibility and better quality were immediate benefits, while labour cost savings were minimal at this stage, because there were no significant differences among the wages of employees on the subassembly line and those on the assembly line. In the 1980s Fiat implemented one of the first attempt to reduce the amount of small parts and components that were installed on the assembly line, by establishing a few large subassemblies on separate lines inside the factory (Macduffie, 2013). These early manufacturing initiatives encouraged outsourcing of modules to proximate suppliers; indeed, soon the physical separation of production from assembly line made evident that a specialized external firm with lower labour costs could be entrusted for the task. Starting in the 1980s, U.S. OEMs started demanding their suppliers to produce some subassemblies (Jacobides et al., 2016). Seats were the first module to be outsourced; the variable content due to customer-chosen options, their bulky structure and the high cost related to seats production, made impractical to hold a large inventory for them. Lead firms required a single supplier to establish dedicated plants within a 30- to 60-minute delivery range and to deliver seats just-in-time for a specific vehicle, in exact match to the assembly sequence. European, Japanese and Korean automakers embraced the approach, so that by the mid-1990s, none of them were still making seats internally (Macduffie, 2013). The regime was then extended to other large chunks components.

The move toward modularity fostered the creation of *supplier parks*, namely the colocation of suppliers nearby to an OEM assembly plant. Physical proximity was indeed seen as useful mean to implement TPS concept of minimal inventory (Sturgeon et al., 2009). The first experiment was piloted by Volkswagen, that established a modular consortium bringing together its key suppliers on a common site in Resende, Brazil. Thereafter, the concept spread in particular throughout Europe, were automakers were able to attract government subsidies for consolidating jobs at a supplier park. The model is particularly suitable for

components with high logistic costs, such as large, delicate and bulky built-up modules, or for parts that need to be delivered on a JIT basis (Macduffie, 2013). Yet these first actions had a narrow scope and a limited impact on structural characteristics; once the concept took hold for production, it was a short step to considering outsourcing design. In Japan, lead firms already worked closely to their supplier on design phase, and U.S. and European OEMs rapidly realized that drawing on suppliers' skills also for module design could further reduce the cost and complexity of product development (Macduffie, 2013). Stimulated by the successful examples of computer and electronics industries, executives and engineers began to aspire to a new division of labour and new methods of coordination. Suppliers taking over both design and manufacturing of complex subassemblies could allow OEMs to focus on their "core competences" and rely on "best in class" suppliers for the others, rather than pursuing excellence in making all components. Ford, for instance, conceived this as an opportunity to concentrate on new business models, in particular downstream consumer services that would foster its share of customer interactions and expenditures after the sale (Jacobides et al., 2016). The emphasis on modularity varied widely among regions. In the U.S., modular production was the driver of an acceleration of outsourcing already underway at the component level. In Japan, instead, less interest was posed to modules, since auto companies were already gaining the benefits of a high degree of collaboration with their suppliers. Figure 2 shows differing degree of vertical integration between U.S. and Japanese OEMs. Europe, as mentioned above, was instead characterized by the proliferation of supplier parks and modular consortium (Jacobides et al., 2016).



Figure 2: Vertical Integration, US and Japan<sup>3</sup>

Source: Data from MacDuffie and Helper (2007), adapted from Jacobides et al. (2016)

<sup>&</sup>lt;sup>3</sup> For the US OEMs it has been estimated that GM, Ford and Chrysler levels of vertical integration were similar-around 30%, after Delphi and Visteon spin-offs.

Despite the outlined benefits rising from modularity and outsourcing, the division of labour along the industry value chain presented serious challenges to carmakers. First of all, it has to be considered that the automotive industry is characterised by sub-systems that are in general specific to particular vehicles. Only a few parts are fully generic and can be applied in a variety of end products without extensive customisation. The absence of open, industry-wide standards distinguishes the sector from other industries as electronic and apparel, and undermines value chain modularity. Suppliers are often the sole source for specific modules variants, requiring a close collaboration between OEMs and their producers. Because of this, suppliers of parts, who have taken on a larger role in design, has decided to establish their own design centres close to their major clients, encouraging the rise of geographic clusters (Sturgeon et al., 2009). Over the years, OEMs have been attempting to diminish the design effort needed by sharing car "platforms", which typically incorporate rolling chassis and sometimes braking systems, suspension parts, engine and transmission, across a class of vehicle models. However, end product performance features such as noise, handing and vibration are deeply interrelated and quantifying their interactions in advance has proven to be difficult (Sturgeon, et al, 2009). As a consequence, for automobile designers it is hard to achieve specific performance goals using standardised parts. Besides, by heavily outsourcing the design and the engineering of specific subsystems, lead firms lose familiarity with component-specific technologies. This weakens their understanding of potential interdependencies, ultimately hindering their capability to act as system integrator (Trombini and Zirpoli, 2013). The difficulty to codify tacit knowledge embedded in mechanical processes, and the unwillingness of the oligopoly of leading firms to collaborate to develop industry-standards, have further limited the application of modularity both in design and value chain (Sturgeon et al., 2008).

When they began to be implemented, some consultants and academics considered outsourcing and modularity initiatives as portents of disruptive changes in the industry's architecture. In particular, they forecasted that, as suppliers got more experience and volume production on module, they would start to dictate design and price to OEMs (Jacobides et al., 2016). Suppliers, for their part, immediately anticipated the opportunity coming from the new strategic vision and their new role, and embraced the changes. From the start, they recognized that building a module would be deemed as a high-value-added task, which would eventually allow them to charge more. Nevertheless, their hopes were soon dashed as they learned that leading firms intended to keep hierarchical control over the supply chain. Modularity initiatives that were launched in the late 1990s, were mostly closed down or

abandoned within five to seven years, as cases of opportunism or suppliers lacking the capabilities, which had not been fully forecasted at the outset, occurred (Jacobides et al., 2016). Unlike what happened in other industry that unbundled into independent vertical segments, as the computer sector, leading automotive firms were able to reverse the changes and to keep the control over suppliers by maintaining and also reprioritizing their central role as system integrators. Regulatory responsibility and legal liability served as a reinforcing mechanism of the status quo, and ownership of customer experience and distribution also help them to dominate. Thus, in sharp contrast to PCs, vehicles are still manufactured through a hierarchically managed supply chain (Jacobides et al., 2016).

The vision of modularity and outsourcing as combining strategies for restructuring the sector, was quietly disbanded and the two themes were decoupled, with outsourcing that continues today and modularity that largely stalled (Jacobides et al., 2016).

#### 2.2.3 Leading Firms and Suppliers

In his late work, Schumpeter (1950) emphasized the role of leading firms in shaping the whole innovative process, in contrast with his earlier thought (1934), which underlined the importance of newcomers in the process of "creative destruction".

Automotive industry provides an illustrative case in this sense. Far from being conservative, leading firms were able to shape the architecture of the sector, proactively advocating modularity in the 1990s, and then rowing back when the new structure threated to erode their supremacy. The influence that OEMs have on the overall system is rooted in the tremendous buying power they gained in the course of time (Sturgeon et al., 2008). As mentioned, at the turn of the last century the industry structure was quite horizontal, with numerous suppliers delivering raw materials and components to the firm, who crafted automobiles for their customers. After the advent of Ford's mass production system and the consolidation of the industry around those players that were able to adapt to the dominant design, large vertically integrated organizations developed. From that moment forward, the industry's key structural characteristics have been vertical integration, capital intensity, and economies of scale (Jacobides et al., 2016).

As of today, automakers perform most R&D, build product architecture, fix specifications for components, and carry out the production of most engines and transmissions (Sturgeon et al., 2009) while, as stressed above, they have externalized to suppliers the production and design of the majority of other components. From the outset of outsourcing strategy implementation, however, suppliers have been under tight hierarchical

control, and have been required to make asset-specific investments for each OEM customer, due to the presence of proprietary (closed) designs (Macduffie, 2013). Over time, lead companies also arranged high-volume contracts, which ensure them the control over the supply chain. The high-volume purchasing power, indeed, gave them the ability to influence pricing, standards, specifications, or other business issues to their advantage. Suppliers, from their side, operate with an ever-present risk of being undercut on price and struggle to adapt to automakers necessities, in order not to be discharged. The fact that OEMs do benefit from a long-term relationship, given the asset specificity associated with many modules, is insufficient to re-balance bargaining power among players (Jacobides et al., 2016).

Final assembly, where system-integration capabilities and scale economies are important, is also up to leading firms. Since typically is the final assembler the one responsible for product defects and failures, OEMs must validate components from suppliers, acting as guarantors of quality control over the supply chain. They then distribute finished automobiles to dealerships for sales to end costumers. By and large, dealership are separately owned franchisees, bound to automakers by contracts and responsible for representing the brand, sell the vehicles, and provide maintenance and repair services to car buyers. Auto companies control the brand and marketing activities, and influence dealership sales via incentives (Jacobides et al., 2016). Furthermore, OEMs are sought to confront strict regulatory parameters to certify product features and performance. Automobiles are in fact large, heavy, fast-moving machines moving in public space, which relates them to a particular set of public policy issues: safety, fuel, efficiency, emissions, etc. Even though legal requirements vary by country, in the great majority of cases regulatory responsibility is given to OEMs. Developing countries are following patterns of developed nations for these issues, as their level of motorization increases (Jacobides et al., 2016).

Over the years, sector-level dis-integration, based on hierarchical structures and closed standards, have allowed OEMs to disciplines and redirect their suppliers and keep a significant part of the value-add, even while outsourcing massively. In GVC parlance, automotive industry value chains are producer-driven (Sturgeon et al., 2009).

This paragraph, as well as the previous and following ones, has looked at the characteristic and the evolution of OEMs as a group, but has also focus on individual firms at the forefront of changes. Nowadays, there are few car manufacturers that count for the great majority of vehicle production and sales. They are all originate from the U.S., Europe, Japan, China, Korea, and India, home country of Tata Motors. The table below (Table 1) shows the world motor vehicle production by manufacturers, in the year 2017. It is worth

noticing that the first 25 OEMs in the list account for more than 90% of the total production (OICA).

WORLD MOTOR VEHICLE PRODUCTION										
	-	-	-	-		Total:	96.922.080			
1	ΤΟΥΟΤΑ	10.466.051	10,798%	26	MAHINDRA	612.595	0,632%			
2	VOLKSWAGEN	10.382.334	10,712%	27	ISUZU	612.421	0,632%			
3	HYUNDAY	7.218.391	7,448%	28	CHERY	605.331	0,625%			
4	G.M.	6.856.880	7,075%	29	FAW	592.688	0,612%			
5	FORD	6.386.818	6,590%	30	GAC	513.870	0,530%			
6	NISSAN	5.769.277	5,952%	31	ANHUI JAC AUTOMOTIVE	493.199	0,509%			
7	HONDA	5.236.842	5,403%	32	BYD	421.590	0,435%			
8	FIAT	4.600.847	4,747%	33	BRILLIANCE	362.166	0,374%			
9	RENAULT	4.153.589	4,285%	34	HUNAN JIANGNAN	315.363	0,325%			
10	PSA	3.649.742	3,766%	35	CHINA NATIONAL HEAVY DUTY TRUCK	296.594	0,306%			
11	SUZUKI	3.302.336	3,407%	36	CHONGQING LIFAN MOTOR CO	214.145	0,221%			
12	SAIC	2.866.913	2,958%	37	SHANNXI	189.066	0,195%			
13	DAIMLER AG	2.549.142	2,630%	38	ASHOK LEYLAND	160.208	0,165%			
14	B.M.W.	2.505.741	2,585%	39	SOUTH EAST (FUJIAN)	159.473	0,165%			
15	GEELY	1.950.382	2,012%	40	PACCAR	153.405	0,158%			
16	CHANGAN	1.616.457	1,668%	41	CHANGFENG	135.682	0,140%			
17	MAZDA	1.607.602	1,659%	42	RONGCHENG HUATAI	132.511	0,137%			
18	DONFENG MOTOR	1.450.999	1,497%	43	TESLA	101.027	0,104%			
19	BAIC	1.254.483	1,294%	44	HAIMA CARS	94.932	0,098%			
20	MITSUBISHI	1.210.263	1,249%	45	GAZ	88.902	0,092%			
21	SUBARU	1.073.057	1,107%	46	CHENGDU DAYUN	79.737	0,082%			
22	GREAT WALL	1.041.025	1,074%	47	NAVISTAR	68.258	0,070%			
23	TATA	932.387	0,962%	48	ZHENGZHOU YUTONG	67.231	0,069%			
24	IRAN KHODRO	710.869	0,733%	49	PROTON	67.170	0,069%			
25	SAIPA	648.324	0,669%	50	LEYLAND TRUCKS	59.795	0,062%			

#### Table 1: World Motor Vehicle Production

#### Source: OICA

In order to provide a comprehensive overview of actors and players operating the global automotive industry, the attention has to be moved to the production chain. In line with the phenomenon noted at OEMs' level, since the mid-1980s and through the 1990s, global integration has led to the consolidation and globalization of the supply base. As a result of outsourcing practices, suppliers in the automotive industry took on a more extensive role in the both the areas of design and production of components. US-based suppliers, where the trend has been most pronounced, made radical leaps in skills and special coverage through the acquisition of firms with complementary assets and geographies (Sturgeon et al., 2008).

After 1985, as automakers carried out fewer sub-assemblies in house and purchased them from outside, the employment switch into the supply base to almost equate assembly level. This led to a rapid growth among the largest suppliers, and many of them engaged in (mostly) horizontal mergers and acquisitions to meet the increased capabilities demanded by OEMs. What became known as "mega-suppliers" emerged in multiple ways. At the end of the 1990s, both GM and Ford spun off their internal part divisions, creating what were at the time the world's largest automotive parts suppliers: Delphi and Visteon. These "new" firms were born with an international footprint and the capability to supply complete automotive subsystems, because they demerged from parent companies with strong global operations. Chrysler, historically the least vertically integrated of the Big Three, had deverticalized by spinning off its component's subsidiaries into a much smaller entity, called Acustar (Jacobides et al., 2016). Figure 3 shows the rise in the number of mega-suppliers from 1992 to 2004.

Figure 3: The rise of mega-suppliers, 1992-2004



Source : Jacobides et al. (2016).

At the worldwide level, supplier consolidation has initially been much slower compared to North America, but it has sped up in the first decade of the 21<sup>st</sup> century as a consequence of the formation of new global lead firms and groups (Sturgeon et al., 2008).

As OEMs moved final assembly plants in new countries, they pressured their suppliers to transfer abroad with them. The necessity of co-locating parts with final assembly varies by type of component and by stages of production for a single sub-system; suppliers with a global presence can achieve scale advantages by concentrating production of particular parts in a few sites and ship products to plants closed to their OEM customer's assembly plants where sub-systems are built up and assembled. Accordingly, global supply

base in the automotive industry is not unified, owing to the co-existence of cost reduction and scale pressures, and just-in-time and local content needs (Sturgeon et al., 2008).

Globalization and technology have also deepened the need for leading firms to build long-term partnerships with suppliers, in order to cope with the complexity related to new product development (NPD). Allowing automakers to focus on their core competences required the creation of "full-service suppliers" that could handle the design, purchasing, and production of all components in a complex module (Jacobides et al., 2016). In fact, the traditional mix of criteria taking into account by leading firms to evaluate suppliers (price, delivery performance, defects) has broadened to include more product development and globalization issues. Automakers no longer look to suppliers to merely enhance product quality and cut costs; yet, they expect them to generate new ideas for differentiating products, and to offer turnkey solution and support throughout the whole product's life cycle (Swink and Mabert, 2000).

In recent years, top performance of suppliers is more and more related to product innovation and scale economies. Product innovators outpaced process specialists in terms of profitability and growth; on average, innovative products feature greater OEM willingness to pay higher prices, due to the consolidation of the competitive structure of the industry in innovation-driven segments. Moreover, large difference in growth rates between top and low performing producers indicates the relevance of economies of scale (KPMG, 2018).

OEMs have recognized that only a selected group of suppliers are a major contribution to sustainable success; for instance, for Japanese automakers only a dozen of the 100-200 first-tier components' providers play a "full partner" role in NPD (Swink and Mabert, 2000). They are central to the network, having direct links with both the focal firms and downstream suppliers. However, suppliers do not need to remain in their initial position in the supply system; on the contrary, they can move up and down, shifting tiers and roles (Trautrims et al., 2017).

In this dynamic paradigm of ownership structures and control brought about by outsourcing strategies, a new set of skills is required to generate positive outcomes from collaborative relationships. The centrality for OEMs has moved from merely pursuing economies of scale to governing complexity in value chain links. The choice of the governance mechanism appears to be key in order to boost inter-firm collaboration while avoiding issues of opportunism, knowledge leakage and appropriability (Trombini and Zirpoli, 2013). Traditionally, auto manufactures have exploited a diversified portfolio of contractual arrangements to deal with the relations with external producers (Trombini and

Zirpoli, 2013). According to Bensaou (1999), four types of exchange are alternatively implemented, on the ground of the standardization levels and the complexity of the underlying technologies. For highly standardized subsystems based on mature technologies, which did not ask for coordination or knowledge sharing mechanisms, market exchange is adopted. Yet, this method does not work when the tie is characterized by an asymmetric commitment of the partners; for instance, in the case of bearings or glass products, which typically require customization but do involve stable technologies, suppliers benefit from a strong bargaining power over the carmaker, making way for a captive buyer relationship. On the opposite contingency, namely the exchange of components based on a new technology owned by the supplier, but whose commercialization depend on the OEM, the supplier is held hostage of the leading firm and commits large investment to hold the client. Finally, strategic partnerships are associated to highly customized and complex parts, as the airconditioning system. In such a case, both the carmaker and the supplier undertake specialized investments and the transaction usually demand for extensive coordination mechanisms.

Since automakers often cooperate with the same supplier on a set of multiple projects, each featuring different level of involvement of the supplier, it appears useful to take as unit of analysis the project-level rather than the partner's one, when selecting the governance relationships (Trombini and Zirpoli, 2013). Furthermore, general conditions should be clarified from the beginning to give to each partner the orientation in approaching the project. The literature outlined that the content of the contract produces important consequences in terms of sense making and trust building between partners, and misalignments may substantially hamper firm's ability to obtain value from alliances (Elvers and Song, 2014).

## 2.3 Innovation process in the automotive industry

Today's ever-changing business environment, has led many innovative firms to shift to an "open innovation" model, which can be defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation" (Chesbrough and Crowther, 2006). Previously in this analysis, the role of networks, communities and linkages has been pinpointed, highlighting that innovators rarely innovate alone, but instead band together in teams and coalitions. According to Chesbrough (2003), the advantages gained by firms from internal research and development (R&D) expenditure have declined, yet companies are able to successfully innovate by drawing in the knowhow of actors outside firm's boundaries. Collaborative relationships not only allow companies to reduce the cost of R&D, but also to decentralized the risk and to stimulate the involved organizations to gain complementary resources, resulting in a win-win scenario for all the partners.

In the automotive industry a trend toward Open Innovation has taken on greater saliency in light of the successful application in other sectors, as software industry (Ili et al., 2010). Indeed, the traditional mindset of generating and exploiting innovation seems to have reached its limits, and carmakers, who have historically invested in their own R&D to boost innovativeness, are turned to new sources for help in achieving innovations goals (Ili et al., 2010). Some of the most important factors leading the shift from a closed-innovation model to a distributed one are technology evolution, customers and globalization. As mentioned in the previous paragraphs, the enlargement of the car's technological components and the rise of new trajectories, have expanded the set of knowledge and resources involved in the innovation process of the sector, often requiring the combination of technologies from other industries (Trombini and Zirpoli, 2013). Let's consider a concrete example: in the last decades, car seats have developed from being a commodity item to a technology device, which interacts deeply with the vehicle. As a consequence, automakers now entrust a small number of specialised suppliers for the manufacturing of this complex part, once produced internally (Trautrims et al., 2017). Furthermore, car buyers' wants and expectations are driving OEMs into a race to innovate: especially in industrialized countries where markets are mature, they require sophisticated technologies and outstanding design at the luxury end of the spectrum and basic features at an exceptionally low cost at the other end. For much of its history, the auto industry has based innovation related decisions on engineering or finance. This was probably the result of the influence of Henry Ford's, who has been attributed as saying that if horse and buggy drivers had been asked what type of innovation they sought, they would have said they wanted a faster horse. Nevertheless, nowadays the role of the consumer is becoming far more integral to the process. Identifying and satisfying users' needs that include such things as the merging of communication technologies and the ability to integrate seamlessly with other products, is became of utmost concern. In this regard, a survey-based study on the major German car manufacturers and automotive suppliers, asserted that customers are the most important source for innovation, followed by competitors and suppliers (Ili et al. 2010). Besides, strict environmental protection guidelines and safety regulations deeply affect the way of developing new products and features; companies have indeed to handle innovation in a scenario of ever-increasing government oversight.

