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Digital transformation in the automotive supply chain: China, Germany, Italy and Japan in a comparative perspective

Margherita Russo[1]

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[1] University of Modena and Reggio Emilia, Department of Economics Marco Biagi and
CAPP, Center for the Analysis of Public Policies
Address: Viale Berengario 51, 41121, Modena, Italy
E-mail: margherita.russo@unimore.it

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Digital *transformation* in the automotive supply chain: China, Germany, Italy and Japan in a comparative perspective

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Abstract

A wide literature on digital transformation in manufacturing and services has explored its impact on long term changes in labour demand and skills and on productivity and growth. A new perspective on the ongoing digital transformation has been prompted by Oecd to highlight specific metrics needed to assess its impact on the economy and society and to support innovation policies. Drawing on these contributions, this paper aims to shed light on the impact of digital transformation on the reorganization and relocation of the various segments of the automotive supply chain. In particular, it will focus on the effects generated by different paces of adoption of digital technologies in this supply chain, with regard to both the various segments and the various sizes of companies, in different countries. The causes of this heterogeneity will be discussed and the implications for the full impact of the ongoing transformation will be considered in relation to industrial and innovation policy in Europe. The paper addresses the issue by reviewing empirical evidence on the automotive supply chain, which includes the most advanced manufacturing and service companies that are now adopting digital technologies. Evidence from case studies in the automotive industry in China, Germany, Italy and Japan will help in identifying the main challenges of digital transformation for European countries, which will involve a strongly interrelated supply chain both within and outside Europe.

Keywords: digital transformation, automotive global supply chain, China, Germany Italy, Japan

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1. Introduction

In recent years, a wide literature on digital transformation in manufacturing and services has grown up.[1] Much of this literature has explored the impact on many diverse aspects: from long term changes in labour demand and skills (Frey and Osborne, 2013; Brynjolfsson and McAfee, 2014; Chuah *et al.*, 2018) to the impacts on productivity and growth (Bajgar *et al.*, 2019).

A new perspective on the ongoing digital transformation has been prompted by Oecd to highlight specific metrics needed to assess its impact on the economy and society and to support innovation policies. Relevant projects are *Going Digital*[2] and *Digital and open innovation* (Oecd, 2019a).[3] Drawing on these contributions, this paper aims to shed light on the impact of digital transformation on the reorganization and relocation of the various segments of the automotive supply chain. In particular, it will focus on the effects generated by different paces of adoption of digital technologies in this supply chain, with regard to both the various segments and the various sizes of companies, in different countries. The causes of this heterogeneity will be discussed and the implications for the full impact of the ongoing transformation will be considered in relation to industrial and innovation policy in Europe. These perspectives are essential to foster structural changes in the economy and society, which are necessary for European cohesion and growth (Simonazzi *et al.*, 2016).

The paper addresses the issue by reviewing empirical evidence on the automotive supply chain, which includes the most advanced manufacturing and service companies that are now adopting digital technologies (Calvino *et al.*, 2018). Although it has a level of digital intensity greater than in other supply chains, there is no alignment across the many specializations within the supply chain nor across countries. The automotive supply chain is essentially a global value chain but it has regional characteristics for the production of specific types of cars or types of components. Within Europe, Germany has world level key players among car makers - BMW and Audi-Volkswagen group - with a leading role in the supply chain, characterised by strong links with manufacturers located in Central and Southern Europe (Simonazzi *et al.*, 2016; Celi *et al.*, 2018), but also in China and Mexico (Amighini and Gorgoni, 2014; Gorgoni *et al.* 2018). Currently, and increasingly, China plays a crucial role in the European side of the automotive supply chain. Evidence from case studies in the automotive industry in China, Germany, Italy and Japan will help in identifying the main challenges of digital transformation for European countries, which will involve a strongly interrelated supply chain both within and outside Europe.