Beyond these variables that drive OEMs to look outside their own boundaries, the industry idiosyncrasies also correspond to some trends that render the environment notably fruitful for the adoption of an Open Innovation model. Gassmann (2006) argued that the extent to which (1) globalization, (2) technology intensity, (3) technology fusion, (4) new business models, and (5) knowledge leveraging are occurring, is relevant to determine if the scenario is appropriate for the employment of a distributed innovation system. The significance of increasing technology intensity and fusion entails the integration of external technology as well as intensive collaboration with other industries to increase innovativeness. The rapid shift of technology borders, in turn, discloses new opportunities and innovative business models. At this point of the analysis, is should be evident that the occurrence of the first four developments is rather high; instead, the relevance of knowledge leveraging, which refers to knowledge diffusion process and the personal mobility of knowledge workers, is not distinctive, which suggests that for companies is still important to identify experts and talents and commit them exclusively to the firm (Ili et al. 2010).

As organizational modes of implementing collaboration, reciprocal license agreements, alliances and joint ventures are the most common, while at firm-level the human profile of gatekeeper is emerging. Learning journeys and trend scouting are also promising approaches to seize new opportunities of innovation from different sources. Companies like VK, Daimler and BMW gave birth to the "trend-scouts" in diverse technological areas such as Palo Alto, North America and Tokyo. In addition, passive web-based techniques are implemented; for example, BMW uses the so-called "Virtual Innovation Agency" and VW employs an online interface which allow engineers from different countries all over the world to provide their contribution with new ideas (Lazzarotti et al., 2013).

The *iDrive*, developed and commercialised by BMW, is a relevant example of an introduction originated through open innovation, which involved both Cross Industry Innovation (the combination of companies operating in different sectors), and the cooperation among a mature firm and a younger one (Lazzarotti et al., 2013). It is an innovative control device providing drivers access to many different functions of their cars using a computer-like screen (*Control Display*). The *iDrive* constitutes a radical innovation in the man-machine interfaces within the industry, as it radically reduces the complexity and the quantity of the control elements in the vehicle's cockpit. BMW engaged many companies in the development of the innovation. First, the BMW Group's technology scouting office in Palo Alto, California, identified Immersion as a potential partner for the development of the project. The company have created the proprietary *TouchSense* 

technology that was mainly applied in joysticks, steering wheels for video games and flights sticks, but it never operated in the automotive industry. Its engineers soon developed a prototype integrated into an experimental car, but eventually was only able to become a technology provider and not a supplier of the complete system. As the knowhow of other partners was needed, BMW delegate the *iController*'s serial production to the Japanese electronics group ALPS and purchased the rights for the *TouchSense* application in cars. Today, the technology can be found in all BMW models (Lazzarotti et al., 2013).

According to Agostini and Caviggioli (2015), the outcomes of R&D collaboration differ on the ground of involved partners; from a patent-based analysis it has emerged that alliance with other leading firms typically lead to inventions that are not diverse from others in the focal firm's portfolio in terms of scope, but they might be technologically diversified. Innovations co-owned with suppliers are instead complex, but are not distant from the focal firms' core technology, while inventions that are out of the company focus are in general codeveloped with subsidiaries. Lastly, non-formalized collaborations generate innovations that are far more complex and diverse in terms of scope and proximity to firm's usual fields. What is more, the type of relationship with the R&D partner affect also the technological relevance of the invention. In particular, the output of collaborations with suppliers and subsidiaries are more valuable than those generated with alliances. This is explained by the lower a priori risk of disclosing technologies and revealing competences related to partners with a tighter relationship, correspondent either to the direct ownership or to a solid supply contract. In these cases, not only OEMs have more familiarity with the environment, but can also exert their controlling power and the threat of changes in the contract (Agostini and Caviggioli, 2015). Similarly, Belderbos et al. (2013) observed that research conducted together with universities generate innovations with higher market value, since appropriation issues are unlikely to play a role. The same study, using forward citations of patents as an indicator of the technological performance of the patented innovation, observed that copatents receive more citation that individually-owned patents. However, patents co-owned with firms active in similar domains, rarely receive self-citations. This could indicate constraints on the future development and exploitation of co-owned technologies by firms, although such consecutive advancements are often crucial in appropriating economical returns. The possibility that partners deploy the co-owned knowledge for similar purposes and the consequent risk of intensified competitions to jeopardize value appropriation, seem to discourage firms who first committed in the R&D effort to invest further resources in the new technology. Firms tend to build strong R&D partnerships with more frequency in emerging technological areas, where there is more uncertainty about the future market development and technological capabilities required (Belderbos et al., 2013). For example, in the field of lithium-ion battery (LIB) for automotive applications, about 10% of patents applied by OEMs are co-owned, which can be considered relatively high, compared to the sector average. Since in the literature it is largely agreed that a co-patent represents an output of a highly intensive business relationship, this data would demonstrate that automakers are trying to bridge the gap between actors from the traditional automotive industry and suppliers of advanced battery technologies by building up long-term partnerships based on trust and experience (Elvers and Song, 2014).

In the automotive industry collaboration with suppliers are particularly recurrent and highly important, to the point that the success of Japanese automakers has been attributed to the involvement of suppliers in innovation procedures. For instance, Toyota has established a number of practices aimed at facilitating knowledge transfer to and among suppliers (Agostini and Caviggioli, 2015). The strategic selection of a supplier is a multi-dimensional decision, in which innovation is a key consideration. In a context of distributed knowledge, the capability to analyse, document, and share data via computer aided-design (CAD), engineering (CAE), and electronic data interchange (EDD) tools is also evaluated (Swink and Mabert, 2000). The new model for OEM-supplier relationship is well exemplified by a development project between Ford Motor Company and its supplier Red Spot Paint and Vanish. In the early 1990s, Ford began exploring the use of thermoplastic olefin (TPO) materials as a substrate for exterior auto parts. Red Spot's existing product could not be used for that surface characteristics, so that the company was not initially identified as a potential supplier of coating materials for TPO materials, and it risked to lose its largest customer. However, Red Spot was invited in data sharing and information development in the new area, having the opportunity to learn about the technology. To maximize responsiveness, it dedicated a cross-functional team to the effort, which frequently shared information on-site at Ford to mitigate the risk of lagging behind competitors. This aggressive strategy allowed the company to develop a suitable product and eventually win the Ford business (Swink and Mabert, 2000).

This scenario featured by highly partitioned knowledge requires companies to watch over their own ability to transfer expertise, as well as the capacity to absorb new competences. Moreover, open innovation model introduces the challenging decision on which disciplines are to be developed in-house and which ones should be contracted out to suppliers. Determining the scope of the knowledge base to master is non-trivial, as it required to balance economies of specializations and the necessity to remain integrated in the knowledge domain (Trombini and Zirpoli, 2013).

While a revolutionary discontinuity in generating innovations and profiting from them is in place, some barriers still exist that prevent car manufacturers from implementing a complete re-organization of innovation system. More into details, the tendency to look outside own boundaries for external sources to enhance innovativeness (i.e. inbound openness) is settled, but external paths to outside the current business with own intellectual property (i.e. outbound openness) are still hard and rare. In fact, there are many unused patents and companies are not even aware of their potential of external exploitation (Lazzarotti et al., 2013). The handling of the intellectual property is mostly defence orientated, in order to impede competitors to profit from the firm's ideas. Besides, the automotive industry predominantly uses own R&D and their direct environment as a trigger for innovation (Ili et al. 2010).

Finally, it is worth mentioning that innovation is taking place in different organizational forms in the contemporary industry. The U.S. and European markets have seen the dismantling of the historically vertical integrated organizational forms and a focus on the core competences, while in Japan, the financial binds that anchored the keiretsu systems have been partially lost. In Korea, instead, relatively closed models do still exist. Lastly, Chinese case represents an interesting approach, as some of the largest OEMs have created vertical integration through a series of joint ventures with foreign companies. Global equity-based partnerships are employed also in other parts of the world, as Renault-Nissan and Fiat-Chrysler examples demonstrate.

#### 2.3.1 Patent portfolios

Given the complexity of innovation dynamics and the highly competitive pressure in the current industry scenario, leading firms are disposed of some mechanisms to appropriate the returns from innovation. More into details, large incumbents traditionally carry out aggressive patent strategies through up-front research, applying for patents worldwide and investing large amounts for maintaining and renovating their patent portfolios (Trombini and Zirpoli, 2013). For instance, on average, more than 3.000 patents families per year are attributed to Toyota, number one player of the industry. Other major carmakers, as Volkswagen, implement similar tactics. At the basis of proprietary patent strategies there is the fact that vehicles incorporate several innovations, which are often controlled by external suppliers and competitors. To cope with distributed and highly partitioned knowledge, OEMs exploit large patent portfolios as isolating mechanisms to exclude others from the development, use and sale of the invention, thus protecting their own competitive advantage (Trombini and Zirpoli, 2013). For those technologies with high "strategic stakes" for the carmakers, firms are likely to build overlapping and complementary patents to exclude the possibilities that the same introductions are invented around. In this respect, Fiat provide an example. In order to protect key core technologies for the its competitive positioning, such as the multi-jet and subsequent multi-air technology, Fiat applied for families of patents worldwide, which were then carefully maintained over the patent life-period (Trombini and Zirpoli, 2013).

An alternative common strategy is instead represented by co-patenting with partners; in other words, the patented invention is assigned both to the OEM and the other inventor, to split the ownership of collaborative outcomes. This allows the carmaker to monitor the use the other co-assignee makes of the technology and eventually limit its diffusion to competitors through licensing. Firms are more likely to prefer joint intellectual property (IP) when the invention in question has the potential to become a core competency for one partner and/or when there exists a chance that the other partner could abuse individually owned patent. Besides, competing firms often rely on same suppliers for specific components, so that it is key to aver risks of knowledge leakage or innovation re-engineering by other players. Lastly, the instrument of co-patenting has assumed increasing importance because in high-tech domains interdependencies between the various parts of a process leading to a product are recurrent and it is therefore more difficult to claim for different patents (Agostini and Caviggioli, 2015).

Building large patent portfolios also reduces the chances of being held up by competitors – for instance – and to prevent potential patents disputes. In the automotive industry, where patent infringement is a recurrent event, patents serves as a powerful defensive mechanism. By guaranteeing patent coverage on a technology that other firms are using or developing, the patent also reinforces the bargaining power of the carmaker through the possibility of pursuing patent litigation (Trombini and Zirpoli, 2013).

By concluding, patent portfolios are important tools both for defensive as well as leveraging purposes; nevertheless, there is still no mindset of active exploiting. The automotive industry owns several unused patents and most of the companies are not even aware of their potential of external utilization, as proactive sale of intellectual property is not frequent (Lazzarotti et al., 2013). The majority of firms grants a license only on request, and licence parties are, in the majority of cases, competitors. As far as appropriation mechanisms

are concerned, major competitors of the industry employ – and sometimes prefer – other instruments such as secrecy, lead time, and the control over strategic complementary assets like manufacturing and commercialization infrastructures (Trombini and Zirpoli, 2013).

# 2.3.2 Software

Nowadays, in many technical products, software has a predominant role. In vehicles, this applies even to the extreme. The first software found its way into cars only at a time about forty years ago, and, from one generation to the next, the amount of software into vehicles has grown exponentially. Today, premium products feature more than ten million lines of codes and the growing trend is expected to continue for other some decades at least (Broy et al., 2007). In the late 1970s/early 1980s computers began being put into cars mainly to control the engine and, specifically, the ignition. These first software-based solutions were very local, isolated and unrelated, and only appeared in high end and performance vehicles. This established the basic infrastructure, with dedicated controllers (Electronic Control Units or ECUs) for the different tasks as well as specific sensors and actuators. Given such an architecture, bus systems were deployed to optimize wiring, and the ECUs become connected with the sensors, and actuators. Before long, ECUs got connected, too, and could exchange information. As a consequence, following a systematic bottom up design, the automotive industry began to introduce functions that were distributed over several ECUs, connected by the bus system. Software, as well as hardware, turned out to be enabling technologies in automobiles, supporting ever more new functionalities (Broy et al., 2007).

## Figure 3: The Network on a Car



Source: Broy, 2016

While hardware is increasingly becoming a commodity, as seen by the price decay for ECUs, software is taking on a dominant role in determining functions. These days, we find in premium cars not less than 70 ECUs connected by more than five different bus system (Broy, 2016). Yet software does not merely allow the realization of new functionalities, but offers also new ways of implementing existing functions with reduced costs, less weight or higher quality, energy saving, and the correlation of these function into multi-functional systems. As a result of software coming up, the behaviour of cars is much more programmable, as certain properties, like comfort or sportive handling are no longer solely determined by the mechanics (Broy, 2016).

Software issues hit the automotive industry in a dramatic way. When first application on cars appeared, companies were not able to adapt fast enough to the requirements of software-intensive system, which cars were becoming, and they did not acquire the competencies necessary immediately. At the time, there were not software engineers trained by the universities in the knowhow needed in the cars' domain. Besides, following its tradition to find own proprietary solutions, the automotive sector developed to a large extent its own approaches also in software area. Nevertheless, the industry could have performed much better by benefiting from existing experiences and technology from other fields, in particular, telecommunications and avionics (Broy, 2016). With software becoming a major force of innovation, a further breakpoint was posed to the independent development and production of sub-parts and division of labour. Indeed, traditionally unrelated functions (braking, steering, or controlling the engine) got related and start to interact, turning the car from an assembled device into an integrated system as it is today. In addition, the cost of the automobile is more and more influenced by development costs related to software, for which the standard cost models dominated by the cost of components are no longer fully valid; up to 40% of the production costs of a final product are due to electronics and software (Broy, 2016).

As the car transition from a hardware-driven machine to a software-defined vehicle continues, the relevance of software for core technology trends is increasing rapidly, thus rewriting the auto industry's competitive rules. Software and electronics solutions provide companies with an enormous potential, but, as their importance has grown, so has complexity. The exploding number of software lines of code, for example, is causing significant software-related quality issues (Burkacky et al., 2018).

If the engine was the technology and engineering core of the 20th-century automobile, today, software, large computing power, and advanced sensors increasingly step

into that role. According to Chanaron (2001) the establishment of gasoline-powered automobiles as the dominant design has brought about a technological inertia in the industry. The paradigm has reduced alternative techniques with the possibility of replacing existing regime, that have been assimilated by the industry or which development has been blocked by the participation of lead automakers. Software, and the consequent redefinition of the car as an integrated system, acted as a predecessor, or starting point for subsequent developments that truly have the potential of challenging the automotive industry in almost every aspect of its traditional ways of working. What is more, in light of the increasing importance of electronics and software in automobiles, some established IT firms, such as Microsoft, are diversifying into the automotive business, increasing the threat of new entrants in an industry traditionally characterized by high entry barriers.

## 2.4 New patterns of development

"The mobility systems of the future are likely to be very different from what exists in most of the world today. The individual traveller is at the heart of this evolution, so consumers will need to be open to adopting new technologies and services. However, both the public and private sectors will have roles to play in paving the way." (Hannon et al. 2016)

The automotive industry is in the midst of a new era. Many emerging technologies, markedly different from existing ones, are struggling to establish themselves. Autonomous vehicles, hybrid and electric powertrains, artificial intelligence, and big data analytics are entering the automotive landscape and promising to deeply affect its dynamics. Changes are gaining speed, impacting business models, product portfolios and required employee skills. Traditional OEMs are facing pressure from many sides, not only in new expansion areas, but also in their core business. New entrants, by leveraging technological innovations and non-automotive mindset, are setting up to capture future businesses, threatening to erode incumbents' market share (Attias and Mira-Bonnardel, 2017).

According to a report by KPMG (2018), it is possible to recognize four megatrends that are causing disturbance to the industry's players, both automakers and their suppliers:

- electrification;
- autonomous driving;
- shared mobility;
- digitalization.

By all means, from a technological point of view, the boundaries of the mentioned trends are blurred, as the same technologies are embodied in more than one trend. For example, autonomous driving and digitalization are both involved in the concept of Industry 4.0. For the sake of simplicity, we will refer to this classification, even though the notions are strongly interrelated.

According to Sprei (2018) these trends have not only the potential to disrupt the automotive sector, yet their consequences will impact the entire transport infrastructure, energy system and city development. Considered singularly, none of these trends have actually made any major dent in the personal vehicle dominated system; however, their combination – i.e. shared autonomous vehicles (SAEV) – could provoke a disruption comparable to the one occurred more than 100 years ago, when cars replaced horses as main mobility solution. The change process will impact the ecological footprint of future mobility, resulting in better resource allocation, more efficient usage of vehicles and fewer personally owned cars produced and sold.

The remainder of the paragraph will focus on three out of the four megatrends, referring to previous analysed models to assess the disruptive potential of each of them. Digitalization will be dealt with in the following chapters.

# 2.4.1 Electrification

Electric-powered vehicles enjoyed popularity between the mid-19<sup>th</sup> century and early 20<sup>th</sup> century, but eventually lost the contest for the dominant design in the automotive industry to gasoline power (Christensen, 2013). As a response to the energy crises of the 1970s and 80s the research on electric propulsion accelerated. Furthermore, the need to move toward more sustainable trajectories of innovation and to reduce dependence of fossil fuel has been becoming apparent for decades now. The automotive industry is one of those sectors where this has come to the fore rather prominently. Lead companies, stimulated by widespread government support, are investing in the development of low-emission vehicles (LEVs), such has hybrid and fuel-cell vehicles (Pinkse et al., 2014).

In the early 1990s, the California Air Resources Board (CARB) mandated that, starting in 1998, no automaker would be allowed to sell any vehicles in California if electric cars did not represent at least two percent of its unit sales in the state. This policy, which forced un unprecedent injection of resources to the electric cause, is one of the first governmental policies aimed at reducing urban air pollution<sup>4</sup> (Christensen, 2013). Though, at the time, electric vehicles were not suitable to satisfy costumers' requirements, namely a minimum cruising range of about 125 to 150 miles (electric cars only offered a minimum cruising range of 50 to 80 miles), and the capacity to accelerate from 0 to 60 miles per hour in less than 10 seconds (most electric cars took nearly 20 seconds to get there) (Christensen, 2013).

The fact that electric vehicles underperformed gasoline-powered cars on factors that determined the basis of competition, brought about a spread scepticism among industry experts. For instance, in 1995 William Glaub, Chrysler general sales manager, has stated the following<sup>5</sup>:

Markets are developed with fine products that customers desire to own. No salesman can take marginal product into the marketplace and have any hope of establishing a sustainable customers' base. Consumers will not be forced into a purchase that they do not want. [...] for electric vehicles to find a place in the market, respectable products comparable to today's gasoline-powered cars must be available.

Similarly, John R. Wallace of Ford, made the assertion below in 1995, at the CARB Workshop on Electric Vehicle Consumer Marketability held in El Monte.

The dilemma's is that today's batteries cannot satisfy these consumer needs. As anybody who is familiar with today's battery technology will tell you, electric vehicles are not ready for prime time. All of the batteries expected to be available in 1998 fall short of the 100-mile range [required by consumers]. The only solution for the problems of range and cost is improved battery technology.

Despite unpromising beginnings, the performance of electric vehicles has improved speedily throughout the years, encouraging the investment of further resources to sustain technological advances and carry EVs to a position in which they might compete in mainstream markets (Cebrian and Diaz Vázquez, 2010). In this regard, Table 2 shows the specifications of some of the last models of electric cars.

<sup>&</sup>lt;sup>4</sup> In 1996 the government delayed the implementation of this requirement until the year 2002, because of automakers' protests that there was no demand for electric vehicle, given the performance and cost of the vehicle they had been able to design.

<sup>&</sup>lt;sup>5</sup> William Glaub's statement was made in the context of the California Air Resources Board mandate that, starting in 1998, no automaker would be allowed to sell any vehicles in California if electric cars did not represent at least two percent of its unit sales in the state.

Model	Accele. 0–100	Range km	Top speed	Consump. kWh/km
	km/h		km/h	
	s			
<u>BMW</u> MINI E	8.5	240	152	0.12
Ford e-Ka	12.7	150	130	0.19
Mitsubishi <u>i MiEV</u>	11.6	144	130	0.16
<u>Tesla</u> <u>Roadster</u>	3.9	400	200	0.13
Model	Weight kg	Battery V & kg	Output kW	Battery capacity kWh
Model           BMW           MINI E	Weight kg 1465	Battery V & kg 380 & 260	Output kW 150	Battery capacity kWh 35
Model <u>BMW</u> <u>MINI E</u> Ford e-Ka	Weight         kg           1465         1134	Battery V & kg 380 & 260 & 280	Output kW 150 65	Battery capacity kWh 35 51
Model <u>BMW</u> <u>MINI E</u> <u>Ford e-Ka</u> <u>Mitsubish</u> <u>i i MiEV</u>	Weight kg           1465           1134           1080	Battery V & kg 380 & 260 & 280 330 & 165	Output kW           150           65           47	Battery capacity kWh 35 51 16

Table 2: Specifications of Electric Cars

Source: Cebrian and Diaz Vázquez, (2010)

Nowadays, operating costs of an electric car can be directly compared to those of a gasoline-powered vehicle. The comparison varies on the ground of the costs of gasoline and electricity, the kms of the vehicle and the type of driving being considered. For instance, in EU, where fuel is more expensive, driving an internal combustion engine-powered (ICE) car is far more costly. In general, the cost advantage of EVs increases when driving in cities, because the regenerative braking systems recapture much of the kinetic energy of the moving vehicle and use it to recharge the batteries upon braking. On the contrary, in the highways, most of the energy is dispersed through wind resistance, so that gasoline-powered cars perform better. In addition, electric car's peak torque begins at 0 rpm, the opposite of the gasoline engine's case, which instead has very little torque at a low rpm and only reach peak torque in a narrow rpm range. Lastly, what is perhaps the most striking benefit of new electric power train technologies, their CO2 emission per kilometre driven is well below the ICE powered car's threshold (Cebrian and Diaz Vázquez, 2010).

Ongoing battery technology advances have addressed many of the issues that historically limited the widespread adoption of electrical vehicles: high battery costs, short range between battery recharging, charging time, and battery lifespan. Currently, EVs still have limited charge time and shorter life than engine-powered cars (Cebrian and Diaz Vázquez, 2010). Charging infrastructure are gradually getting better, as illustrated by the

Figure 4 which consider the number of charging station per 100 kms railroads in 2017, 2018, 2019. However, many countries still have a long way to go.



Figure 4: Charging Infrastructure for Electric Vehicles

Source: KPMG (2019). Global Automotive Supplier Study

Having defined the features of electric vehicles as compared to ICE cars, the next step is to understand if they are a candidate disruptive innovation, which could replace the incumbent technologies in the automotive industry, namely internal combustion engines. First of all, firms producing the disruptive technologies are typically not the same companies as the one who operate using establish technological regime. In the case of electric vehicles, this may not necessarily apply to the OEMs themselves, but it definitely does apply to the component suppliers. In fact, drive train components, including exhaust systems, gear boxes, carburettors, depend on the electric sector and not anymore on engine suppliers. The electrification of the sector might favour the entry of new players (e.g. electricity providers, battery suppliers, etc.), which would have important consequences for what concerns value appropriation strategies of leading carmakers in the management of innovative activities (Hardman et al., 2013).

As far as users are concerned, the adoption of an electric car requires behavioural changes in the way in which they interact with the infrastructure. The EV, for example, would be plugged in at home over night to be refuelled rather than being driven to a refuelling station (Hardman et al., 2013).

The most significant aspect of disruption, however, is the need for changing infrastructure. The widespread adoption of electric cars would cause the breakdown of the petroleum industry. Existing framework would be impacted negatively and a new one would be needed, demanding for significant investments to install a recharging network for EVs (Hardman et al., 2013). The introduction of the EVs has proved to be problematic to date, due to the technological lock-in of petrol and diesel vehicles, and issues related to public perceptions and users' preferences. In the time-honoured tradition of established firms, the great part of OEMs has employed an entry strategy for electric vehicles aimed at massmarket. This is the case for Nissan Leaf, Peugeot iOn, Mitsubishi i-MiEV, Renault Twizy and Zoe, Smart Electric and a few more examples. All of them are produced at a low price, without sacrificing too much of the quality and performance of modern vehicles. They do not have much added value and are created to fit today's functionality expectations of every day vehicle users who exploit their automobiles as transportation devices. Nevertheless, the cost of electric cars is still too high in comparison with conventional petrol and diesel vehicles and they offer little advantages to justify this price premium. Thus, the mainstream market for EV is still struggling (Hardman et al., 2013).

On the opposite end of the spectrum, Tesla Motors has developed vehicles aimed at niche markets. Founded in 2003, the company is one of the youngest car manufacturers operating today (Hardman et al., 2013). Tesla was able to recognise the potential of the new technology and to set up an entry strategy which allowed it to find its place in the highconsolidated automotive sector. First of all, it has dismissed the route of cost minimisation that its mass-market rivals pursued to make the new technology cost competitive. Instead, targeting specific niches, Tesla built an expensive, high performance product which consumers have been found to be willing to pay for; what is more, Tesla "enthusiasts" emerged, who take their cars to automotive shows, racing events and take them touring. The move seems to have paid off, since the company sold in some years an impressive number of vehicles for a young company marketing a disruptive technology (Hardman et al., 2013). Tesla appears to have applied efficiently Christensen's suggestion that a disruptive technology cannot be aimed at mainstream market, as it proposes a set of attributes that is orthogonal to those that command attention in the gasoline-powered value network. Though, its foothold is in the high end of the auto market, and this segment is not uninteresting to incumbents (Christensen et al., 2015).

By concluding, the picture that arise on electric vehicles, their evolution, companies' strategies and appropriability regimes is marked by a high degree of uncertainty. The

innovation is still in the phase of technological ferment, with electric power train competing with many hybrid technologies and they altogether struggling with other "green" and perhaps more efficient solutions (EUCAR 2009). The mechanisms leading to a selection of a dominant design are far from being clearly defined, as firms are still exploring the diverse solutions and gain capabilities on a wider set of technological domains, in order to come prepared to an eventual shift towards the electrification of the industry (Christensen, 2013). The electric car might remain confined to a niche-market, without causing changes in the structural organization of the sector and without disrupting the knowledge-base that industry incumbents have accumulated over the years. On the contrary, in case of their emergence as a dominant design paradigm, new hybrid and electric power-train technologies will trigger relevant change in industry dynamics, provoking a re-organization and a re-assessment of the value distribution along the automotive value chain.

#### 2.4.2 Autonomous Driving

Among the trends that are going to re-configurate the automotive industry in the coming years, autonomous driving overhangs as the one which have the potential to completely change the sector as we know it. While researchers and analysts may still argument about the pace of change and the power dynamics between incumbents and new entrants, there is no longer a debate over if autonomous driving is going to happen, but when (Gao et al., 2016). Opinions related to the timing of market introduction and penetration of AV differs on the ground of diverse views on technological development and diffusion rates, public acceptance and regulations.

The massive introduction of driverless vehicles can lead to high environmental benefits, through the reductions in energy consumption and emissions, the optimization of highways and the decrease of required cars to only 15% of the amount currently needed (Rosenzweig and Bartl, 2015). What is more, driverless car will also impact on societal aspects as the reduction of commuting time per individual per years, as well as the immense productivity gains while commuting, the decline on incidents rate, and the fall of the parking space to up to ¼ of the current capacity (Alessandrini et al., 2015). However, there are those who argue that AVs come with a certain amount of complications and drawbacks. In the first place, humans are poor monitors of automation. Hence, driving performance is thought to decline as automation increases, leading to safety troubles as the individual being "out of the loop" when a prompt reaction is required (Rosenzweig and Bartl, 2015). It is also claimed that fuel consumption can increase significantly if travel costs are reduced, and if currently

unserved groups, as elderly and people with disabilities, get access to motorized mobility. Since driverless cars can circulate empty to avoid parking fees, drive the vehicle home again, or run errands while owners are at work, the occupancy levels in vehicles could dramatically decline. These scenarios threaten to annul energy and emission reductions obtained from the more efficient vehicle operation (Sprei, 2018). Moral issues are also involved; indeed, although traffic accidents would be reduced by driverless cars, not all crashes will be avoided, requiring AVs to make difficult decision in cases which include inexorable harm. For instance, self-driving vehicles could be forced to choose between running over pedestrian or sacrificing its passengers to save them. Albeit appearing unlikely, these lowprobably events are bound to occur with millions of AV on the road, and defining the algorithms that will help autonomous cars to make such decisions is a formidable challenge (Bonnefon et al. 2016). Having a closer look at the history of autonomous driving, it emerges that the technological development and main milestones of the field started a few decades ago. The development of some present semi-autonomous functionalities, are somehow a consequence of previous advances in car's technology. Progresses on cruise control starting from the 1960s, Electronic stability control invented by BMW, Bosh and Continental, Nissan Cima's lane departure warning system and Toyota Harrier's pre-crash mitigation, established the basis for further research in the autonomous-related technologies (Rosenzweig and Bartl, 2015). Nowadays, as the interest on the topic increases, developments are happening rapidly. Almost two decades ago, in 2004, DARPA (Defense Advanced Research Project Agency) arranged a Grand Challenge for self-driving car in the desert outside of Barstow, California, and none of the starting fifteen cars finished the route. Six years later, in 2010 Google declared that they created an autonomous vehicle and that it was driving around the streets of San Francisco (Sprei, 2018). Today, self-driving features can be found in cars out on the market, as demonstrated by the Figure 5 below, which provides an overview of automated driving functionalities according to the official classification by the National Highway Traffic Safety Administration, and a timeline of their commercialization. The NHTSA (2013) divide self-driving cars into No-Automation (Level 0), Function-specific Automation (Level 1), Combined Function Automation (Level 2), Limited Self-Driving Automation (Level 3), and Full Self-Driving Automation (level 4).



Figure 5: Commercialization Timeline of Automated Driving Functionalities

Source: KPMG (2017). Global Automotive Supplier Study 2018

It is interesting to note that main automakers in the race such as Audi, Land Rover, Cadillac, GM, Ford, Jaguar, Lincon, BMW, Mercedes-Benz, Tesla, Nissan and Volvo, are trying to integrate highly automated features slowly in their models, despite having announced to be ready for their production. This can be explained as an attempt to keep this disruptive technology controlled, and to have overall slower customer acceptance (Rosenzweig and Bartl, 2015). Legal liability, policymakers, and customers' reluctance seem to be the three biggest barriers that still impede the mass adoption of self-driving cars. Even though there have been significant progresses in the last few years, legislation remains a limiting factor, often hampered by ethical discussion. By now, several states in the US have adopted laws permitting autonomous cars testing on their roads. Europeans are also moving towards the same direction, as demonstrated by some modifications made to the Vienna Convention on Road Traffic and the Geneva Convention on Road Traffic. However, issues and doubts arise about how to deal with civil and criminal liability, corporate manslaughter and insurance (Rosenzweig and Bartl, 2015). Though, the most inhibiting factors are those related to human experience. The fear of technology failure prevents customers from trusting AVs, and makes zero-error ability a key element of future mobility. Besides, recent studies pinpoint that motion sickness is higher in self-driving cars, and passengers that do not drive suffer discomfort at lower acceleration rates than car drivers do (Rosenzweig and Bartl, 2015). Further worries derive not from the experience in driverless

car itself, but rather from the social impact of the technology. A shift toward autonomous vehicles will cause massive job loss, as well as the change of social structures as public transport systems and insurance companies, which conveys the impression that the disruption is ethically wrong (Rosenzweig and Bartl, 2015).

Considered as being predominantly technology driven, AV can be disruptive for the automotive industry. In spite of the fact that all the major carmakers are proactive and are actually investing in automated technology, their position and market share is at risk due to the emergence of new competitors, as Einrinde, a Swedish company founded in 2016 which is launching a semi-truck that can be controlled remotely. New entrants in the field might be more open to creative solutions, while the incumbents, victims of a strong technological inertia (Birchall et al., 2001) are more vested in old ideas. An additional risk come from "online players" such as Google and Apple who are currently investing on the marketability of fully autonomous vehicles. The Global Automotive Executive Survey of 2017 by KPMG, indicated that Silicon Valley's firms are having a "honeymoon period" since shortcomings in quality and even fatal errors are more quickly forgiven by consumers. Nevertheless, the same research showed that the majority of car buyers still trust premium manufacturers the most when sitting in a driverless vehicle, suggesting that OEMs should build on this trust advantage and position themselves in the market to be competitive in the future.

Thus, autonomous technology has the potential to disrupt market leaders' current business model; furthermore, they definitely are disruptive to end users, since their adoption will completely change the way in which vehicles are utilized. Lastly, AVs will impact on the infrastructure, with effects that will not be confined to automotive industry, but will reach other related sectors, among which energy and insurance industries are the most vulnerable. Further societal aspects will be shaped by an industry shift toward autonomous technologies, such as the transport system on the whole, land use and legal liability (Sprei, 2018).

# 2.4.3 Shared Mobility

The term "shared mobility" defines transportation services shared among users. A variety of options, from the sharing of the vehicle itself, as the traditional free floating, bike sharing, to situations where the ride is shared, are embedded in the definition. Established public transport services and taxi, as well as innovative systems of car-pooling or ride hailing are thus involved in the concept, making it challenging to distinguish among the emerging services and to find a proper term to describe them all. Indeed, while some of shared mobility proposals are new, the concept has been around for a long time. The difference today is that

the convergence of different technological advances, GPS and smartphones, have made these services much more accessible and convenient, and have allowed to offer new ones (Sprei, 2018).

When shared mobility became to spread, it attracted environmentally conscious consumers or users attracted to the sharing economy as a concept. Nowadays, professionalization of companies in the sector and the improvement of services offered have helped to increase customer base beyond the early niche (Sprei, 2018). In some instances, government policies have also played a role in creating prerequisites to sharing services, for example by introducing stricter parking regulations and fees. Finding parking is one of the disadvantages of owning a vehicle, as well as maintenance and repair. Some cities are leveraging it as a tool to reduce the number of vehicles and car ownership. However, in other cases municipalities have also chose not to support a specific type of proposal, in the fear that the drawbacks would exceed the benefits. Uber provides a striking case, as it has been banned in a number of cities and countries, due to reasons related to not complying with regulations (Sprei, 2018).

One way to enhance the attractiveness of shared mobility is to combine different services creating Mobility-as-a-Service (Maas). The term was first coined in Finland and applies to a very innovative mobility concept, occurring with the emergence of new technologies and advances in ICT. Information and communication technologies are the main component of MaaS systems, as the collection, process and transmission of data and information are indispensable for identifying the optimal transport solution for each consumer. By combining existing transport modes, MaaS offer a tailored mobility package, charging for a subscription or proposing a pay-per-use contract, and includes other complementary services like trip planning, reservation, and payments functionalities, through a single interface. Thus, the user-centric vision frames the mobility service provision, giving rise to a product which is personalized and on-demand (Jittrapirom et al., 2017). So far, different schemes have been implemented in the context of MaaS around the world; some of the existing cases are TransitApp (USA, UK, Canada, Europe, Australia), Optymod (Lyon, France), Mobility 2.0 services (Palma, Spain), Mobility Shop (Hannover, Germany), Tuup (Turku Region, Finland), My Cicero (Italy), Moovel (Germany), Whim (Helsinki, Finland). While there is large variation in the criteria implemented by the schemes above and many others, it is possible to note some common patterns. In the majority of cases, public transport is included as part of the solution offered. Furthermore, bike sharing, car sharing and taxi are nearly always added. Additionally, some of them also involve rental car,
parking, regional transport, and permits to congestion charging zone. Lastly, a few schemes propose perks such as integrated invoice, real time congestion monitoring, access to municipalities services, and planned freight services (Jittrapirom et al., 2017).

MaaS has the potential to achieve a more sustainable transport; shifting the interest from private car usage to alternative solutions could counteract the negative externalities of current transport mode on urban context and the environment. What is more, shared mobility is believed to have societal value, as it enhances accessibility in reaching places and in the opportunity to exploit transport system. The move from ownership-based to access-based transportation strengthen equity by offering an affordable service even for low-income households. Thus, MaaS can induce a better allocation of resources and services, through the full deployment of ICT and an improved cooperation between public and private transport providers (Hietanen, 2014). In fact, public transport services are historically supplied by monopoly or multiservice providers who exploit economies of scope and scale. The spread of MaaS will eventually impact their existing business model, requiring them to integrate with other operators. However, MaaS can be conceived as an advanced version of integrated public transport services that rely on a platform technology to facilitate the interactions between travellers and suppliers and create value by providing information about the prices and the quality of the services offered. Personalisation is a significant advantage resulting from subscription, which is absent in traditional public transport and bring about the inconvenience of not covering passengers' needs. Lastly, the disruption of current practices could resolve issues related to the often-under-utilised capacity of buses and trains (Jittrapirom et al., 2017).

This bundling of mobility modes embeds a different conceptualisation of travel. In this new setting, people will have a wide list of options to choose from, based on their needs and preferences, and a service which allows them to pursue multitasking, performing more activities within the same timeline. It is a marked departure from how mobility has been delivered until now, and it threatens to induce a shift from existing ownership-based system toward an access-based one (Jittrapirom et al., 2017). A comparison between personal vehicles and car sharing aimed at deducing if shared mobility has the potential to disrupt automotive industry is not straightforward. In fact, the cost structure is very different; in personal cars the upfront expenses are high while the running costs are lower. For sharing car, instead, there are only running costs. Depending on the service's pricing model, there can be fixed costs consisting on a monthly fee. Hence, for users who do not drive on a regular basis car sharing appears economically favourable. On the contrary, in the case in which the vehicle is rented for a longer time, the cost structure can be conceived as a barrier. The evaluation of the flexibility of the two different systems of mobility is shaped by what attributes are valued. There are those who claimed that personal vehicles represent the most flexible option, since it is available for the owner all of the time. From another point of view, flexibility is given by a wide range of car models, a fit-for-purpose mobility solution, and having to pay for a vehicle only when one actually needs it (Sprei, 2018).

Considering the consequences for the energy system and the whole transport industry, MaaS has the promising perspective to diminish the number of vehicles, the amount of vehicle-kilometre-travelled per person, and to improve car efficiency because of a higher utilization rate of the vehicle. On the whole, shared mobility seems to provide a service the has lower costs, but need for a better assessment to compare main stream products' performance. However, it is still hard to ascertain if it can improve and outperform the established transport regime over time (Sprei, 2018).

What is certain is the fact that a shift to car sharing will imply a change in consumers' attitudes. Today vehicles are not simply a transport mode, but they also carry a lot of symbolic value, such as status, political views and emotional values (Sprei, 2018). Bardhi and Eckhardt (2012) draw the attention on the difference among ownership and access, relating ownership to a sense of responsibility and attachment, and access to a utilitarian view of a service or object. Studies to date found out that shared mobility fascinate people with low sense of ownership of cars and a more utilitarian vision of transport services. By and large, persons that give up a car have in general other reasons than joining shared rides, such as a car that broke down or increase in costs (i.e. because of insurance), or a new job. Thus, car sharing alone is not sufficiently appealing to convince users to let go their own vehicle for city commuting (Sprei, 2018).

MaaS initiatives are growing very fast throughout the world, especially in Europe. The Figure 6 shows the growth of global car sharing within the timeline 2006-2014, and, according to the Centre for Automotive Research, car sharing members, that accounted for 2.2 million in 2014 can reach 10 million in 2021. The growth in the U.S. will be slower.



Figure 6: Global Car-sharing Growth, 2006-2014

Source: Goodall et al. (2017).

The Global Automotive Supplier Study 2018 by KPMG forecasted that vehicles sales for new mobility service will exceed 10% of new car sales by 2025 in U.S. and Europe, due to growing urbanization as well as enhancements in technology and mobility business models. In China, the disruption potential is even higher because of its relatively low base of ownership levels today (1 car for 7 people vs. 1 for 2 in Europe and 1 for 1.25 in U.S.). The following year the same study highlighted how frequently people in Asia have the opportunity to decide between different transport modes, compared to Europe and U.S. For instance, in China participants to the interview affirmed that on the 50% on all the trips they took they have the choice for a different solution of travel. Lastly, the Global Automotive Executive Survey 2017 by KPMG predicted that, by 2025 more than half of all car owners today will no longer want to own a car. While it is not that stronger today, the tendency toward less car ownership is already recognizable among consumers, with younger users that agree the most about the occurrence of the disruption in the near future.