Beyond its relevance for the adoption of digital technologies, the automotive supply chain is important for its cross-sector interrelations (De Backer and Miroudot, 2012; Russo, 2015; Oecd, 2017). I will argue that interrelations matter because they mark the

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[1] See Agrawal *et al.* (2019) for a detailed survey.

[2] The project website http://www.oecd.org/going-digital/ presents several reports, the digital roadmap, policy briefs and a toolkit for the analysis of digital technologies to support innovation policies.

[3] OECD is developing measurements of digital transformation (OECD, 2019b). The goal is not to rank countries or to create composite indicators, but to provide policy makers and analysists with key indicators of the Going Digital policy framework (Ibid: 3). Four main overarching actions aims at building a new generation of data and indicators: make the digital transformation visible in economic statistics; understand the economic impact of digital transformation; measure well-being of digital transformation; design new approaches to data collection. Five actions will target specific areas: monitor transformative technologies (in particular Internet of Things, AI and Blockchain); make sense of data and flows; define and measure the skills needed in the digital era; measure trust in online environments; assess governments' digital strengths. The measurements so far made available (OECD, 2019b) provide significant insights on trends in the digital era, growth and well-being access and use of connectivity, innovation cascades, skills needed in the digital transformation, social prosperity, trust and market openness.

pace of changes within the many subsystems (energy, transport, industry, public administration) in the sociotechnical and economic systems.

Section 2 presents an outline of what is meant by "digital transformation" and discusses the specific research questions on how digital transformation has brought about changes in the working of the production systems. Section 3 presents a taxonomy of various sectors' digital intensity (proposed by Calvino *et al.*, 2018) and discusses the importance of country case studies to explain the wide cross-country variation observed within each sector. The empirical evidence presented will refer to available case studies on the adoption of big data in Japan (Motohashi, 2017) and on Industry 4.0 technologies in Italy (Brancati *et al.*, 2018). These two country case studies will pave the way for a focus, presented in Section 4, on differences occurring within the value chains, which I will illustrate with regard to the automotive supply chain in China, Germany, Italy and Japan. Section 5 discusses the results focusing on the changes driven by the production of electric vehicles and by cross-country collaboration. Section 6 concludes pointing out the implications of the ongoing transformations for industrial and innovation policy in Europe.

2. What is meant by "digital transformation"?

The ‘digital economy’ has become a common term used in both political and academic spheres, but there is no universally accepted definition. The Internet economy is often used as a synonym for the digital economy, although its scope is narrower. The Internet economy is the transformation of the economy and society brought about by the use of information technologies. These transformations occur in practically all sectors of the economy since the full range of our economic, social and cultural activities are supported by internet and related information and communication technologies (ICTs).

Digital transformation is a term associated with cross-sector technological changes (Bajgar *et al.*, 2019).[4] Most of these changes are summarised with a focus on industry by the label "Industry 4.0", adopted by governments and by business companies to refer to the development of "smart factories" (Wang *et al.*, 2016), involving greater flexibility, large-scale customization, speed and autonomy in production and collection of large amounts of data, and a significant reduction in costs by increasing efficiency and reducing the duration of innovation cycles.

According to the “German Plattform Industrie 4.0” (the platform responsible for Industry 4.0 in Germany),[5] “The term Industrie 4.0 stands for the fourth industrial revolution, a new level of organization and control of the entire value creation chain during the life cycle of products. This cycle is oriented toward increasingly individualized customer demands and stretches from the concept, to the order, to development and manufacture, to the delivery of a product to the end user, right up to the recycling process, including the associated services.” (Sendler, 2017: 15). The "four" in the term "industry 4.0" indicates the fourth industrial revolution (Davies, 2015). The three previous industrial revolutions refer to the changes brought about by hydropower and steam power, electricity, and automation, respectively. The Fourth Industrial Revolution refers to the use of a range of technologies (Liao *et al.*, 2017; Yin *et al.*, 2018): information technologies, digital technologies (e.g. 3D printing, Internet of Things, advanced robotics), new processes (e.g. data-based production, artificial intelligence, synthetic biology) and new materials (e.g. bio- or nanotechnology).