# **III. Industry 4.0 in the Automotive Sector**

Starting from 1760, the First Industrial Revolution changed everyday lives and turned the agrarian and aircraft economy into one dominated by industry and machine manufacturing. More than a century later, the Second Industrial Revolution ushered an era of rapid industrialization using oil and electricity to power mass production. In the Third Industrial Revolution, the implementation of electronics and information technology facilitated the automation of production. By and large, each industrial revolution is deemed as a separate event; however, together they can be better understood as a series of events leveraging innovations of the previous revolution and leading to more advanced forms of production (Xu et al., 2018). According to many, we are now entered the dawn of the Fourth Industrial Revolution, which is building on the Third and has been occurring since the middle of the last century. The transition towards "smart" factories, and the deployment of connected objects in transport (autonomous vehicles), energy (smart grids), cities, healthcare, agriculture and many other fields, is already under way, and promises to profoundly change the current organizational schemes of these sectors (EPO, 2017).

Over the last decades, innovation rhythm and globalization has generated a dynamic market where competitive advantage is temporary and companies must continually adapt. At the same time, collaboration and external knowledge sourcing are becoming more important to innovate and to operate. In this highly competitive panorama, the effect of Industry 4.0 is twofold: at the one hand, it proposes modular, self-configuring systems that can be easily rearranged, and thus provide a good response to the shortening of product life cycle and time-to-market. On the other, digitalization of industries has posed further challenges to organizations and emphasized the need of expanding knowledge boundaries (Klingenberg and Antunes, 2017).

To date, research on Industry 4.0 has primarily investigated the digital transformation in industries whose core products could be completely digitalised, such as media and music industries (Hanelt et al., 2015). The automotive industry deviates substantially from the characteristics of the sectors that have been the focus of most studies thus far, as its core product, the car, cannot be fully digitized. Besides, automakers have a long tradition in satisfying a basic human need, i.e. mobility, while now transportation infrastructure is facing a growing diversity of consumers' requirements, such as information, responsibility, safety and digitally enhanced mobility experiences (Piccinini et al., 2015). Accordingly, the challenges stemming from the digital revolution in this context are not completely clarified. Confronted with an environment going through significant technological change, leading companies in the automotive industry are obliged to rethink traditional forms of cooperation, and set up cross trades and sectors relationships in constantly evolving production modes (Attias and Mira-Bonnardel, 2017).

The aim of this chapter is to grasp how OEMs are proceeding to bridge their competence gap, and to source digital knowledge, which is spread across heterogeneous disciplines and domain. In the first section, the basic concept related to the Fourth Industrial Revolution will be discussed. Then, the focus will move on the changes that affect directly the automotive industry, both at the process and product level. Ultimately, the impact of such discontinuities will be assessed through the implementation of disruptive technologies theories.

Since the literature about the Fourth Industrial Revolution is still nascent, consulting reports, and official publications were also considered.

## **3.1 The Fourth Industrial Revolution**

The term "Fourth Industrial Revolution" (4IR) was coined by Klaus Schwab, founder and executive chairman of the World Economic Forum, and denotes a world where connected technology allows individual to move between digital domains and offline reality (Schwab, 2015). The expression "industrial revolution" conveys the pervasiveness and the disruptive potential of the changes coming about, which promise to cause shifts in power, wealth and knowledge. The speed of current breakthroughs has no historical precedents; the digital revolution is evolving at an exponential pace, and it could disrupt many industries in every country (Schwab, 2015). The vision of the imminent revolution has been incorporated in concepts as Industry 4.0 in Germany, Advanced Manufacturing in the United Stated, Made in China 2025 in China, and Japan 25 in Japan. These are political projects build by consortiums of dominant industries to promote the development and selling of emerging technologies (Stăncioiu, 2017).

However, there is yet no consensus as to whether we are observing the onset of a Fourth Industrial Revolution and whether this coincides with Industry 4.0 paradigm. Over the years, hand in hand with the proliferation of the research on the field, a certain scepticism about the issue has also been spreading. Many authors, indeed, argue that some components of the Industry 4.0 technologies were already present 30 years ago, and more recently the paradigm has been rendered more feasible, because of higher maturity of ICT and lower costs of hardware and software (Klingenberg and Antunes, 2017). The Third Industrial Revolution did not deliver all its promises, and this is often responsible to some cynicism related to the Fourth. Benefits of Advanced Manufacturing Technologies, for instance, have been the focus of a debate for decades, and there is not yet a definitive position on the subject (Klingenberg and Antunes, 2017). Furthermore, although the impact of emerging technologies on product conception, production and distribution could break existing industrial paradigm, technological advances per se might not result in a fundamental disruptive change (Klingenberg and Antunes, 2017). Lastly, since the Digital Revolution is being identified before it happens, all results or effects are forecasts, assumptions or projections (Klingenberg and Antunes, 2017). Henceforth, we will use the terms "Fourth Industrial Revolution" or "Digital Revolution" as synonyms of Industry 4.0, yet it should be kept in mind that the issue is strongly discussed.

The literature provides various diverse definitions of Industry 4.0. The most recurrent theme, however, is the higher degree of digitalization for products and production, supported by ICT solutions, and connection to the development process (Armengaud, et al. 2017). Digitalization connotes the structuring of many diverse domains around communication and media infrastructures. As it enables other characterizing attributes, digitalization is the most important feature related to the concept of Industry 4.0 (Kern and Wolff, 2019).

The genesis of the Fourth Industrial Revolution should be sought in the massive deployment of information and communication technologies (ICT), which have been the engine of innovation since the early 1980s (EPO, 2017). The spread of ICTs led to the presence of a computer and internet access in homes and workplaces, and later on to the integration of computers into mobile communication devices. In recent decades, technical progresses in the cost-effectiveness and size of processors has given a major contribution to the development of interconnected smart objects operating autonomously. However, it would be misleading to consider 4IR as a mere prolongation of the Third Industrial Revolution (EPO, 2017). Although some of the Industry 4.0 technologies are more evolutive than disruptive, their combined use, which includes digitalisation, highly effective connectivity, cloud computing and artificial intelligence (AI), and their velocity, scope and system impact enforce us to look at the new wave of technological advances as constituting a distinct phenomenon (EPO, 2017).

There is a heated debate about the existence of a general-purpose technology (i.e. technology that have important and longstanding aggregate impact) among the numerous technologies involved in the concept of Industry 4.0. However, some authors consider that the more suitable for the role is the Cyber-Physical System (CPS), which is defined as the combination of physical and cybernetic systems (Klingenberg and Antunes, 2017). Cyber-Physical Systems derive from some important technical advances, in primis the Internet of Thing (IoT), also called the Internet of Everything or the Industrial Internet. It consists in a new technological paradigm envisioned as a global network formed by billions of objects capable of interacting with each other (Lee and Lee, 2015). The insurgence of the connected life came about during the last century thanks to the advance of the Internet; the potential of new connected objects, however, goes well beyond the traditionally connected laptops or smartphones. IoT is assumed to offer advanced connectivity of systems that exceeds machine-to-machine (M2M) communications. Embedded electronics and sensors, software and network enable devices to collect and exchange data without any involvement of human beings. Machines and robots, buildings, vehicles, smart clothes will be endowed with their own internet address, contributing to the increase in data traffic in the near future. The communication infrastructure will be provided by the 5<sup>th</sup> generation (5G) of mobile networks, which is featured by faster speeds, low energy consumption and reduced network latency (EPO, 2017). Then, the accurate information gathered by sensors and connected objects provide the raw materials for the applications of 4IR technologies. Cloud computing has the potential to store and process huge amount of data on networks of remote servers located in multiple data centres. Data analytics tools and diagnostic systems offer the capability to process the vast amount of data and to detect and interpret patterns, changing the paradigm of people performing analyses supported by computers (Armengaud, et al. 2017). Large data sets are already reality: every day, around 2.5 quintillion bytes of data are generated, and the amount is growing by 40% each year (Armengaud, et al. 2017). Lastly, by using data sets, new technologies make the results viewable to humans. New interfaces and virtual reality display such diagnosed information, allowing for the application in a wide range of situations, from gaming to remote surgery, and from flexible design to production of any type of item (EPO, 2017).

Like previous industrial revolutions, 4IR raises major economic and social issues. Artificial intelligence (AI) systems have the potential to rationally solve complex problems, while robotics will improve the quality of jobs and will offer people more time to focus on what they want to do. Thus, digitization threatens to displace low skilled and low wage workers, making talent, more than ordinary labour or capital, the scarcest and most valuable resource for production in the near future (Xu et al., 2018). What is more, the large-scale automation will involve not only physical tasks, but also intellectual tasks previously performed by human beings (EPO, 2017). In other words, as occurred in the past, the Fourth Industrial Revolution is going to destroy the jobs created by the industrial age.

In addition to the issue of massive job displacement, there are other challenges related to the ongoing of the digital revolution, such as cybersecurity and ethical dilemmas (Xu et al., 2018). With more knobs and connections, systems need to be more secure. Companies, in particular, should examine accessibility, to assess possible risks from internal sources (data lost or stolen by employees, either inadvertently or intentionally), and from external sources, including hackers and cyber terrorist (Xu et al., 2018). Lastly, robots have become smarter and more autonomous, but still lack the capacity of moral reasoning, which hinders their ability to make ethical decisions in complex situations. Moral values differ greatly across cultures and even from individual to individual, so that which moral standards robots should inherit is a critical question. Hence, policy makers are facing the challenge of supporting and encouraging the development of new digital infrastructures, while at the same time creating appropriate legal frameworks to safeguard competition, cybersecurity and consumer rights (Xu et al., 2018).

Within a corporate setting, digitalization is changing business models and transforming production processes, supply chains and innovation and development procedures. 4IR technologies are supposed to generate a supply-side miracle, with long-term gains in efficiency and productivity (Schwab, 2015). The advanced digitalization within factories is setting up the basis for a new fundamental paradigm shift in industrial production. According to Lasi et al. (2014), social, economic and political forces induce a remarkable need for changes in business operations. "Time to market" is becoming an essential success factor for many enterprises, so that development and innovation periods must be shortened. Moreover, a shift from a seller's into a buyer's market is occurring, which leads to a more customization or to individual products in extreme cases. Emerging technologies provide the tools to leverage flexibility, decentralization and faster decision-making procedures, as well as resource efficiency to successfully compete in the changing business environment (Lasi et al. 2014). On the other hand, a technology-push is becoming evident in industrial practices. Further increasing mechanization and automation are transforming production sites in smart factories, where manufacturing will be completely equipped with sensors, actors, and autonomous systems that provide support for the functions of analysis and control. The scenario in which products control their own manufacturing process, is believed to realize the production of individual items in a batch size of one, while keeping the economic dynamics of mass production (Lasi et al. 2014). Networking, in turn, acts as a driving force for the application of new technologies like simulation, virtual augmented reality and digital protection. Driven by a drop in transportation and communication costs, logistics and global supply chain will also become more effective. Real-time information via RFID, for instance, allows a widespread integration of systems independent from the location (Lasi et al., 2014).

Thus, the Fourth Industrial Revolution promises to deliver both decreased production costs and increased flexibility, two competitive capabilities that have traditionally been seen as trade-offs. Due to these potentials, many industries are strategically working to introduce new digital technologies into their factories (Lorenz et al., 2020).

At the same time, Industry 4.0 forces companies to rethink their business models and to adapt to new forms of competition. One of the already evident implication of 4IR is that product and process innovation is more and more taking place in the virtual layer of software, rather than in any hardware component (EPO, 2017). Inventions based on software implementation, are known as computer-implemented inventions (CII) and account for a large part of technological advances in many diverse areas. 4IR technologies are set to replace hardware innovations by shifting functionalities of inventions from mechanical or electrical parts to the digital world (EPO, 2017). While the opportunity to upgrade the device with new applications instead of buying a new one is already familiar in PCs and smartphones, the generalisation of IoT is reproducing the same pattern to all sort of hardware, including vehicles and factories. As a consequence of the transition toward software-driven inventions, the physical complexity of product, namely the number of physical components or the production steps required to build and assemble them, is reducing (EPO, 2017). Also, computer-generated product design and three-dimensional (3D) printing, are likely to reduce barriers between inventors and markets. New technologies for prototyping allow entrepreneurs to bring their idea "to reality" without the traditional time constraints and to establish small companies with lower start-up costs (Armengaud, et al. 2017).

A small number of large companies, most of them with a strong focus on ICTs, are driving the development of such emerging 4IR technologies. Europe, U.S. and Japan started investing in the field in the mid-1990s, and they are still the main innovation centres. Within Europe, Germany and France are foremost in 4IR domain. In the Republic of Korea and in

China, the revolution started later; however, during the last decades it has been increasing at a faster rate than other regions (EPO, 2017).

### 3.2 Industry 4.0 in the Automotive Sector

"Digital transformation will affect the entire automotive value chain, including design, production, distribution and retail, reshaping the traditional automotive business model. New models will consider data, connectivity and cybersecurity."

- (Frost & Sullivan's Future of Mobility, 2017)

According to many, the automotive industry is at the forefront of the new industrial revolution. The headlines portend the advent of an imminent disruption since years, and the literature on the theme appears to generally recognise the tumultuous potential of the emerging technologies. The Global Automotive Executive Survey 2019 ranked digitalisation and connectivity as the key trend up to 2030.

For the truth, it has also to be highlighted that a minor part of the automotive consultants and researchers are sceptical about the disruptive impact of Industry 4.0 on the sector. These argue that digitalisation in the industry is still modest, and there is no empirical evidence that it will cause major changes in the near future. According to Pardi (2019), the turmoil about the incoming revolution led to a paradoxical situation where it is no longer the future that is envisioned as the result of current evolutions, but is the present that is shaped by visions of future based on the promises of the digital technologies. Furthermore, the research so far has predominantly focus on industries whose products are non-physical; as a consequence, the managerial challenges stemming from digital transformation in sectors with characteristics similar to the automotive remain to be partially determined (Hanelt and Piccinini, 2015).

In order to provide a comprehensive examination of the impact of the Industry 4.0 on the automotive sector, it is useful to organize the analysis into two macro areas. The first section of the paragraph will focus on the implementation of 4IR technologies along the automotive supply chain, to assess the benefits and the challenges of the changes in the development and design processes, production and assembly line. At a later stage, it will be assessed the impact of emerging technologies on the end product. The redefinition of the nature of the car and, more in general, of the entire concept of mobility, is the crucial factor

that is leading automakers to revisit their business models, and is paving the way for the entry of new players (Hanelt et al., 2015).

#### 3.2.1 The Impact of Industry 4.0 on Automotive Supply Chain

Since the introduction of mass production, the stamping, welding and painting of the vehicle have been gradually mechanized, preparing the ground for the automation of most of these assembly activities in the 1970s and 1980s (Pardi, 2019). GM, Fiat and Volkswagen were among the most engaged in the process of searching efficiency through the implementation of advanced technology. Nevertheless, these massive efforts resulted in extremely expensive factories, whose performance were unsatisfying due to frequent machine stops and low flexibility (Pardi, 2019). A second wave of automation was instead promoted by Japanese carmakers in the second half of the 1980s. As in the case of the Western experiments, the higher level of automation generated high capital costs and lower flexibility (Pardi, 2019). Furthermore, for some decades the pace of adoption of automated technologies in global automotive factories has slowed down because of two main connected factors. The first one is related to the entry of China in the WTO and the consequent addition of millions of skilled and unskilled workers to the world supply of workforce. To reduce costs, rather than pursuing automation, OEMs have shifted production to low-wages countries. A second factor must be sought in the constant increase in product variations driven by competition in the first decade of the millennium. In fact, the reduction of product variation has been identified as one of the preconditions for the further diffusion of automation (Pardi, 2019). Nowadays, instead, industry 4.0 pushes for a revival of that hightechnology strategies that the automotive sector has been exploring since the early 1980s.

As already mentioned, a multitude of interrelated technologies are involved in the context of the Fourth Industrial Revolution, some of which represent new forms of automation, and some of which do not (EPO, 2017). Apart from robots, cyber-physical systems, that is, self-regulating constellations of objects that communicate through the IoT and employ sensors and real-time computing techniques (Krzywdzinski, 2017), is a core development in the field of automation. Some authors also mention the introduction of artificial intelligence solutions as a way of automating some areas of white-collar work, but we are still far away from such developments (Krzywdzinski, 2017). Other significant paradigms involved in the concept of industry 4.0, instead, do not proper correspond to automation, as digital assistance systems. Taken as a whole, 4IR technologies allow for the reduction of production costs while improving product quality, production scalability and

individualization, by means of digitalization. Digital tools promise considerable rewards, and leading multinational organizations and their largest suppliers seem intent to take the opportunity stemming from their implementation. For example, Dieter Zetsche, Chairman of the Board of Management of Daimler emphasized that "for Daimler, digitalization is the biggest enrichment since the invention of the automobile" (Kern, and Wolff, 2019). Considering it as a matter of strategically relevance, biggest OEMs drive the revolution forward. They already have the infrastructures and employees with certain skills in place to implement such emerging technologies, even though it will not lead to immediate improvements. On the contrary, small and medium enterprises face a different situation: they have less resources available and must manage them guardedly. Thus, digitalization for the sake of digitalization is not an option, and many digital technologies are deemed as comporting big costs compared to the little positive impact they have. As a consequence, the adoption of 4IR technologies varies widely among actors in the automotive sector, especially on the ground of firms' size and position (Kern, and Wolff, 2019).

Differences in attitude toward Industry 4.0 are also visible when comparing different countries. In China, for instance, the labour costs are lower, making the return on investments for technologies aimed at improving efficiency, such as AGVs or robots, lower than in other nations. For this reason, some companies could prefer to pilot new technologies in developed countries first, and eventually introduce them to their plants in China. On the contrary, other firms choose to adopt a technology in all factories simultaneously, in order to maintain a global standard and exploit economies of scale (Kern, and Wolff, 2019). The motivation for embracing new technological procedures also varies across countries. A study about digital transformation of the automotive supply chain found that in China emerging technologies are implemented in the pursue of efficiency and cost reduction, while in Germany the reason is better planning, flexibility and customer satisfaction (Kern, and Wolff, 2019).

Experiments with the implementation of emerging methods are thriving among automakers, which employ diverse technologies in various areas, and to a different extent. What is going to be discussed next is an overview of the concepts with a high practical relevance for the digital transformation of the automotive supply chain, as emerged from a literature review.

Starting from the product development process (PDP), the growing use and accuracy of virtual development and simulation tools has been a major source of novelty (Trombini and Zirpoli, 2013). Car design requires continuous adjustments and reviews, and demand to

revert previous decisions several times before the vehicle reaches production stages. These characteristics make it the most expensive and time-consuming phase of the entire process, accounting up to 70% of the total cost of the end product (Lawson et al. 2015), and taking from 4 to 6 years (Kern, and Wolff, 2019). The use of virtual tools is associated with the reduction of both costs and time, due to the replacement of physical mock-ups with virtual ones than can be modified in real time. VR can be utilized for the evaluation already in the early stage of PDP, which would be impossible for physical prototype because of the required production time, and the rebuilt in case of design changes. In this way, virtual experimentation provides carmakers with the opportunity for investigating hypotheses that are not constrained by the bounds of the premises one starts from. Furthermore, thanks to virtual tools, multidisciplinary teams and geographically dispersed teams can work together on the same prototype at the same time (Lawson et al., 2015). The design quality is also optimized via the availability of information very early in the process and the avoidance of the so called "bottleneck effect", which manifests from errors in the inception of the development (Lawson et al., 2015). The integration into the digitalisation of information related to the end product during its in-use phase, ensures that data collection covers all the aspects of the product lifecycle, including customers' usages as late configuration or remote upgrades. The interaction back from production and usage to earlier development steps would enhance the efficiency and flexibility of the innovation procedures (Armengaud, et al. 2017). Most importantly, the use of virtual tools in the design process provides the chance to enlarge and differentiate product portfolios without scarifying efficiency. The final advantages consist in the reduction of both time-to-market and total cost of ownership (TCO), guarantying in the meanwhile a higher degree of customization. By all means, the proliferation of model variants is limited by the necessity of sharing components and platforms across these models, to leverage economies of scale and scope (Trombini and Zirpoli, 2013).

Virtual realities alter the infrastructure management and the customer interface to a large extent; when virtualization tools are employed, competencies and cost structures are also distorted. Historically, vehicle design and production has been core processes of the automotive sphere, associated with their engineering expertise. Now, digital skills partially replace them (Hanelt et al., 2015). Several OEMs around the world are currently investing in the implementation of VR products. One striking example is given by Jaguar Land Rover, whose design and engineering headquarters in Warwickshire, UK, hosts the Virtual Innovation Centre (VIC), a milestone for VR technologies for automotive applications.