In order to analyse digital transformation, it is necessary to shift the attention from the individual manufacturing factory to the entire production system. This implies that

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[4] OECD refers to those transformations as the "next production revolution" (Oecd, 2017)

[5] Detailed information is available at https://www.plattform-i40.de/PI40/Navigation/EN/Home/home.html (Accessed: 29 June 2019).

the relevant unit of analysis becomes the entire production system in which automation and connectivity in production, sales, transport and logistics, and after sales occur (Yin *et al.*, 2018).

The main technology drivers of the digital transformation are the devices enabling communication between machines, products and people in cyber-physical systems. In such systems, exchanges of matter, energy and information, incorporate data flows and calculations into physical environments and processes (e.g. manufacturing processes). This is done via radio frequency identification (RFID), a technology that uses a chip device (the size of a grain of rice) related to the products, or via micro-electro-mechanical systems (MEMS), a technology of microscopic devices, particularly those with moving parts.[6] Through cloud systems, data are transferred to centres that evaluate information and communicate with machines, other products and people. A new level of synchronization of production processes and monitoring of product data in real time is thus framing the organization and working of production systems: from product development to manufacturing and sales. It is expected to have far-reaching consequences on productivity, job design, labour competences and skills, income distribution, wealth and the environment. In this framework, artificial intelligence allows production systems to go further:[7] by automatically optimizing them, by predicting machine failures and by simulating new production and product innovations.

Crucial players in digital transformation are the digital start-ups: they put on the market new products, additional functionalities for existing products and digital services. They transform existing commercial activities into digital ones (for example, the adoption of digital technologies increases the affordability of a product or service, or allows the introduction of new functionalities). Other players in the digital transformation are digital platforms: meta level agents emerging from different economic sectors, such as a telco like Vodafone, that uses its technological infrastructure (internet connections) to supply new services built on data analytics, or platforms supporting transactions between producers and consumers, like Amazon, or between customers and producers and between producers, like Alipay. Other relevant players are the regulators who orient, enhance and support the pace of digital transformations in their development and adoption.

The state-of-play of digital transformation embraces developments and devices that are at the core of the iconography of smart manufacturing in the Industry 4.0 paradigm. This iconography generally conveys a very strong message of connectivity and integration within and outside the factory, as key features. Another strong message of both iconography and literature is the disappearance of routine and physical effort in factory manufacturing (Brynjolfsson and McAfee, 2014; Chuah *et al.*, 2018). The dimensions involved in this integration essentially bring together the internet of things and the internet of services, with "smartness" characterizing energy grids, people mobility, logistics in transport of goods, ways in which buildings are built and interact with the environment and with the activities inside, and products. In smart manufacturing, the "digital twin" models the product, or part of it, with regard to the memory of its production process, thus allowing flexible product-driven configuration of production, intelligent automation using robots - collaborating with robots and people - and increasing efficiency of inventory management.

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[6] This technology merges, at the nano-scale, with nanoelectromechanical systems (NEMS) and nanotechnology. MEMS are also referred to as micromachines in Japan, or micro systems technology (MST) in Europe.

[7] Presented at the end of the 1950s as the technology that in ten years would challenge human strategic thinking (Simon, 1957), artificial intelligence started to become effective only in the last decade, when computational features were expanding its adoption well beyond the academic sphere.

A multilayer structure must be considered in order to analyse smart manufacturing in Industry 4.0. In fact, it is embedded in a multilayer network of interactions involving several types of agents (located at different levels): service partners; suppliers of raw materials, intermediate goods and services; customers; competitors; investors; technological providers, but also regulators and media. A number of technologies and devices support these interactions through an array of (smart) manufacturing support services and (smart) operation services: project management, customer relationship management, information rights management, supply chain management, technology scouting.

When one moves from the iconography of connectivity (the essential character of the fourth industrial revolution) to a more analytical framework of connections, the attention has to focus on potential leakages, but also on spillovers and complementarities that might emerge within and between companies belonging to the same sector or to different sectors.

To this end, it is useful to refer to the analytical framework developed by Motohashi (2017) to study the diffusion of big data in manufacturing companies in Japan. First of all, he highlights the main areas of activities: product development, production, sales and after sales services. Because the level of vertical and horizontal integration may differ between firms, the activities might be undertaken to a different degree within and outside the company. The generation and use of data in each activity and the exchange of data between activities (as in the case of the development department using data collected in the production process) is a critical feature calling for collaboration within companies' departments or between companies (suppliers or customers). The management structure adopted in the use of data, the presence or absence of a specialised department to promote the use of big data, the human resources needed for the use of data in the various departments might create barriers to the use of data and might hamper the impact of big data on the performance of companies.

As shown by Motohashi (2017), there are various types of data that are generated within the company,[8] such as computer aided design data and simulation data (generated by the development of products) or ordering data (generated in the interaction with the after-sales services and after-product activities). Data are generated also in the relationship with customers (operating data and failure data) and with suppliers (manufacturing process data and procurement goods inspection data).

Flows of information within the company, between the development department and the production activities (or between a company and its product developer), relate specifically to manufacturing and design requirements and the setting of allowable tolerances. Within production activities, information refers to mass production customisation and process improvements. Information flows between production activities and after-sales services or after-product development characterize traceability, which is relevant for improving companies' performance. In particular, prediction of failures and potential cost reduction is associated to the information flows between after-sales activities and the customers. Information on consumable orders fosters a more effective prediction of demand and management of inventories (of both final products and bought raw materials, intermediate goods and components).

All the information flows mentioned above require not only the investment in dedicated machinery, devices and software applications, but also a structure of permissions within and outside the company, to support effective actions. Although this

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[8] The several, diverse flows of information are supported by different software applications, such as Computer Aided Design Manufacturing; Computer Aided Engineering (CAD/CAM, CAE), Simulation, Product Life Cycle Management (PLM); Manufacturing Execution System (MES), Supply Chain Management (SCM); Enterprise Resources Planning (ERP).

issue is not new in the organisation literature dealing with innovation processes (Lane *et al.*, 1996), it becomes a critical feature to be considered when interpreting the different patterns of adoption of digital technologies within a supply chain.

In the following two sections, differences in the adoption of digital technologies will be considered with regard to sectors and various supply chains (Section 3) and within the automotive supply chain (4). The cross-country perspective is limited to the available case studies that present a relatively homogeneous set of information.

3. Digital transformation in progress

A taxonomy of digital intensity

A taxonomy of sectors' digital intensity has been proposed in the context of the Oecd project Going Digital (Calvino *et al.*, 2018). The taxonomy is grounded on several dimensions, explored in a set of Oecd countries for which data were available:[9] (i) a technological dimension (measured by the share of ICT tangible and intangible, i.e. software, investment; share of intermediate purchases of ICT goods and services; stock of robots per hundreds of employees ICT investment, ICT intermediate consumption and robots); (ii) a human capital dimension (i.e. skills, knowledge) required to embed technology in production (measured by the share of ICT specialists in total employment); (iii) an organisational dimension that look at changes in the way firms behave on the output market (measured by the share of turnover from online sales). These three dimensions provide input for defining a global index of digital intensity, with regard to 36 ISIC rev.4 sectors. The dimensions and the global index are computed for the period 2001-03 and 2013-15.