Virtual realities do not affect only processes before the vehicle production (i.e. design phase), but also the phases after. Car manufacturers in fact provide virtual showrooms or even allow potential buyers to test the vehicles virtually in video games (Hanelt et al., 2015).

Moving to the production and assembly stages, IoT is considered nearly indispensable within firms and across the supply chain; in particular, it permits to monitor parts and serves to optimize the logistics flows. For instance, RFID can be installed in pallets that carry the item, so that once the product arrives at a production line where RFID gates are set up, it signals the required next manufacturing process. If the process is not finished correctly or a part is defective, the pallet can be sent to a dedicated station where operators receive automatically information about the progress (Kern and Wolff, 2019). Volkswagen employs a similar technology to trace special load carriers and returnable packages in their way from suppliers to assembly plants and vice versa.

As far as robotics is concerned, automotive industry is a pioneer in robot usage in production, and now it is actively working on utilising this technology further across the supply chain (Kern and Wolff, 2019). Order preparation, in particular, represents a key focus in the pursue of automation, as it accounts up to half of the storage and handling costs (Kern and Wolff, 2019). Here, pick-and-place robots can speed the process by picking parts up and placing them in new sites. Working both autonomously or alongside with humans, robots perform non-value add and repetitive tasks, as packaging, to let operators focused on more skilled activities. This results in a higher productivity with zero maintenance.

Automated Guided Vehicles (AGVs), which move either along physical or magnetic guidelines, by laser or with satellite navigation, represent another spread innovation, and are mainly exploited to tow and carry raw materials inside plants. Driverless trains bridge the distance from the warehouse to the production lines, so that workers do not need to spend time picking up materials and freed for higher added value tasks. Accordingly delays and materials damages are dwindled down (Kern and Wolff, 2019).

Lastly, digital assistance systems, which include not only tablets and smartphones, but also data glasses, smart watches etc., are become an integral part of supply chains. In the automotive context, there exist the more varied applications of mobile devices. To name one, in its Anderson plant, Bosch equipped line operators with smartwatches. In case any line fault occurs, a message is sent to smartphones which is then transmitted via Bluetooth to all smartwatches on the line. The vibrations on their wrist warn the operators that an urgent message has arrived and they immediately apprise the type of error and the exact location. Thanks to these real time alerts workers can react to faults even before line stops occur, thereby reducing downtime (Lee, 2015).

While it provides exceptional opportunities to OEMs, digital innovation also comes with significant challenges. Asides the high costs to implement new technologies, standardization is one of the main issues related to the digitization of the industry. In the automotive sector, there exist various competing standards, typically developed by regional industry associations such as Odette in Europe, VDA in Germany, AIAG in North American or JAMA in Japan (Kern and Wolff, 2019). However, standards often do not keep up with latest industry developments, thus encouraging the proliferation of companies' own solutions. Besides, OEMs frequently set up own standards and force them on their suppliers (Kern and Wolff, 2019).

As argued above, digital manufacturing and smart product and service systems, empowered by a seamless end-to-end information flow spanning the complete product life cycle, go hand in hand in Industry 4.0. These paradigms are rendered possible by the high integration of complex interconnected embedded systems of electronics. Such cyberphysical systems are progressively taking over control of essential value-added functions, which, in industries like automotive, aeronautics, medical, nuclear power plants, are often safety critical (Armengaud, et al. 2017). Due to the Industrial Internet of Things (IIoT) and the growing reliance on automation and big data, the vulnerability of CPS is significantly increased with respect to traditional, less networked systems, making cybersecurity the biggest risk, and the major priority, in manufacturing. With increasing amounts of data and the advances in computing, data security is become one of high priority (Armengaud, et al. 2017). To avert the risk of a security threat, companies store data on own servers in countries with a supportive regulatory framework, use firewalls and systems without internet access. Data are often classified based on sensitivity, and they are stored according to their security class. Nevertheless, companies are aware that certain data must be secured while other has to be shared with supply chain partners (Kern and Wolff, 2019).

Among the other changes, the digital transformation implies also a shift in the workforces' competences. With data being more pervasive in the supply chain, employees must be versed in data analytics and data management techniques. Asides of this professional competence, soft skills, such as interpersonal cooperation, will become more and more significant in an interconnected business world featured by people moving between different roles and projects (Kern and Wolff, 2019). Employees have to be open to new ideas and innovations, in addition to embracing changes that the digital transformation will bring.

Conscious of the importance of investing in people, OEMs are implementing advanced training approaches. For example, Volkswagen offers its employees a dual education "Robotronics Program" in its own Volkswagen Academy, which will teach the use of advanced manufacturing skills involving robotic technologies, engineering design, network programming, and troubleshooting and maintenance. This two-year program combines classroom education and paid on-the-job training.

Despite the active effort of leading firms, it persists the threat of a massive job displacement, in common with other industries affected by the advent of the digitalisation. Two years ago, GM announced the cut up to 14.800 jobs in the U.S. and Canada. This decision, which was all over the papers, has been ascribed to the company's aggressive transition from analog to digital products. GM's layoffs reflect the talent strains associated with the diffusion of digital technologies in the auto sector – and also in firms all across the economy (Muro and Maxim, 2018). What is more, emerging technologies are going to contribute in deskilling of roles, and in intensifying the disciplinary control over work, through data collection and analysis. These changes will further weaken bargaining power of autoworkers; in Germany, for instance, trade unions have identified the threats and negotiate the introduction of new technologies (Pardi, 2019).

## 3.2.2 Autonomous and Connected Cars

It has been more than 30 years since the first introduction of ECUs in cars; as mentioned in the previous chapter, those small software components have been the preamble for the development of a huge amount of services building on new enabling technologies and the creation of complex architectures, networks and programs (Broy, 2016). From that point forward, more and more sophisticated functionalities have been provided in dashboards, especially GPS functions, which laid the foundation for the concept of Intelligent Transportation Systems, where cars are conceived as moving nodes whose location can be traced and used to perform traffic management operations (Coppola and Morisio, 2016). More recently, research efforts have been focused on the opportunity of enabling communication between vehicles and Internet, in order to access a variety of data sources and to provide advanced multimedia and infotainment services to passengers, that extent beyond navigation and radio functionalities traditionally provided by carmakers (Pini, 2018). Lastly, due to the diffusion of smartphones, it has taken hold the idea to integrate connected devices with in-car dashboards. The result are modern cars equipped with connections either internal, such as the bus systems connecting sensors and computers on

board, and external (Coppola and Morisio, 2016). "Connected cars" have been defined as "vehicles capable of seamless integration with multiple systems, connecting passengers to the digital world" (Brookes and Pagani, 2014). The automobile is become itself a system with a wide number of computing devices connected one another via dedicated buses.



Figure 4: Connected Car

Source: Coppola and Morisio (2016)

According to Scalas and Giacinto (2019), the information exchanges done by connected cars can be clustered into *Vehicle To Sensors On Board Communication (V2S), Vehicle To Vehicle Communication (V2V), Vehicle To Road Infrastructure Communication (V2R),* and *Vehicle To Internet Communication (V2I).* V2S, or intra-vehicle connectivity, refers to the information transmission between the ECUs and sensors disseminated inside the car, and can occur both on wired, or wireless network. V2V, or inter-vehicle connectivity, indicates data exchanges between different cars, without the intermediation of a centralized remote hub, that form a vehicular ad hoc network (VANET). Some companies have also developed *Vehicle To Pedestrian* (V2P) technologies which send people alerts about dangerous vehicles nearby. V2R connotes the connections between a car and an intelligent road structure, consisted of street signs, roadside sensors, and traffic lights, while V2I alludes

to the fundamental prerequisite for a connected car, namely the access to the Internet. The figure above (Figure 1) offers a graphical representation of a connected car and its connections.

Interconnected smart vehicles offer a range of sophisticated services that benefit vehicle owners, transport authorities, car manufacturers, and other service providers (Dorri et al., 2017). For example, they can monitor driver stress in term of heart rate variability though advanced seats or by steering wheel speed sensors. If the driver is a dangerous condition, they have to be effectively alerted. Driver fatigue, anger, and stress detection have an enormous potential to prevent car crashes, as drowsiness is among the major causes of serious or fatal accidents (Coppola and Morisio, 2016). What is more, Driving Assistance Systems are capable of analysing the road to signal to the driver spotting risks, maintaining a proper trajectory, circumventing sudden obstacles, or even taking an automatic decision. When accidents actually happen, smart SOS systems notify the nearest service for road or medical assistance, thus mitigating the consequences of the crash.

With the establishment of automatic brake and speed control, steps have been taken towards a fully Autonomous Vehicle (AV), corresponding to the *level 5* of the framework provided by the Society of Automotive Engineers (SAE), where the presence of the driver inside the car is not needed at all. Full vehicle automation lies within the wider notion of Automated Highway Systems (AHSs): the final goal is to remove the human factor as much as possible from the control of vehicles, thus increasing transportation system capacity, improving safety, reducing environmental impacts of transportation, and assuring long-term cost savings (Coppola and Morisio, 2016). AVs are one of the most discussed topics in the automotive market, and there persist legal constraint for concrete adoption.

In-advance diagnostics of malfunctions, made possible by information gathered onboard, contribute to provide maintenance support to the car owner. In case of theft, stolen vehicle assistance allows to take some action, such as blocking the car or contact the authorities immediately.

As far as infotainment is concerned, modern technologies substitute traditional radios with online streaming services similar to the ones that are available on smartphones, enrich the dashboard with internet browser functionalities, video streaming and gaming services, and many other functions. By all means, the activations of those systems must be carefully supervised, because the driver's attention cannot be taken off the road. In-car interfaces have historically been produced by car manufacturers, following automotive industry's tradition of developing proprietary and closed systems. However, new infotainment services

emphasize the need for applications capable of running on platforms adopted by more than just one car manufacturer. Software Development Kits (SDKs) shall be provided to thirdparty developers that will manage to render their apps available on a marketplace for car users to download them. If there is not a standardized approach for communicating with the car, then a specific version of the software has to be created for each automaker (Coppola and Morisio, 2016).

Online route planning, traffic and road condition monitoring, as well as tools to calibrate the car functioning to optimize energy consumption are all options provided by digital technologies, which OEMs across the world are exploring. Groupe Renault, for instance, is experimenting with installing digital twin on its vehicles, and storing them on a blockchain-based system. Some years ago, the company released a prototype, co-developed with Microsoft and VISEO, that uses blockchain to connect each new vehicle's maintenance events to the vehicle's digital twin. This data is visible to authorized parties. As the digital twin is fully transferable on the blockchain-based system, each vehicle's maintenance history remains connected to the vehicle even when there is a change of vehicle ownership (Heutger et al., 2018). Technologies similar to this one are useful to accurately evaluating the car, in a more detailed way than the traditional vehicle self-diagnostic and reporting functionality (OBD) permit to do. OBD-II, an evolution of the first technology, is mandatory for all cars manufactured since 1996 (Coppola and Morisio, 2016). Now, algorithm-based tools can also price used car, according to the data gathered. An analogue procedure can instead measure driver's behaviour and profile the insurance.

Some automakers are also investing in the integration of vehicles with smart-home functionalities, to provide passengers with the opportunity to enable devices such as lighting or heating before approaching home. Ford, for example, has developed a connection from the steering wheel to Amazon's Alexa, giving access to devices as garage doors.

The advent of digital technologies brings about an expanded amount of legal constraints, government regulations and standards that OEMs must fulfil, by virtue of their role of system-integrators. The electronic architecture of the vehicle has traditionally been designed and standardised as a "closed" system, in which all the data of the ECUs remained in the internal network. However, the above new services imply instead that data spread across multiple networks. This result in a bigger attack surface, namely new possibilities to be vulnerable to the attackers, similarly to the scenarios portrayed in the context of the supply chain's digitalization (Scalas and Giacinto, 2019). The potential attack might me moved by different motivations, such as vehicle or data theft, extortion or intellectual challenge.

Accordingly, researchers are pledging to leverage IT methodologies from other domain in order to resolve such safety-critical issues. Nonetheless, 84% of the professionals working for OEMs and their suppliers still have concerns that cybersecurity practices are not keeping pace with evolving technologies (Scalas and Giacinto, 2019).

Besides, collecting vast amounts of data from connected cars creates privacy and ethical hazards. Sensitivity of disclosed personal data is bound to be substantially higher for connected car services than traditional electronic services as highly detailed habits and mobility patterns can be derived (Derikx et al, 2016).

# **3.3 Digitalisation of the Automotive Industry: The Role of External Knowledge Sourcing**

From the previous paragraphs it has emerged that automotive industry is en route for a digital transformation. The aim of this section is not to assess if 4IR technologies truly have the potential to disrupt the industry, leading to a breakdown of its competitive patterns, and eventually to the dismission of established organizations. This topic is indeed still strongly debated, especially because the Fourth Industrial Revolution is being identified before it happens, and all its effects are forecasts (Klingenberg and Antunes, 2017). This notwithstanding, is undeniable that emerging technologies promise to deeply alter the dynamics that traditionally ruled the automotive sphere. In fact, while on the supply side digitalisation is expected to generate strong productivity growth, the redefinition of the nature of the automobile from a status symbol to a device for digital experiences threaten OEMs' business models (Hanelt et al., 2015). Moreover, all the major innovations affecting both the end product and the production process have a common denominator, namely information technology, and literature has established long time ago that IT transformation implies massive organizational changes (Piccinini et al., 2015).

Thus, in the next lines it will referred to framework explaining disruptive technological innovations, in order to comprehend which challenges the digital trend is bringing about for automakers. At a later stage, it will be considered how car manufacturers are reacting to such issues, and, in particular, the channels through which they are tapping into external skill and experience. Indeed, while each innovation process relies on the extension of a firm's competences, external knowledge is of specific importance when dealing with discontinuities (Hildebrandt et al., 2015).

#### 3.3.1 The Impact of Industry 4.0 on Automotive Traditional Business Model

Christensen (2013) argues that disruptive innovations imply a different package of performance attributes than those provided by mainstream technologies, thereby shifting the base of competition. In this respect, digital technologies are increasingly catering to the personalized individual needs of consumers, so that diverse industries worldwide deal with a differentiation of quickly changing demands (Hanelt et al., 2015). Automotive sector is not the exception: customers call for environmental responsibility, safety, as well as digitally enhanced mobility experiences. It appears that car buyers' preferences are no longer focused on technical performance measures, but rather on aspects such as connectivity, information or entertainment. Consistently with other industries impacted by digital transformation, the automotive sector is moving from a goods-dominant- towards a service-dominant logic, which forces car manufacturers to rethink their business model, in order to find a balance between physical components and digital functionalities within and outside the vehicle (Hanelt et al., 2015).

According to Hanelt et al. (2015), automakers have already extended their offering for specific customers niches, without introducing serious changes to the core logic of the dominant business model of the industry. Firstly, they addressed users' growing requirement of getting access to personal data and entertainment the same way whether they are in their home, office, or car. In order to do so, OEMs undertook significant efforts to ensure the compatibility of mobile devises, especially smartphones, with the car. Moreover, they have approached an emergent customer group: young and tech-savvy people. Digital natives place more emphasis on the digital expect of life and expect more information, dialogue, and dynamics when buying a car. To boost interactions with this segment, automobile manufacturers developed customers interfaces, e.g. in the design phase. Researchers in the field of product co-creation has indeed pinpointed that virtual interactions enable companies to promptly perceive and react to variable customers' needs and preferences (Hanelt et al., 2015). On the other hand, this trend alters the role of the customer towards a co-creator of value, which cannot be captured in established business model designs. As customers want to be more than just buyers, the customer relationship is getting more demanding for automobile manufacturers (Hanelt et al., 2015).

The opportunity of delivering services through the car, such as smartphone capabilities, infotainment services, driver-assistance apps and so on, represents a promising area for future differentiation and profits. Drawing on Industry 4.0 opportunities, especially

big data, cloud services and mobile technologies, automakers are enabled with new possibilities to propose mobility solutions that do not require a vehicle at all (Hildebrandt, 2015). Digital technologies unlock new types of business models, either targeting at the driver or at new possible customers, such as municipalities or local governments. Here, the physical process of driving is only used to generate the core offering (data), which is completely digital (Hanelt et al., 2015).

However, the new digital ecosystem puts into question traditional carmakers, which, in the near future, could become car service providers and no longer car manufacturers (Attias and Mira-Bonnardel, 2017). Several reasons are involved in this scenario: the creation of value generated by service contracts (availability of autonomous driving software, memory card to manage traffic or weather, etc.) will be greater than that initially created by the manufacture of cars. Most of the income resulting from these service sales already goes to companies other than the carmakers (Attias, 2016). Nowadays, the displacement of added value from products to services is a trend that many industrialized economies have in common, which is responsible for a drop in profits (Attias, 2016).

Current top end vehicles have about 200 million lines of code, up to 200 Electronic Control Units (ECUs) and more than 5 km copper wires, meaning that the "mechanical" world of original equipment manufacturers is converging towards that of IT companies (Scalas and Giacinto, 2019). Accordingly, even though traditional business models are still dominant, digital business models are more and more acquiring importance for an OEM to be successful (Piccinini et al. 2015). Leading firms are charged with the challenge of simultaneously handling established business operations while immersing into new value creation activities. For instance, they need to align considerable short-term digital technology investments with long-term strategic business planning and digital capability development (Piccinini et al., 2015). Furthermore, they are required to integrate different innovation philosophies of digital products (i.e., experimental, unfinished, market learning) and the car (i.e., planned, finished at time of market introduction) (Piccinini et al., 2015).

Self-driving, from its part, also represents a dramatical variation of the value proposition. Here, the drivers no longer need to drive the car, and have the freedom to use their smartphones, check their emails or make use of infotainment (Hanelt et al., 2015). Despite having revealed to be ready for the production of fully autonomous vehicles, main OEMs in the race are integrating automated features slowly in their models. Legal issues, as well as customer acceptance are certainly the main reasons that prevent lead firms to commercialise AVs; however, some scholars have identified in this delay, an attempt to keep

the disruptive technology controlled and to moderate the impact on value architecture (Bartl, 2015; Hanelt et al., 2015).

Lastly, through mobile devices and GPS technology, multi-modal mobility solutions become more integral; OEMs have thus begun to offer integrated mobility services involving several means of transportation. In this case, the value proposition changes from delivering a product (the car), towards delivering also an integrated service (mobility), and the link to the customers is no longer a 1:1 relationship between car and user (Hanelt et al., 2015). Daimler AG and BMW AG, for instance, have launched sharing programs, in which cars can be reserved on the Internet or by using an iPhone with an application that indicates the place in which available vehicles are parked (Automotive News, 12/10/2010).

Effects of entirely connected and autonomous vehicles (CAVs) on car ownership and car travel demand are still unclear. If most CAVs are privately owned, car ownership levels could remain untouched or even increase. On the contrary, if CAVs will be part of carsharing-like programs with robotic cars ordered on-demand, car ownership rates may drop (Buehler, 2018). According to Buehler, the achievement of fully self-driving and connected vehicles, prove a threat to traditional public transportation. CAVs, indeed, by allowing individuals to engage in activities other than driving a car, mimic one of public transportation's competitive advantages, and make the two value propositions mutually exclusive. While in large metropolitan areas and central cities public transportation demand is strongest due to the limits of automobile usage, driverless cars may further increase suburban sprawl and create more sites that are difficult to serve by public transportation. Governments and policy makers will have a crucial role in shaping the competitiveness of public transport services. They could invest heavily in the development of infrastructure for CAVs, thus reducing funds available for public transportation. On the contrary, they could exploit emerging automated and connected technologies for public transportation, integrating it with other mobility services (Buehler, 2018). For instance, employing suburbs automated and connected buses would allow to carry passengers from and to public transportation stations to access light rail, regional rail, or metro rail.

# 3.3.2 External Knowledge Sourcing

Competence-based explanations of disruptive innovations assert that the position of incumbent organizations is threatened when technological discontinuities undermine existing capabilities (Tushman and Anderson, 1986). Dropping this reflection in the automotive reality, OEMs have traditionally followed a dominant engineering logic,

whereby the tangible goods (i.e. the car) holds centre stage, and the complete production process, from design to manufacturing, is organised into linear and subsequent steps (Hildebrandt et al., 2015). Product functionalities are decided and designed beforehand; once the characteristics are settled, firms focus on process innovation and economies of scale rather than fostering technology innovation. In contrast, digital technologies rely on a layered architecture in which devices, networks, and contents chase a different functional design hierarchy. The physical aspects of digital devices, the hardware, are split from the non-physical side, the software (Hildebrandt et al., 2015).