The results of the comparative analysis using the taxonomy proposed by Calvino *et al.*, (2018) show that between the two periods, the various sectors show a different degree of positive dynamics in the various dimensions and in the global index, without a sharp change in the overall ranking (a result due to the different structural characteristics of the various sectors). Another result is, for each dimension, the large dispersion of the indexes among the countries under analysis. Limiting our attention to the cross-sector comparison in manufacturing activities (ISIC rev.4 codes: 13-33),[10] with regard to the global index of digital intensity computed on 12 countries, the taxonomy returns four groups of sectors according to the quartile of global digital intensity:[11]

- Low: Food products, beverages and tobacco;
- Medium-low: Textiles, wearing apparel, leather; Coke and refined petroleum products; Chemicals and chemical products; Pharmaceutical products; Rubber and plastics products; Basic metals and fabricated metal products;
- Medium-high: Wood and paper products, and printing; Computer, electronic and optical products; Electrical equipment; Machinery and equipment not elsewhere classified; Furniture; Other manufacturing; Repairs of computers;
- High: Transport equipment.

In concluding their study, Calvino *et al.* (2018: 34) highlight that - although promising in supporting country-specific analyses - the taxonomy of digital intensity would benefit from other indicators on ICT-related patents, use of robots in services and,

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[9] Australia, Austria, Denmark, Finland, France, Italy, Japan, the Netherlands, Norway, Sweden, the United Kingdom, and the United States are the countries for which the array of sector-specific indicators is available (see Calvino *et al.*, 2018: 9, who are aware that "the extent to which the measures computed generalise to other countries remains an empirical question that deserves further investigation").

[10] The full list for the 36 ISIC rev.4 sectors is available in Calvino *et al.* (2019).

[11] According to the classification: "'High' identifies sectors in the top quartile of the distribution of the values underpinning the 'global' taxonomy, 'medium-high' the second highest quartile, 'medium-low' the second lowest, and 'low' the bottom quartile" (Calvino *et al.*, 2019: 31)

in particular, "from an indicator of the value of data used by companies in production", information for which a complete time series across sectors and countries is not currently available.

In the absence of such comparative frameworks, two country case studies, on Italy (Brancati *et al.*, 2018) and Japan (Motohashi, 2017), summarised below, present empirical evidence on differences in the digital transformation among industries and supply chains. These case studies are particularly interesting because these two countries have taken up – with their national industrial policies - the challenges posed by the digital transformation promoted by the German Industry 4.0 national plan.

Big data in Japan

In 2015, the Research Institute of Economy, Trade and Industry (RIETI) sponsored an empirical analysis on the adoption of big data in Japanese manufacturing companies (Motohashi, 2017). Representing a response rate of 14 percent, the 561 interviews collected information on companies of different sizes, mainly medium-sized and large companies.[12] The topics addressed by the empirical investigation focused on three main areas: the organization of the enterprise; its collection and use of big data (by type of data); the use of data generated outside the enterprises. Companies' activities were analysed with regard to three macro-areas: design and development, manufacturing, after-sales services.

The main results are that big data in Japan are widely used in all activities, and companies with a big data function are more likely to use them in various departments, and this improves their performance. However, there is a great disparity in terms of style of use of big data, depending on the size of the company. More than half of small and medium-sized enterprises responded that, despite having heard of the Internet of Things, they did not know how they could use this technology.

The policy implications of these results impinge on three areas of intervention: promoting the diffusion of the use of big data, in particular for in small and medium size enterprises (SMEs); supporting the development of human capital needed for the use of big data; defining strategic standardisation activities for the Internet of Things.

Industry 4.0 in Italy

In 2017 Italy launched a national industrial policy to support the upgrade of equipment needed for the big step towards the fourth industrial revolution. In 2018, the Italian Ministry of Economic Development sponsored an empirical survey to assess the rate of adoption of Industry 4.0 technologies in the Italian manufacturing sector (Brancati *et al.*, 2018). The national survey reveals a significant dissemination of digital technologies, which is greater in larger companies, but also a non-negligible diffusion in the SMEs, involving more than 20 percent of companies with 10 or more employees, and almost 50 percent of large companies.[13] A very high diffusion is expected among SMEs in the next two years (also in the South of Italy, generally lagging behind in innovation processes and in economic development). The set of technologies taken into consideration by the empirical survey are: cyber security, horizontal and vertical integration of information, cloud computing, big data analytics, Internet of Things, collaborative robots, 3D printers, simulation, smart material and augmented reality. The rates of use vary, with the highest share for IoT and the lowest for augmented reality (respectively 3.7 and 0.4

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[12] In Motohashi (2017) size classes are defined as follows: small are the companies with 300 employees or less, large are the companies with 301 employees or more.