When digital functionalities are embedded into physical products, a hybrid, layered modular architecture arises, which engenders dramatic alterations in the way firms organize their logic of innovation (Hildebrandt et al., 2015). Most notably, in a digital context the knowledge is spread across heterogeneous disciplines and domains, and no longer concentrated in the hands of a few specialized firms. The exponential growth and development of Industry 4.0 technologies, as well as their variety and embedded complexities, make it extremely difficult for firms to keep abreast of all new opportunities for innovation (Lorenz et al., 2020). As a consequence, OEMs are forced to source new knowledge from very different actors and fields to bridge their competence gaps, thus accentuating the need for an open innovation model that was slowly spreading in the industry during the last decades. In fact, the automotive panorama was extended over time, with alliances, collaborations and partnerships whose goal was to pool technical and financial resources while keeping a dominant share of the market (Attias and Mira-Bonnardel, 2017). The emerging mobility paradigm has created a new innovation momentum, and with the arrival of new entrants, led to a reorganization of the entire industry (Attias and Mira-Bonnardel, 2017).

Consolidation has always been a key trend within the automotive industry (Sturgeon et al., 2008). Greater size safeguard against regional sales volatility and contributes to spread investments across a larger number of cars, which is essential in a capital intensive, fiercely competitive environment, such as the automotive. This results in significantly high entry barriers, and meaningless threat of new entrants. Over the last 15 years, despite the digitalization process that the industry went through, only 2 new players have appeared on the list of the top 15 OEMs. The figure is all the more significant if compared with handset sector - which in turn experienced technological discontinuities - where the number of players is increased of ten units (Auto Tech Review, 2016). However, the digitalization of the entire value chain, inevitably constrain traditional leading firms to compete on multiple

fronts. The overlap of physical and digital infrastructures involves the emergence of new and non-industry rivals, IT organizations and start-ups, which have specific knowledge and more experience with digital products than automotive firms. Mobility providers (e.g., Didi Kuaidi, Uber, Zipcar), tech giants (e.g., Apple, Google), and emerging OEMs (e.g., BYD, Tesla) intensify the complexity of the industry's competitive landscape (Auto Tech Review, 2016). New players are believed to initially target only specific, economically attractive segments or focus on selected activities along the value chain, and eventually expand from there (Christensen, 2013). While Tesla, Google, Apple, Intel, and Uber have already aroused the interest of consultants and academics, they might represent just the tip of the iceberg. Many more new players are likely to enter the market, especially start-ups and high-tech companies (Auto Tech Review, 2016). Similarly, some Chinese car manufacturers, who experienced impressive sales growth recently, could also play an important role globally by leveraging the ongoing disruptions and outranking established competitors (Auto Tech Review, 2016).

In order to survive in the new digital ecosystem, digital knowledge must be incorporated in the knowledge domain lead firm need to master. The need of integrating knowledge from distinct and distant areas can be accomplished by attracting new talents with expertise in digital technologies and business, which is extremely though, as such people generally find technological organizations (such as Google or Apple) more interesting to work at than automotive organizations (Piccinini et al., 2015). A further demonstration of the effort that leading firms are taking to adapt internal competence to digital necessities is given by the current workforce composition. The industry is no longer anchored by workers responsible for mechanical and machine-maintenance roles, as the increasing electronic content of the car and the digitalisation of the supply chain have led OEMs to increasingly look for software engineers, energy management experts, and data scientists. Within the automotive industry, IT has taken on a new role, switching from the function of back-office support to become an integral part of the business model and strategy (Piccinini et al., 2015). These units now must work seamlessly with the manufacturers' other functions; there is no place for the traditional barriers that have separated the various internal functions (Wee et al., 2015).

As of 2016 the fastest growing occupations in the U.S. auto sector were computer network support specialists and software developers while machine operators and metal workers were the categories where cutbacks achieved the higher level (Kern and Wolff, 2019).

Figure 2: Growth Rate of U.S. Auto Sector Occupations<sup>6</sup>



Source: Muro and Maxim, 2018

However, adjusting competences internally may not be enough to deal with the digital transformation of the industry, so that automakers are forced to leverage collaborations with other actors. An example of the effort of taking advantage of external knowledge is provided by Volkswagen's initiative "Future Automotive Supply Tracks" (FAST). Launched in 2015, the program is instrumental for implementing technical innovations more quickly than before, with a view to partnerships. Thanks to FAST, Volkswagen was able to partner up closer with selected allies, such as Microsoft, Infineon, Cree/Wolfspeed and AVL List (Volkswagen AG, 2019). One of the latest announced strategic partners is IBM, with which Volkswagen will share its cloud services and AI-based technologies (Volkswagen AG, 2019).

As a response to digital transformation, car manufacturers are increasingly approaching to a competition-cooperation strategy, coined as "coopetition" by Brandenburger and Nalebuff (1996), that first spread in high-tech industries. Here, collaborative allies are already part of the automotive industry (Attias, 2016).

<sup>&</sup>lt;sup>6</sup> Tool setters, operators, and tenders, metal and plastic.

In September 2013 PSA Peugeot-Citroën established The Business Unit Smart Car whose purpose is "developing services based on connected and digital cars that will make it possible to respond to new uses and requirements in terms of mobility", as explained by the strategy manager Bonnefont<sup>7</sup>. To speed up the development of services tailored to customers, the French carmaker decided to lean on IBM's MobileFirst and Big Data and Analytics. According to Courtehoux<sup>7</sup>, PSA's Connected Services and Mobility Business Unit Director, the analysis of collected data provides precise knowledge about vehicles' faults and drivers' behaviours, allowing to the optimization of the offers, in terms of both product quality and price (Attias and Mira-Bonnardel, 2017). Most recently, BMW and Daimler have teamed up to develop autonomous vehicles, targeting 2024 as a key date for installing the technologies in cars. They announced the cooperation is "non-exclusive", as partner manufacturers and technology firms take part in the work (Reid, 2019). Similarly, Honda has joined General Motors to produce an autonomous car through GM's subsidiary Cruise automation – and the list goes.

Car manufacturers integrate these coopetition strategies with new kinds of crossindustry relationship (Piccinini et al., 2015). The cooperation between carmakers and IT service or communication companies, is a new type of alliance that, out of all, is becoming notably widespread (Attias, 2016). An example is provided by the Spanish OEM Seat, which started to cooperate with Samsung, the Korean telecommunications and electronics company, to annex a connection interface to its cars with smartphones. The alliance was then extended to SAP, the world leader in enterprise applications and business networks. The project, unveiled in 2016, consists in the development of a virtual key to identify vehicle users and a connection to access and pay for parking places from a telephone. In 2016 was instead the turn of SAIC, who announced a billion-yuan investment to create a fund aimed at developing connected cars together with the Chinese electronic commerce giant Alibaba.

New strategic alliances are also emerging in supplier companies. For example, Bosh and TomTom forged a partnership to work together on high-precision mapping, a key technology for the realization of automated driving. TomTom will bring its knowhow in the field of mapping and traffic monitoring, while Bosh will provide its systems management experience to define mapping precision. The fact that two suppliers intend to exploit the opportunities offered by the development of autonomous vehicles, without involving any OEMs for the time being, is sufficient to raise the issue of tomorrow's leadership (Attias and

<sup>&</sup>lt;sup>7</sup> L'usine digitale, 2014. PSA veut valoriser le Big Data de ses voitures connectées.

Mira-Bonnardel, 2017). Besides, established suppliers are expected to capture a larger portion of the vehicle's total value. As they move to produce more complete vehicle subsystems, suppliers will even set up their own touch points with the end consumer to further appropriate of aftersales mobility expenditure (Auto Tech Review, 2016).

Beyond collaborative alliances and partnerships, mergers and acquisitions are among the most prominent solutions traditionally exploited by car manufacturers to obtain external expertise, especially in the case of knowledge complementary to the existing one (Hildebrandt, et al. 2015). According to Hildebrandt et al. (2015), M&As strategies are positively associated with digital business model innovations, in contrast with previous researches that demonstrated that M&As tend to produce negative impacts on innovation in automotive industry. By acquiring external heterogeneous know-how via M&As, lead automotive organizations appear to be capable to avoid the trap of deploying the same process and mindset they established for physical innovations, and benefit from the potential of digital technologies. The same study emphasized the role of past experiences in enhancing the outcome of such collaborative strategies; albeit being new to collaboration with digital partners, the general expertise with external knowledge acquisition in other, non-digital contexts increase the likelihood that new partnerships improve the innovation performance. When it comes to the digitization of manufacturing industries, a broad external search is especially important, as it permits to draw ideas from a wide range of different knowledge sources (Lorenz et al., 2020). Since 4IR technologies have already passed the "emerging" stage, and are now maturing into the growth phase (EPO, 2017), the network supporting innovation has expanded. As a consequence, firms can scan across a wider number of sources to make significant improvement in the technologies (Laursen and Salter, 2006). However, the internal knowledge base is assumedly larger for technologies closely related to the core competency of OEMs. To illustrate, many automakers have used automation technologies for a long period of time. Hence, they are likely to have built in-house expertise in the field, which allows them to be more selective when seeking the necessary external knowledge, and they need to scrutinize deeper to gain new competences. On the opposite, for technologies that are less familiar to automotive firms, such as computing technologies and big data analytics, OEMs are motivated to seek broadly externally (Lorenz et al., 2020).

Once lead firms have gained access to new knowledge, the major challenge is to integrate it within the organization, which demand for absorptive capacity. This process is crucial to enable value creation and value capture from acquired external competences. In other words, managers must escape the pitfall of considering "buying" new knowledge on

the market as sufficient to succeed innovating digitally (Hildebrandt et al., 2015). What is more, automakers need to strategically evaluate which parts of the connectivity ecosystem are critical enough to cover internally, in order to profit from emerging technologies and keep the car itself from turning into a commoditized platform (Wee et al., 2015). For those pieces of the process chain identified as control points, the necessary competences need to be built up and kept in-house. Acting as system integrators, OEMs traditionally coordinate the work of suppliers thus maintaining their hierarchical power (Jacobides et al., 2016).

Incumbents seem to have understood the potential for capturing value through the innovative cooperation with companies far removed from the sector. However, the latter compete themselves with start-ups like Lyft, a company General Motors has invested in, which contends market share with Uber (Attias and Mira-Bonnardel, 2017). Likewise, the driverless-car start up Argo AI, backed by Ford, offers an equity stake for new hires. The link to the Dearborn carmaker contributes to lure talents, engineers and robotic researches, to companies of Apple' and Uber's calibre.

In such a fast-changing and chaotic business environment, being able to react rapidly to changes in the ecosystem (i.e., partners, competitors, etc.), the infrastructure (i.e., blending of physical and digital), and the resource composition (i.e., from automotive manufacturer to mobility services provider) is a crucial challenge, which go beyond the mere product innovations (Piccinini et al., 2015). The implementation of a more dynamic, startup-like mentality in leading automotive firms could be difficult because of their long-established organizational culture that does not permit the creation of an environment in which it is considered "safe" or acceptable to fail (Piccinini et al., 2015).

On a final note, it is significant to observe that Big Data analysis provides a great technological chance to grasp valuable information that has been hidden until now, thus sustaining most of the benefits of the open innovation paradigm. It enables organizations to access and handle big volumes of new data from multiple sources, especially sources outside the usual firm boundaries, and to select advanced analytic tools that help predict outcomes of business decisions from these data. To mention one of the countless applications, intelligent marketing feedback empower companies with the opportunity to react to variations in customers' needs more quickly (Del Vecchio et al, 2018). Automakers can benefit from customers interactions to speed up their process of adapting products and services to new trends, which typically require up to two years (Wyman, 2017). In this sense, Industry 4.0 technologies serve both as an input accentuating the need for external search, and a valuable tool to access information from diverse contexts.

# IV Knowledge Sourcing in the Field of Industry 4.0

In a digital context the knowledge is spread across heterogeneous disciplines and domains. The exponential growth and development of Industry 4.0 technologies, as well as their variety and embedded complexities, make it extremely difficult for firms to keep abreast of all new opportunities for innovation (Lorenz et al., 2020). When dropped in an already complex technical environment, such as the automotive industry, the challenges coming from digitalisation are doubled.

In Chapter 3, attempts have been made to understand how OEMs are proceeding to bridge their competence gaps, sourcing knowledge outside traditional boundaries and setting up new forms of cooperative partnerships. Starting from such considerations and trying to provide empirical evidence of the previous results, the aim of this section is to describe the direction and the extent of knowledge flows in the automotive sector, as far as Industry 4.0 is concerned. At this purpose, a patent-based analysis has been performed.

The analysis is structured into two macro area. The first section focuses on focal firms' external innovative search effort as reflected in patent citations, emphasizing first the search along technological domains, and then the variety of sources used by OEMs, such as suppliers, competitors and potential new entrants of the industry. The second part of the chapter will instead exploit the phenomenon of patent co-assignment to detect any trend in the R&D partnering activities of automakers, our focal firms.

## 4.1. Patent-based analysis

Patents are government grants of the exclusive right to make, use or sell an invention, usually for a limited period of time (16-20 years). For a patent to be granted, the invention must be non-trivial, meaning that it would not appear obvious to a skilled practitioner of the relevant technology, novel, namely substantially different from anything else that is public knowledge, and useful, meaning that it has potential commercial value (Jaffe et al., 1993). A patent is thus a class of property rights that can be traded as well as shared with others. Usually, companies apply for patents during the early phase of the overall trajectory of product and process development, namely before commercial feasibility or the actual introduction of new products (Hagedoorn, 2003).

The front page of a patent document has extensive information about the inventor, the company to which the patent is assigned (if any), and the technological antecedents of the invention, which is useful to the study of innovation and innovative influences. It permits to pinpoint an innovation in geographic, technological and temporal space (Phene and Almeida, 2008). There is no other form of data that gives such broad coverage of the output of the research effort of the enterprise (Jaffe et al, 1993). Moreover, patents are easily available and have been well documented, especially in recent years thanks to the extensive on-line information that can be suitably organized into databases. Because of these reasons, in the literature, patent documents and patenting rates have long been used as a well-grounded proxy for measuring technological innovations. Along with input data such as R&D expenditures and the human capital employed in research, patents have become one of the most common measure of innovation (Giuri et al., 2007). Also, it is common knowledge that in general there exists a positive relationship between the R&D input of companies and their R&D output through patents (Hagedoorn, 2003).

Among the information contained in the front page of the patent document there is the list of patent "citations" or "reference". In fact, the patent applicant is obliged by law to specify any and all of the "prior art" of which the applicant is aware. The list of citations for each patent is established through a uniform and rigorous process applied by the patent examiner (Phene and Almeida, 2008). The examiner, who is supposed to be an expert in the technological area and be able to identify relevant prior art that the applicant misses, can add further citations. The framework for the search of prior art is the patent classification system: every patent is assigned to a 9-digit patent class, as well as an unlimited number of additional or "cross-referenced" classes. The overall pattern of citations to earlier patents provides a credible record of built-upon knowledge: a citation from patent B to patent A suggests that inventors on B knew about and utilized A in developing B (Alcacer and Gittelman, 2006). Because each backward citation is itself a patent, is possible to develop measures of association – technological, organizational, geographical, temporal – between citing and cited patents (Frost, 2001). Jeffe et al. (1993) argue that "Krugman [...] perceives that knowledge flows [...] are invisible; they leave no paper trail by which they may be measured [...]" (p. 2) "But despite the invisibility of knowledge spillovers, they do leave a paper trail in the form of citations to patents" (p. 26). Since that pioneering work, patent citations have been used extensively to trace the diffusion of knowledge across a variety of dimensions: geographic space, time, technological fields, organizational boundaries, alliance partnerships, and social networks (Alcacer and Gittelman, 2006).

Citations have also been widely used to measure the "importance" and economic value of patents, building on the conjecture that the influence of a patented invention is reflected by the amount of forward citations (i.e. patents that cite that patented invention).

Many authors, instead, have exploited patents to identify R&D collaborations among different entities. The patent document lists the names of the inventors, but does not indicate whether the collaborations are among inventors appertaining to the same or different organizations, or gives details of the type of collaboration they establish. In fact, businesses cannot be listed as inventors of a patent. However, the inventors of a patent (i.e. the "assignor"), can transfer their patent rights to an organization (i.e. "assignee"). Accordingly, the information about collaboration provided by the patent document is co-application, where two or more patent-holders are assigned to one patent (Giuri et al., 2017). In legal terminology, the US Patent Act claims that "[..] when an invention is made by two or more persons jointly, they shall apply for a patent jointly and each make the required oath [...]. Inventors may apply for a patent jointly even though (1) they did not physically work together or at the same time, (2) each did not make the same type or amount of contribution, or (3) each did not make a contribution to the subject matter of every claim of the application [...]" (Title 35 USC § 116). Joint patents are quite different from other multi-party patent agreements, such as cross-licenses, licences for reciprocity, pooled patents, and patent infringement agreements, because in most of these forms, companies choose to share the property rights of existing patents to avoid infringing the patent rights that were made by at least one of the companies involved. Hence, they cannot be related directly to situations where companies co-developed the invention (Hagedoorn, 2003).

Co-applications are largely the result of small-scale inter-firm R&D alliances, where it is difficult for companies to divide the inventions among the partners. Often, it is the acquisition process that led to the joint ownership of patents: if the acquired company is about to file a number of patent applications, the acquiring company is typically listed as the co-owner of the patent. Informal R&D alliances with a number of spin-off companies are another major explanation for joint patenting (Hegerdoon, 2003).

#### 4.2. Data sample

This chapter employs backward citations searching to grasp knowledge flows through which OEMs, our focal firms, tap into external skills and expertise in the field of Industry 4.0. The first objective of the analysis is to detect any technological trend that is most widely cited. Indeed, not only is the extent of knowledge available to a firm important, but also the nature of this knowledge. The second goal instead is to identify the assignees of the cited patents, and to classify them on the ground of different variables to assess whether focal firms are more likely to draw upon the knowledge of certain kind of companies.

Because there are those who argued that backward citations are a noisy measure of knowledge flows, the last part of the chapter will provide additional results coming from the analysis of the phenomenon of co-assignment. In fact, one of the most prominent mechanism to internalize external knowledge, is the creation of formal and informal networks of collaboration among researchers and institutions (Giuri et al., 2017). Thus, the aim will be to assess whether focal firms are exploiting co-patenting, and if specific trends in R&D partnering can be revealed.

Our sample consists of the 25 top OEMs, which account for the 90% of the overall production of the industry. To identify them, the firms operating in the automotive sector have been ranked according to four variables: (1) revenues, (2) market capitalization, (3) production and (4) patents production.

Since the patent not only involves a technical but also a legal aspect, the same subject-matter has to be filed in all countries for which protection is sought (Michel, and Bettels, 2001). In order to avoid counting the same innovation as many times as the countries where it is protected, patent families have been utilized. A patent family is a collection of patent applications covering the same technical content (EPO). Within one year from the priority date, namely the first date of filing of a patent application in an office of their choice (i.e. priority year), the applicant may file extensions of the same technical content in other countries. All of the subsequent applications will be linked by a common priority date (Michel, and Bettels, 2001). It has been considered every patent family generated by the focal firms over a 25-year period (1990-2014). The year does not refer to the publication of the patent, but to priority date. Since many months may pass between the first date of filing of a patent application, priority date is deemed as closer to the time of invention. All data are held in tables of a relational data set.

To perform complementary analysis, suppliers and potential new entrants of the sectors have also been identified. Exploiting information gathered from Automotive News and Bloomerg's Supply Chain function, all the suppliers that have a business relation with any of the top 25 OEMs have been considered. Instead, to determine who are the potential new entrants, it has been replicated the procedure implemented by the European Patent Office (EPO) to detect patents related to 4IR technologies<sup>8</sup>. EPO has classified 4IR patent into technological classes, among which there is the category "vehicles". Accordingly, all the patents within this category, which is relevant to the automotive industry, have been analysed, and the corresponding assignees have been included in the group of potential new entrants<sup>9</sup>.

## **4.3 Empirical Analysis**

## 4.3.1 Backward Citation Searching

Backward citations searching has been performed as followed. It has been considered only patent families filed out by focal firms and identified as 4IR, following the EPO classification (i.e. 2091 patent families)<sup>10</sup>. 1886 out of 2091 focal patents contained some citations, while the other 205 focal patents seemed to cite nothing<sup>11</sup>. However, a more accurate analysis showed that 110 out of 205 focal patents actually made some citations.

The result is a sample of 25.105 cited patent families. For each of them the Priority Year is considered. 2621 patent families do not fall into the time frame considered by the original data set (1990-2014); still, it has been decided to count them in order to have a more comprehensive view of patent families to which focal firms have drawn so far. The following Figure 1 shows the cumulative percentage of cited patent families over time. The percentage of patent families which Priority Year is before 1961 is almost irrelevant (less than 0,5%). As expected, the great majority of patent families cited by focal firms, are temporally located

<sup>&</sup>lt;sup>8</sup> The explanation of the procedure implemented by EPO is contained in the report: "Patents and the Fourth Industrial Revolution: The Inventions Behind Digital Transformation". EPO (2017).

<sup>&</sup>lt;sup>9</sup> Note that this method allowed to identify companies that have shown an interest for the automotive industry, but does not provide definitive evidence in relation to whether or not they actually entered the industry, or will enter in the near feature.

<sup>&</sup>lt;sup>10</sup> In the patent portfolio of the OEM Chang'an Motors there are no patent families identified as 4IR. Because of this reason, it is not included in these analyses.

<sup>&</sup>lt;sup>11</sup> In the literature, patents with fewer backward citations rely less on technical prior art and are typically considered to be more novel (Ahuja and Lampert 2001).

after the 1990s. Indeed, the number of patent applications in 4IR technologies was very low before that time, and only began to rise in the mid-1990s (EPO, 2017).



Figure 1: Distribution of cited patent families by year

In order to identify the more recurrent technological domains in the sample of cited patent families, Schmoch's Classification has been utilized. This classification links the International Patent Classification (IPC) to 35 technological fields, which are in turn aggregated into 5 main sectors: *Electrical engineering*, *Instruments*, *Chemistry*, *Mechanical engineering*, and *Other fields*<sup>12</sup>. Table 1 reports the number and percentage of cited patent families in each sector and field of the Schmoch's classification.

The most representative sector is *Mechanical engineering*, which covers the technologies that mostly characterize the automotive industry. *Electrical engineering* and *Instruments* also embed a significant portion of our sample. The most populated fields (i.e. fields that cover more than 6% of the total number of cited patent families) are, in order of importance, *Transport*, *Control*, *Measurement*, *Computer technology*, *Engines*, *pumps*, *turbines*.

<sup>&</sup>lt;sup>12</sup> As each patent family can embody more than one IPC classes, some patent families are related to multiple technological fields of the Schmoch's classification, and are thus counted more than once. 736 patent families could not be matched and are excluded from the following data and considerations (the total number of cited patent families considered in Table 1 (45.504) differs from the total number of cited patent families considered in the sample (25.105) because of these reasons).

Technological Sector	Technological Field	Field Number	Total Number of Cited patent families	Share of Each Sector/Field on the Total Number of Cited patent families
Mechanical engineering			16475	35,63%
Mechanical engineering	Transport	32	10250	22,17%
Mechanical engineering	Engines, pumps, turbines	27	3222	6,97%
Mechanical engineering	Mechanical elements	31	1642	3,55%
Mechanical engineering	Handling	25	384	0,83%
Mechanical engineering	Other special machines	29	325	0,70%
Mechanical engineering	Machine tools	26	290	0,63%
Mechanical engineering	Thermal processes and apparatus	30	267	0,58%
Mechanical engineering	Textile and paper machines	28	95	0,21%
Electrical engineering			13041	28,20%
Electrical engineering	Computer technology	6	4191	9,06%
Electrical engineering	Electrical machinery, apparatus, energy	1	2596	5,61%
Electrical engineering	Telecommunications	3	2183	4,72%
Electrical engineering	Digital communication	4	1603	3,47%
Electrical engineering	Audio-visual technology	2	1255	2,71%
Electrical engineering	IT methods for management	7	744	1,61%
Electrical engineering	Semiconductors	8	362	0,78%
Electrical engineering	Basic communication processes	5	107	0,23%
Instruments			12726	27,52%
Instruments	Control	12	6182	13,37%
Instruments	Measurement	10	5513	11,92%
Instruments	Optics	9	480	1,04%
Instruments	Medical technology	13	277	0,60%
Instruments	Analysis of biological materials	11	274	0,59%
Chemistry		r	2237	4,84%
Chemistry	Environmental technology	24	767	1,66%
Chemistry	Chemical engineering	23	458	0,99%
Chemistry	Surface technology, coating	21	296	0,64%
Chemistry	Materials, metallurgy	20	255	0,55%
Chemistry	Basic materials chemistry	19	166	0,36%
Chemistry	Organic fine chemistry	14	77	0,17%
Chemistry	Macromolecular chemistry, polymers	17	74	0,16%
Chemistry	Biotechnology	15	60	0,13%
Chemistry	Food chemistry	18	34	0,07%
Chemistry	Micro-structural and nano- technology	22	28	0,06%
Chemistry	Pharmaceuticals	16	22	0,05%
Other fields		[	1025	2,22%
Other fields	Civil engineering	25	577	1,25%
Other fields	Furniture, games	33	261	0,56%
Other fields	Other consumer goods	34	187	0,40%

Table 1 Distribution of cited patent families into sectors and fields of the Schmoch's classification
Transport, as well as Measurement and Engines, pumps, turbines, are typically among the fields which cover the majority of patents in the automotive sphere; accordingly, it is not that surprising to find them at the top, as firms tend to search for new knowledge in the neighbourhood of their current technologies and practices (Almeida and Phene, 2004). Transport includes all types of transport technology and applications with dominance of automotive technology. Measurement refers to a broad variety of different techniques and applications, such as measurement of mechanical properties as oscillation or speed, while Engines, pumps, turbines covers non-electrical engines for all types of applications. The situation is slightly different in the case of *Control* and *Computer technology*. Indeed, despite representing a considerable portion of patent applied by focal firms, the fields usually tend not to be among the most populated. Control covers elements for controlling and regulating electrical and nonelectrical systems and referring test arrangements, traffic control or signalling systems etc. Computer technology includes technologies related to electrical digital processing (arrangement for programme control, methods and arrangements for data conversion etc.). It should be emphasized that, when focusing on 2091 4IR patent families applied by OEMs in 1990-2014, *Control* is actually the most representative field, together with transport (27,84%). Besides, it represents the field with the greater percentage of 4IR patent families on the total number of patent families included in the field (6,3%). Computer technology is also one the most populated fields, albeit representing a modest percentage (3,16%). Both *Control* and *Computer technology* cover technologies which can be easily associated to digitalisation, as the "automatic controller", meaning a system, circuit, or device in which a signal from the detecting element is compared with a signal representing the desired value and which operates in such a way as to reduce the deviation (G05B), tools for regulating power supply of digital computers (G05D), or devices or arrangements for storage of digital or analogue information (G11C), to name a few<sup>13</sup>.

On the whole, these data may suggest that, while keeping the focus on core fields, OEMs are also extending beyond traditional technological boundaries to fulfil the knowledge gap in the digital domain.

The second objective of the research consists in the classification of the assignees of the cited patent families. To achieve the goal, several phases have been necessaries. Starting from the 1996 4IR patent families than actually contained some citations, it was draw up a

<sup>&</sup>lt;sup>13</sup> To trace back the subclasses associated to the fields of Schmoch's classification it has been used the IPC accordance table provided by the WIPO (2008).

list of the assignees mentioned in the citations. The resulting data set included 6971 companies.

To classify the assignees of cited patents it was firstly applied a cross match with the corporate tree of OEMs and suppliers, and with the list of potential new entrants. This allowed to identify the parent company in the case of subsidiaries and to assess whether they were OEMs, suppliers, or potential new entrants. 732 assignees were matched automatedly, while the remainder required a manual check.

At this point, it was decided to focus on the companies that were cited with more frequency. More into detail, all the assignees that were cited at least 4 times were considered (558 firms), while the other were excluded. The classification of these assignees took place in two stages; a first screening was made using the global database ORBIS Bureau Van Dijk. Companies' names were uploaded, taking care to check that the database actually selected the correct match. Since not all the assignees were identified, a further research was required, which exploited different sources on the Internet. In some tricky situations, both the approaches were implemented (research through ORBIS and through the Internet) and the results were compared.

Despite several attempts, some firms did not have been recognized. This was due to diverse issues; in the majority of the situations the information contained in the focal patents was no clear enough to unequivocally identify the assignee of the cited patents. In other instances, the company was not included in ORBIS, neither appropriate information was obtained elsewhere. Only a case has been found of wrong assignment, namely that diverse providers assign the same patent to diverse companies. For some of the non-identified assignees, it was concluded with some degree of certainty that they were neither OEMs, suppliers nor potential new entrants. Accordingly, they were included in a fourth category, labelled "*others*". For 21 companies, instead, the situation was indefinite, so that it was agreed to rule them out of the sample in order not to alter the results.

All the identified assignees were then uploaded on ORBIS, and the GUO Name<sup>14</sup> function was applied to the search to assess whether the company was a parent or not, and to identify the parent companies in the case of subsidiaries. The operation was carried out also for the 732 companies that have been traced automatedly, which brought out a few numbers of incongruences between the GUO selected by ORBIS, and the parent identified

<sup>&</sup>lt;sup>14</sup> A GUO (Global Ultimate Owner) is the individual or entity at the top of the corporate ownership structure (ORBIS).

through cross match. These inconsistencies forced to conduct a further check. In most of the cases, the discrepancy among the data arose from M&A that have been concluded after 2014, and consequently not considered by the original data set. In some other cases, the assignee in question was the fruit of a joint venture. In such situations, it was taken into account the information initially provided by the data set, which means that M&A occurred after 2014 were not considered<sup>15</sup>.

After having completed the manual check of the assignees that have not been identified automatedly, subsidiaries were linked to their parent. From this point forward, it was not considered the original assignee, but its parent company. This responds to the necessity to aggregate firm's patent portfolio across the entire corporate tree. Moreover, data concerning parent companies are more easily available, which permits to include a major number variables in the classification. A second cross match was then applied to assess whether these companies fell into the corporate trees of OEMs and suppliers, or in the list of potential new entrants. The assignees that are not part of any of the mentioned categories, were included in the group "others".

Afterwards, the BvD Number was downloaded for all the firms included in ORBIS database. The code is crucial to unequivocally specify the companies, and is useful to access to more information provided by ORBIS easier and faster. At that stage, there were sufficient elements to delete duplicates, namely assignees with the same name, the same BvD number, the same GUO and the same GUO BvD.

A draft of the final file on Excel was created, including 1243 assignees, and 627 parent companies. The draft comprised three columns:

*Assignee\_name*: the column yields the assignee, as indicated in the patent document. *Parent\_name*: the column shows the Company name of the assignee, or the Company name of the corresponding parent, in case of subsidiaries assignees.

*BvD*: the column displays the BvD Number of the company indicated in the preceding column *Parent\_Name* (please note that the code corresponds to the BvD of the assignee only for parent assignees. In case of subsidiary assignees, the BvD refers to the parent).

<sup>&</sup>lt;sup>15</sup> Fiat Chrysler Automobiles N.V. partially constitutes an exception: while for subsidiaries it was possible to trace back if they belonged to Fiat or Chrysler before the merger, some citations cite FCA. In such cases there were no other options than consider FCA.

*OEMs:* if the company has been identified as an OEM, the corresponding cell in the column records its name; if the company has not been identified as an OEM, the corresponding cell in the column is blank.

*Suppliers:* if the company has been identified as a supplier, the corresponding cell in the column records its name; if the company has not been identified as a supplier, the corresponding cell in the column is blank.

*Potential NE:* if the company has been identified as a potential new entrant, the corresponding cell in the column records its name; if the company has not been identified as a potential new entrant, the corresponding cell in the column is blank.

*Other:* if the company has not been identified neither as an OEM, a supplier, nor a new entrant the corresponding cell in the column records its name; if the company has been identified as an OEM, supplier or potential new entrant, the corresponding cell in the column is blank.

The columns OEMs, Suppliers, potential NE and Other are not dummy variables; this responds to the potential necessity to easily go back to companies that are cited more frequently in each category.

The phases described so far has enable to perform a first classification of parent companies of cited assignees, which results are displayed in the Figure 2 below.



Figure 2: Distribution of parent companies of cited assignees in the categories of OEMs, Suppliers, potential NE, Others

Suppliers have confirmed themselves as the most relevant source of external knowledge. As previously argued, starting from the late 1980s globalization and technology complexity have deepened the need for leading firms to build long-term partnerships with suppliers, in order to cope with the sophistication related to new product development and improvement. Collaborations with suppliers are particularly recurrent and highly important in the automotive panorama, and the advent of Industry 4.0 seems not to have changed this trend. On the other hand, the category "Others" is also representative, which means that, in the field of digitalisation, OEMs are also searching outside the industry boundaries (among the most cited companies in the category there are, for example, JPMorgan Chase, Nippon Telegraph & Telephone, Stryker Corporation and Benesse Corporation). The figure is even more significant if we consider that the class "Potential New Entrants" includes firms that will potentially enter the industry in the near future, and for which automotive is not the core business area (among the most cited companies in the category there are, for example, Nuance Communications, Philips and Nokia Corporation). The class "OEMs" is the less populated. Apparently, competitors are not the most prominent channel to seek ideas for the development of 4IR technologies.

As explained, the classification of the assignees in the category of Suppliers and Potential New Entrants (and, by a consequence, Others) has been performed by considering variables other than the company core business and sector of activity. Thus, while providing meaningful data, the classification categorizes parent companies of cited assignees on the ground of their relationship with the automotive industry, and it is insufficient to determine who are the assignees of the cited patent families. Because of that, other parameters have been included in the research. The additional features are: entity type, sector of activity, home-country, and entity size<sup>16</sup>.

First of all, it has to be stressed that not all the organizations in our sample are corporates. Technological innovation, indeed, is no longer the sole prerogative of the business enterprise sector; on the contrary, more and more the credits for new technologies developments and improvements belong to networks of innovators (Schilling, 2017).

<sup>&</sup>lt;sup>16</sup> A portion of assignees could not be identified univocally. While these companies are included in the first classification, (they have been assigned to the category "Others"), it was not possible to classify them on the ground of the subsequent variables. Moreover, for another portion of assignees, despite having univocally identified them, it cannot be obtained additional data, as those employed in the next analyses. These two portions together account for the 4% of the sample.

To determine the nature of cited assignees, it has been exploited the function "type of entity" by ORBIS. In our sample, corporates account for 95,55% of the cited assignees. The remainder 4,45% belongs to other categories, as displayed by the Figure 3.

A significant portion of the remainder organizations falls within the class "Foundation/Research Institute", which includes foundations, universities and research institutes. Public research institutions represent an important source of innovation. Governments often actively invest in research, not only by granting for private entities, but also through their own laboratories or the formation of science parks and institutions. Universities, in particular, are top performer on early stage discoveries and advances in basic science (Asimakopoulos et al., 2020). Besides, Belderbos et al. (2013) observed that research conducted together with universities tends to generate innovations with high market value. The other categories, each accounting for less than 1%, are not very significant, and constitute isolated cases rather than actually represent a trend.



Figure 3: Classification of parent companies of cited assignees other than corporates

As far as sector of activity is concerned, the information has been determined by employing the statistical classification of economic activities in the European Community (NACE REV.2), gathered through ORBIS' functions NACE REV.2 Code and NACE REV.2 Description. Our sample covers 156 different NACE REV.2 Codes. Table 2 yields the distribution of assignees among the most populated sectors of activity (the sectors that

embody at least 10 assignees). The sectors reported in the table incorporate 73% of the companies in our sample.

NACE Rev. 2 Code	NACE Rev. 2 Description	Number of assignees
2932	Manufacture of other parts and accessories for motor vehicles	202
2910	Manufacture of motor vehicles	129
2611	Manufacture of electronic components	80
2630	Manufacture of communication equipment	54
6190	Other telecommunications activities	40
2712	Manufacture of electricity distribution and control apparatus	40
2651	Manufacture of instruments and appliances for measuring, testing and navigation	31
2211	Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	27
2751	Manufacture of electric domestic appliances	26
2640	Manufacture of consumer electronics	25
2815	Manufacture of bearings, gears, gearing and driving elements	24
2059	Manufacture of other chemical products nec	21
5829	Other software publishing	21
3030	Manufacture of air and spacecraft and related machinery	18
8541	Post-secondary non-tertiary education	17
2824	Manufacture of power-driven hand tools	16
2811	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	15
6201	Computer programming activities	14
2620	Manufacture of computers and peripheral equipment	14
2899	Manufacture of other special-purpose machinery nec	13
2434	Cold drawing of wire	13
2790	Manufacture of other electrical equipment	12
7490	Other professional, scientific and technical activities nec	10
7010	7010 Activities of head offices	

 Table 2: Distribution of parent companies of cited assignees among the most populated sector of activity

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The top 2 NACE REV.2 sectors, *Manufacture of other parts and accessories for motor vehicles* and *Manufacture of motor vehicles*, cover the sectors of activity that mostly characterize the automotive sphere. 94,86% of the cited assignees in these sectors are OEMs or suppliers. *Manufacture of electronic components* (2611) ranks fourth by number of cited assignees in the sector, and it can be related to the production of electronic components, as well as to the part of electrical engineering and electrical batteries manufacturing. If we consider it together with other populated sectors as Manufacture of instruments and appliances for measuring, testing and navigation (2651), Manufacture of consumer electronics (2640) and Manufacture of other electrical equipment (2790), we could interpret the data as driven by the increasing presence of electronic components in vehicles such as sensors, actuators, alternators, carputers, telematics, in-car entertainment systems, and others. However, for the purpose of this research, it is fruitful to focus also on ICT-related sectors, as Manufacture of communication equipment (2630), Other telecommunications activities (6190), Other software publishing (5829), Computer programming activities (6201) and Manufacture of computers and peripheral equipment (2620). In fact, according to EPO (2017), one of the already evident implication of 4IR is that product and process innovation is more and more taking place in the virtual layer of software, rather than in any hardware component. Inventions based on software implementation account for a large part of technological advances in many diverse areas and are set to replace hardware innovations. What is more, at a global level, innovation in the digital domain is mainly led by a limited number of large companies focused on ICT (EPO, 2017). Patent citations have often been used to describe the geographical extent of knowledge flows among inventors and patent holders (Giuri et al., 2007). What is going to be discussed next concerns the geographical location of cited assignees in our sample, in order to delineate the direction of the channels employed by focal firms to access into external competences and skills. To perform this analysis, Country ISO Codes have been gained by ORBIS.



Figure 4: Global distribution of parent companies of cited assignees

Figure 5: Distribution of European parent companies of cited assignees



The Figure 4 shows the global distribution of cited assignees, while the Figure 5 focuses on Europe. The results are not very surprising. The headquarters of the great majority of organizations in our sample are located in U.S.A., Europe and Japan. "The Triad" (Sturgeon and Lester, 2004), represents the major markets of the global automotive industry. China instead is the most growing market, as represented by the inclusion of some Chinese manufacturers into the top global OEMs. Within Europe, Germany, home-country of BMW and Volkswagen, stands out, followed by England and France, home-country of Peugeot.

Thus, assignees are predominantly located within areas than constitutes the most prominent automotive markets.

In addition, U.S.A., Europe and Japan are the regions that firstly invested in the development of 4IR technologies, and are still the main innovation centres. 4IR innovation started ten years later in the Republic of Korea and China (CN), but has been increasing at a faster rate than in other regions. In Korea, more than 90% of 4IR applications originate from Samsung and LG. Nearly 70% of Chinese patent applications come from two companies: Huawei and ZTE. In the European area 4IR research is subject to a marked regional concentration. The top two EU regions for 4IR innovations are the greater Paris area, followed by the greater Munich area. While Germany and France are foremost in 4IR innovation in EU, the United Kingdom, Sweden (SE), Switzerland (CH), Finland (FI) and the Netherlands (NL) also show inventive activity (EPO, 2017).

Lastly, assignees of the cited patent families have been classified on the ground of their size. In order to do that, two criteria have been utilized. Firstly, it has been exploited the classification into small, medium and large enterprises provided by ORBIS. Then, the analysis has been completed using a more disaggregated approach and considering the number of employees of each organization (this data has also been obtained by Orbis, and refers to the last year available).



Figure 6: Classification of parent companies of cited assignees on the ground of their size

Predictability, very large companies rank at the first place, accounting for more than 90% of the sample. As mentioned, at a global level a limited number of large organizations

drive technological advances in the digital domain (EPO, 2017). Large companies already have the infrastructures and employees with certain skills in place to take the risk of implementing such emerging technologies, even though it will not lead to immediate improvements. The situation that small and medium enterprises face is very different: they have less resources available and must manage them guardedly. Thus, digitalization for the sake of digitalization is not an option, and many digital technologies are deemed as comporting big costs compared to the little positive impact they have. This trend is also reflected in the automotive industry, where biggest OEMs drive the so-called Fourth Industrial Revolution forward, while medium and small companies are stalling (Kern, and Wolff, 2019).