[13] Small and medium size enterprises (SMEs) are the companies with less than 250 employees. Results are disaggregated by size class according the following size in terms of number of employees: 1-9, 10-49, 50-249, 250 and more.

percent of all the companies in the sample). These technologies have a relatively greater dissemination in larger companies than in SMEs. The analysis also highlights that companies attribute different goals to digital transformation: large companies aim at enhancing their efficiency (even at the expense of employment); SMEs target new business models and quality improvements. There is a close link with innovative strategies and research and the "4.0 companies" are in the excellence range, but small in size (the median value is 7 employees). The quality of the managerial factor (with a strong incidence of training and external relations) is one of the most critical features for the future adoption of Industry 4.0 technologies.

Significant differences emerge from a comparison across the ten value chains considered in the report. In Italy, the clothing supply chain has the lowest share of companies adopting Industry 4.0 technologies (4.7 percent), while the electric machinery and electronic supply chain has the highest share (24 percent).

These results suggest different strands of policy interventions: fostering the quality of management; informing and educating SMEs on the potential benefits deriving from the adoption of Industry 4.0 technologies; supporting companies through organizational changes, as well as the upgrade of capital equipment. Indeed, in Italy, the current industrial policy programme at national level has drastically reduced the previous support to capital substitution in favour of greater support for these policy interventions.

The two country case studies show that in Japan and Italy, different types of industry 4.0 technologies are adopted by companies with different intensity in the various sectors characterizing the two economies. The ongoing digital transformation shows that there are different paces of change across industry, and within industry across companies of different sizes. Indeed, within each industry and value chain, firms of different sizes generally represent various segments of specialisation. These differences matter in the development of the digital economy. But their impact can be better understood, moving from a comparison between countries (looking at different industries) to a closer look at the state-of-play of the digital transformation in the companies belonging to the automotive value chain, in four major countries competing in the world market.

4. State-of-play of digital transformation in the automotive supply chain: China, Germany, Italy and Japan

In what follows, I will focus on the automotive supply chain in China, Germany, Japan and Italy in order to highlight the most critical factors in each country. The comparison aims at providing a better understanding of national strengths and weaknesses in the digital transformation in the automotive supply chain in those countries. And this should help to highlight the implications for industrial and innovation policy in Europe that aims at enhancing the potential of Industry 4.0 on the economy and society.

The case study on China and Germany builds on the ongoing research conducted by Johannes Kern and Pascal Wolff (2019), who interviewed managers in 27 companies in the two countries. Their aim was, among others, to single out the most critical features underlying the digital transformation in the automotive supply chain of the two world-leading countries in car manufacturing, with strong cross-country links in the automotive value chain. The case study on Italy builds on two papers of the Observatory on the automotive supply chain (2018), respectively by Anna Cabigiosu on Industry 4.0 and by myself on the interviews in Emilia-Romagna (Cabigiosu, 2019; Russo, 2019). The case study on Japan is based on the analysis developed by Kazuyuki Motohashi (2018), on the survey conducted by RIETI in 2016. In these case studies, the technologies considered encompassed the main categories of digital technologies.[14]