The Table 3 yields the number of cited assignees in our sample, for each class of number of employees. The majority of cited assignees (70,77%) are embodied in the categories 9-13 (between 10.000 and 500.000 employees).

Classes	Number of employees	Number of assignees per class
1	<50	62
2	>50 and <=100	25
3	>100 and <=200	22
4	>200 and <=500	17
5	>500 and <=1000	25
6	>1000 and <=2000	25
7	>2000 and <=5000	66
8	>5000 and <=10000	62
9	>100000 and <=20000	108
10	>200000 and <=50000	159
11	>500000 and <=100000	132
12	>100000 and <=200000	207
13	>200000 and <=500000	164
14	>500000	14

Table 3: Classification of parent companies of cited assignees per number of employees

It was previously explained that the classification was performed referring to the parent company of each cited assignee. By all means, this choice has partially shaped the results. In order to provide a more comprehensive examination, it has decided to repeat the analyses focusing on individual assignees. As mentioned, for many of them there were not sufficient information, so that this second sample only include 896 organizations. The results obtained do not differ from the previous ones to a large extent. In particular, the classification on the grounds of the type of organization and geographical location yields approximately

the same outcome. However, some dissimilarities were detected when considering the sector of activity (see Table 2.1). In fact, the top 10 of the most populated sectors displays a stronger focus on ICT-related sectors (*Manufacture of instruments and appliances for measuring, testing and navigation* (2651), *Manufacture of communication equipment* (2630), *Computer programming activities* (6201), *Other telecommunications activities* (6190), *Manufacture of computers and peripheral equipment* (2620)).

NACE REV. 2 Code	NACE REV. 2 Description	Number of Assignees
2932	Manufacture of other parts and accessories for motor vehicles	114
2910	Manufacture of motor vehicles	60
2611	Manufacture of electronic components	48
2651	Manufacture of instruments and appliances for measuring, testing and navigation	29
2630	Manufacture of communication equipment	28
6201	Computer programming activities	22
6190	Other telecommunications activities	21
2620	Manufacture of computers and peripheral equipment	19
8541	Post-secondary non-tertiary education	17
2640	Manufacture of consumer electronics	16
2059	Manufacture of other chemical products nec	15
7490	Other professional, scientific and technical activities nec	15
3030	Manufacture of air and spacecraft and related machinery	13
6420	Activities of holding companies	13
7010	Activities of head offices	13
2815	Manufacture of bearings, gears, gearing and driving elements	12
7112	Engineering activities and related technical consultancy	12
5829	Other software publishing	11
8299	Other business support service activities nec	10
7211	Research and experimental development on biotechnology	9
2720	Manufacture of batteries and accumulators	9
2211	Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	9
2711	Manufacture of electric motors, generators and transformers	9
2670	Manufacture of optical instruments and photographic equipment	9

Table 2.1: Distribution of cited assignees among the most populated sector of activity

Though, the more significant variations are related to the classification based on organizations' size. While very large companies still represent the great majority of the sample, medium and small companies account now for an increased percentage of cited assignees, as shown by the Figure 6.2.





## 4.3.2 Co-patenting analysis

The relational table employed to perform this second stream of analysis is structured as follows:

Fid indicates the family ID.

*Epryear* indicates the priority year of the patent family.

*IR4\_def*: it is a dummy variable, which indicate whether the patent family has been identified as 4IR or not.

*compname\_def* shows the name of the OEM, which does not necessarily correspond to the assignee of that patent family. Indeed, in order to measure the technological innovation of an OEM and its subsidiaries, each patent family is attributed to an OEM.

*NoAss* is a dummy variable, indicating whether the application was published listing an assignee or not.

*assegnee\_count* is a variable measuring how many assignees were listed for that application.

 $N_OEM$  is a variable indicating how many OEMs were listed among the assignee. If a patent family was granted to an OEM, and the OEMs is the assignee, N\_OEM yields 1. *CoAssOEM* is a dummy revealing whether that patent family is co-assigned to more than one OEM

*CoAss* is a dummy variable indicating whether the patent family is co-assigned to diverse assignees. For instance, if a patent family in the patent portfolio of Geely, has been assigned to Geely Holding and to two subsidiaries of Geely Hoding, Assegnee\_count counts 3 assignees, and, because two of them are companies other than Geely, CoAss yields 1.

*CoAss\_def* is the dummy variable that definitively yields whether the patent family is co-assigned or not.

Hagedoorn (2003), asserted that the automotive industry is among the sectors where the more significant numbers of jointly-owned patents can be found<sup>17</sup>. Furthermore, the author forecasted that joint patenting was likely to increase because of the growth of R&D collaborations. The experience that companies accumulate in the application for joint patents and in writing additional contracts was also deemed as a factor encouraging the further exploitation of co-patenting. Our data set confirms this prediction: the percentage of co-owned patent families on the total number of patent families was about 14,34% in 1990, and 17% in 2014.





<sup>&</sup>lt;sup>17</sup> Hagedoorn (2003) considered a data set of US patents that refers to the period 1989-1998.

As shown by the Figure 7, co-patenting intensity has increased over the period 1990-2014, albeit with some fluctuations. The vertical axis yields the portion of co-owned patent families on the total number of patent families per year, while the horizontal axis refers to the priority year. In the automotive industry, on average, about 14,7% of the patent families are assigned to more than one assignee. Focusing exclusively on 4IR patent families, the figure is equal to about 11%. Hence, co-patenting activity in the field of Industry 4.0 appears to be lower than the sector average. However, it could be misleading to compare these two data, because the total number of co-assigned patent families in the industry embeds both core technologies and emerging technologies. To provide a more valuable comparison, it should be analysed co-patenting intensity in a domain in which there still exists a large knowledge gap between the competences of OEMs and those of potential new entrants. For instance, Elvers and Song (2014) analysed co-application trend in the field of lithium-ion batteries and determined that about 10% of the applied patents were co-owned. In addition, the number of patent applications by automakers in 4IR technologies was very low in the early 1990s, and only began to rise steeply in the mid-1990s. That growth continued in the years that followed, which suggest that digital technologies have passed the "emerging phase" and are now maturing in the growth phase. As discussed in the chapter 3, because of the industry's digitalisation OEMs have been obliged to rethink traditional forms of cooperation, and set up new types of partnerships that extend across trades and sectors (Attias and Mira-Bonnardel, 2017). The complexities arising from approaching new kinds of alliances might partially explain why the number of co-assigned patents in 4IR domain is lower than the sector average. Several studies have indeed emphasized that firms' past R&D activities, including past cooperations, positively affect the capacity of benefiting from R&D partnering.

About 11,16% of the co-assigned 4 IR patent families are co-owned by two, or more, OEMs. The data is all the more significant if compared with the total number of co-assigned patent families that are co-owned by two, or more OEMs, where the figure is equal to about 9,33%. This result seems to confirm what was argued in the previous chapter regarding the "coopetition" strategy (Brandenburger and Nalebuff, 1996): as a response to digital transformation, car manufacturers resort to alliances with competitors with more frequency (Attias, 2016).

The Table 4 provide data specific to each OEM considered. The first column records the number of patent families identified as 4IR in the portfolio of each OEM. The second column instead refers to the number of co-assigned patent families identified as 4IR, and the last column provides the percentage of co-assigned patent families identified as 4IR on the total number of 4IR patent families in the portfolio of each OEM. The more active automakers in the field of Industry 4.0 correspond to the key players of the industry, which confirms the considerations made so far: digitalisation is drive forward by leading companies. For the truth, it has to be emphasized that the data in the following table are partially biased by the general patenting activity of car manufacturers. For example, Toyota, might appear as the major player in the field of Industry 4.0 as it impacts automotive sector. However, 4IR patent families in the portfolio of the Japanese giant, only account for the 0,47% of the total. Tesla, instead, present the opposite situation: while it applied only for 6 4IR patent families, these build up the 2,25% of its patent portfolio, insinuating that its research effort in the digital domain may be greater compared to other competitors.

OEM	Number of 4IR patent families	Number of co-assigned 4IR patent families	% of co- assigned 4IR PatFam on the total number of 4IR PatFam
ТОУОТА	412	109	26,46%
GM	331	5	1,51%
FORD	224	6	2,68%
HONDA	214	9	4,21%
VOLKSWAGEN	197	26	13,20%
HYUNDAI	148	9	6,08%
NISSAN	113	14	12,39%
DAIMLER	99	5	5,05%
MAZDA	98	0	-
RENAULT	57	2	3,51%
BMW	42	0	-
PEUGEOT	36	0	-
FIAT	21	3	14,29%
MITSUBISHI	19	4	21,05%
GEELY	19	19	100%
KIA	15	13	86,67%
CHRYSLER	11	8	72,73%
ТАТА	13	1	7,69%
TESLA	6	0	-
BAIC	5	0	-
DONGFENG	3	0	-
SUZUKI	3	0	-
SAIC	3	0	-
GREATWALL	2	0	-

Table 4: Co-patenting trend in 4IR patent families per OEM

Returning to our data, it should be note that the companies in which the co-patenting rate is higher, do not match with the companies with the higher number of 4IR patent families. Geely Holding Group provides a striking example, as 100% of its 4IR patent families are co-assigned, suggesting that the company rely heavily on collaborations to build its digital know-how. Kia Motors (86,67%) and Chrysler Corporation (72,73%) show similar data. On the opposite end of the spectrum is located General Motors Corporation. The historical automaker is one of the key players in the research on Industry 4.0: its patent portfolio offers 331 4IR patent families, which account for 1,59% of its patent families. However, only 1,51% of these are co-assigned. Previous studies have demonstrated that, on the whole, Asian manufacturers prefer to establish a stronger tie to suppliers (or competitors) by jointly ownership of patents, while the western OEM tend to not share its right. This could be related both to the cultural or organizational background (Elvers and Song, 2014). Despite some exception (i.e. Chrysler Corporation and Tata Motors) our data reveal that digitalisation has not change this tendency so far.

The Table 5 above displays how many co-assigned 4IR patent families are owned by diverse amount of co-owner. The vast majority (69,57%) of co-assigned 4 IR patent families are owned by two assignees. The greater number of assignees in the sample considered is 12 and it refers to one patent family (Fid of the patent family: 42989910).

Classes	Number of co-assignees	Number of patent families in the class
a	2	160
b	3	49
с	4	9
d	5	8
e	9	3
f	12	1

Table 5: Distribution of co-assigned 4IR patent families per classes of assignees' number

## **4.4 Conclusions and limits**

Digitalisation of the automotive industry is posing serious challenges to OEMs, who are struggling to adapt to technological changes. Our research has demonstrated that, while keeping the focus on core technologies, automakers worldwide are moving beyond merely located search and exploring distant technologies domain. This result is supported by various data; first, *Control* and *Computer Technology*, joined by core automotive fields *Transport, Measurement and Engines, pumps and turbines*, are the most populated technological fields from which focal firms appear to draw. Both *Control* and *Computer Technology* embodies a great portion of 4IR- and ICT- related technologies. Secondly, a great portion of cited assignees fall in the categories "Potential New Entrants" and "Others", which refer to organizations featured by attributes other than the traditional characteristics of companies operating the automotive industry. What is more, a significant portion of cited assignees, the most populated NACE REV.2 sectors are *manufacture of electronic component, manufacture of communication equipment* and *other telecommunication activities*).

As far as global distribution is concerned, cited assignees are predominately located within major automotive markets, which coincide with countries at the forefront of the Fourth Industrial Revolution. Lastly, cited assignees are, for the most part, large companies, which have the resources needed to develop and exploit emerging technologies.

The analysis focused on the phenomenon of co-assignment has revealed an increasing trend in co-patenting, as far as 4IR patent families are concerned. Most importantly, an important portion of co-assigned 4IR patent families are co-owned by more than one OEM. However, the rate of co-assigned 4IR patent families varies largely across OEMs. Besides, higher rates of co-patenting do not correspond to higher number of 4IR patent families. Ultimately, the overwhelming majority of co-assigned 4IR patent families belong to two assignees.

Patents have several shortcomings as indicators of innovation and innovative search. While they can reflect inventive activities, they can also be the outcome of appropriability strategies (Laursen and Salter, 2006). In fact, firms exploit patent for a multitude of reasons. Often, patents are used strategically to block competitors, to avoid be blocked by competitors or to improve the company's bargaining power in cross-licensing agreements (i.e. the patent is licensed to another party in exchange for another patented invention). On the other hand, some patents are not employed at all. The strength of patent protection in an industry can

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augment the propensity to patent and reduce its use. Besides, large companies (which represent the great majority of firms considered in this analysis) have a greater percentage of unused patents as compared to small firms. Since greater organizations presumably have lower patenting costs, they are likely to patent minor inventions as well, which tend to be unexploited. On the contrary, for the smaller firms patenting costs are significant, and they probably patent only inventions for which they can obtain some returns. Patents are also widely acknowledged to be a partial indicator of the innovation process, since many technological innovations are only partially patented or not patented at all (Laursen and Salter, 2006). Much of the output research, indeed, cannot be patented, especially for basic research, which may generate the greatest spillovers (Jaffe et al., 1993).

There are a number of limitations also concerning the use of patent citation data to capture knowledge flows and assimilation. First, patents reflect codified knowledge but not tacit knowledge (such as that embedded in organizational routines), even though the two are closely linked and complementary (Phene and Almeida, 2008). What is more, many of the citations in patents are added by the Patent Office, rather than by the patentee, and in those case the citations itself says little about the importance of different sources of innovation. Indeed, the citing inventor may not actually have been aware of the cited work, or, even if they were aware, they might not have benefited from their knowledge of it (Jaffe et al., 1993). In addition, patent citations may also reflect technological similarities in technological profiles of diverse firms, rather than external sourcing activities (Laursen and Salter, 2006).

As far as co-assignment is concerned, it has to be specified that co-applications capture a small portion of actual R&D partnering, as some collaborations do not end up in a joint application (Giuri et al., 2017). Hagedoorn (2003), in fact, points out that co-owned patents are seen as sub-optimal by firms, due to the legal complexities involved in the management of intellectual properties across firm boundaries and inter-national patent jurisdictions. In order to specify the actual distribution of responsibilities and the concrete terms of third-party licensing, payments, litigations, etc., companies need to draw up supplementary contractual arrangements. Hagedoorn (2003) also shows that the data on copatenting may be biased towards industry specific context. The strength or weakness of a regime of appropriability of a specific industry could affect the propensity of firms to establish co-owned patents. In industries with strong intellectual property rights protection, such as chemicals and pharmaceutical, co-owned patents are disproportionately important, while in sectors with moderate regime of appropriability, such as the automotive, joint patenting has a less significant role. In addition, inter-industry differences concerning the

separability of knowledge into a set of independent pieces of a patentable invention also plays a role, suggesting that there is quite some variation with regard to certain technologies. Lastly, the information on co-applications does not provide any details on several features of the collaboration, like which inventor appertain to which organisations, or whether they all belong to the same one, or what the type of cooperative partnership is (Giuri et al., 2017).

## Conclusion

Automotive industry is en route for digitalisation. Over the last years, the amount of 4IR technologies in and around the vehicle has substantially increased, delivering strong productivity growth on the supply side, and giving rise to new kinds of business models (Hanelt et al., 2015). However, integrating digital artifacts into the car demands a profound understanding and skill set to innovate digitally. For incumbent automobile manufacturers, which have strong foundation in engineering, this development represents a major deviation from the core competences. To complement technological knowledge that exist only at a rudimentary level, or may be absent within automotive organizations, firms must search externally (Hildebrandt et al., 2015). Hence, the advent of Industry 4.0 technologies has accentuated the need for an open innovation model that was slowly spreading in the industry during the last decades.

The purpose of this thesis has been the investigation of the channels through which traditional OEMs are tapping into external know-how, as far as digitalisation is concerned. Indeed, as the complexity associated to technological innovation process has increased, a growing attention have been spent to the division of the innovative labour within automotive supply chain, and, in particular, to the greater role that suppliers have taken on new product development. In line with similar studies published in the literature, attempts have been made to define the inflows of digital knowledge from outside the industry's boundaries.

The elaborate, after having provided the theoretical background necessary to the understanding of current innovative dynamics, has been structured into three main sections. Initially the focus has been posed to the featuring characteristics of the automotive sector, emphasising especially how technological innovation has always been the driving force for the evolution of the industry, and exploring the transformation of the knowledge base.

At a later stage, the impact of Industry 4.0 technologies on the value chain and on the end-product has been analysed. It turned out that, in order to survive in the new digital ecosystem, lead firms are trying to integrate knowledge from distinct and distant areas by attracting new talents with digital skills (Piccinini et al., 2015). Since adjusting competences internally may not be enough to deal with such a transformation, OEMs are also giving rise to a new wave of collaborative partnerships with actors from inside and outside the industry. In particular, they are more and more approaching to "coopetition" strategies, where allies are already part of the sector (Attias, 2016). In the meantime, the cooperation between carmakers and IT service or communication companies is a new type of partnership that is

becoming notably spread (Attias, 2016). Beyond collaborative alliances and partnerships, mergers and acquisitions have established themselves as the most prominent solution exploited by car manufacturers to obtain external expertise (Hildebrandt, et al. 2015).

The last section of the analysis is built upon the previous one, and aims at providing empirical evidence of the trend detected. In the literature, backward patent citations have been widely used to trace the diffusion of knowledge across a variety of dimension, such as geographical space, time, technological fields and many other (Alcacer and Gittelman, 2006). Accordingly, our study considered the citations contained in patent families filed out by carmakers, our focal firms, and identified as 4IR. Initially, we tried to discern any technological trend that is cited more extensively, to define the nature of the knowledge from which automotive incumbents are drawing. It came out that the search is still focus on core technologies. Nonetheless, automakers worldwide are also tapping into distant domains; in particular, they are exploring knowledge embodied in *Control* and *Computer Technology* fields, which cover a great portion of 4IR- and ICT- related technologies. Subsequently, the assignees of the cited patent families have been identified and classified on the ground of various variables, to assess whether focal firms are more likely to draw upon the knowledge of certain kind of companies. Suppliers have confirmed themselves as most relevant source of external knowledge; the categories "Others" and "New Entrants" are also representative, suggesting that carmakers are accessing to the expertise of companies located outside the traditional industry boundaries. A significant portion of the assignees of the cited patents are universities or public research institutes. Universities, in particular, are top performer on early stage discoveries and advances in basic science, and are generally acknowledged as an important source of innovation in many industries (Asimakopoulos et al., 2020). As far as the sector of activity is concerned, it has been noted that focal firms are turning specifically to organizations operating in electronic-related industries, which can be driven by the increasing presence of electronic components in vehicles. ICT-related sectors are also populated; in fact, one of the already evident implication of 4IR is that product and process innovation is progressively taking place in the virtual layer of software, rather than in any hardware component (EPO, 2017). The geographical location of cited assignees has been taken into account as well; it revealed that the great majority of the assignees in the sample are placed within areas than constitutes the most prominent automotive markets. The same regions are also at the forefront of the Industry 4.0, which make this result not very surprising. On a final note, cited assignees are, for the major parts, very large companies, with more than 10.000 employees.

In order to partially make up for the shortcomings associated with backward citations searching, our study has also considered the phenomenon of co-assignment to provide additional results. Based on the assumption that the creation of formal and informal networks of collaboration among researchers and institutions is one of the most prominent mechanism to internalize external knowledge, joint patents are often utilized to determine R&D collaborations among different entities (Giuri et al., 2017). Our study detected an increasing trend in co-patenting, as far as 4IR focal patent families are concerned. However, the companies in which co-patenting rate is higher, do not match with the companies with the higher number of 4IR patent families. In general, Asian manufacturers appear more inclined to establish strong ties, especially with suppliers, while the western OEMs tend to not share their rights. Lastly, the percentage of patent families co-owned by two, or more, assignees is above the sector average, which confirm that, as a response to digital transformation, car manufacturers resort to alliances with competitors with more frequency.

On the whole, the research has proved that, while keeping the focus on core technologies, automakers worldwide are moving beyond merely located search and exploring distant technologies domain. Whether or not these remedies will ensure incumbents a competitive position in the near feature is difficult to assess. However, I would venture that OEMs are not passively observing the tremendous transformation of their industry. Instead, far from being conservative, they are rather proactively exploiting emerging technologies to innovate their business models, and levering R&D partnerships to close their knowledge gaps.

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