Among the key facts that have an impact on digital transformation in the automotive supply chain, some national specificities have to be considered. China is characterised by a huge and expanding domestic market due to rising incomes and a growing middle class; in 2015, the national policy "Made in China 2025" was launched, including detailed guidelines, tasks and target industries to support the digital transformation of the entire economy, targeting the mobility sector and electric vehicles as a key goal in that productive, social and environmental transformation. Many Chinese companies are still at Industry 3.0. Lagging behind in some fields and stepping ahead in others, Chinese suppliers are important not only for the Chinese car makers, but they also crucial for the European, Japanese and US car makers.[15] Germany has key players among the car makers in Europe and at world level. In 2012, it launched *Industrie* 4.0, a set of national policy measures encompassing interventions on Automation and Robotics and standards for effective cyber-physical systems, on education and on the creation of a fine-grain network of competence centres spread all over the country in order to support SMEs in their digital transformation (pathways). Italy has a long tradition as supplier of European, Japanese and US carmakers. In 2017, Italy launched a national policy on Industry 4.0 (as mentioned above), with incentives to support investment in physical assets for Industry 4.0 and to enhance competences of SMEs. Different opportunities and levels of upgrade in the automotive supply chain characterize Italian suppliers. Japanese car production is third worldwide, with challenging transformations in hybrid vehicles and EV. In 2015, Japan adopted the 5th Science and Technology Basic Plan, focusing on Super Smart Society (Society 5.0).

The empirical investigation by Kern and Wolff (2019) highlights some critical conditions that challenge the development of Industry 4.0 technologies. First, data security is a common issue both in Chinese and German companies, with the threat of hacking attacks indicated as a serious issue by the German suppliers. Suppliers in both countries pointed to standardisation as another key issue. For the Chinese suppliers, standards set by car makers could hamper the development of more effective solutions from a closer cooperation with supply chain partners in the value chain. In both countries, the Government is expected to have a crucial role in reducing uncertainty and setting standards. For German suppliers, standards would reduce internal complexity (e.g. reduced number of software solutions) and they could be provided by the German Association of the Automotive Industry (VDA). China has a specific challenge related to employment skills; in particular, there is an issue of know-how loss due to relatively high employee turnover and also a lack of talents for high-tech jobs. German suppliers drew attention to a critical issue stemming from the external relationship with suppliers, because of the inadequate quality of data and of the unsatisfactory level of IT implementation by suppliers, many of whom do not accept a fast adoption of new technologies.

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[14] The full list of technologies considered in the case studies are: cloud computing services providing a platform for worldwide access, mobile services and technologies integration in the working environment, RFID data transfer without physical contact, big data and smart data (analytics converting big data into smart data), all-time localization through sensors and data transfer, robotics in production and logistics, Internet of Things connecting devices, additive manufacturing solutions with 3D printers (flexibility for prototypes and small batches), augmented reality, simulation.

[15] The ongoing changes in the trade and political relations between China and the US are not examined here, but it is worth mentioning that they are strongly affected by the aim of controlling the development of digital technologies, whose application is crucial in electric vehicles and in vehicles with autonomous driving.

As to Italy, the 2018 edition of the survey on the automotive supply chain (with a sample of 441 companies) has for the first time a section on Industry 4.0, focusing on challenges and opportunities for automotive suppliers (Cabigiosu, 2019). Although 40.5 percent of suppliers have so far not reflected on or initiated innovation plans in Industry 4.0 technologies, the remaining share is either very active (25.9%), or has already defined a plan (22.1%), or considers Industry 4.0 a strategic priority of the company (11.5%). Considering willingness to adopt innovative Industry 4.0 solutions, almost 50 percent is focusing on examining at least one Industry 4.0 solution and 37.2 percent will adopt at least one in the future, with 14.3 percent of respondents remarking that they are not willing to adopt any 4.0 solution. In the case of Italy, the main risks and constraints that hinder the activation of Industry 4.0 initiatives differ across the various categories of suppliers specialised in: Engineering and Design, Systems and Modules; Subcontracting manufacturers; Specialists operating in the motorsport niche; Specialists operating in the after-market. The main constraint is the initial investment: on average, this is the case for almost 28percent of the companies, with no sharp differences between the various types of specialisation. 'The firm's culture and the inability to evaluate the opportunities offered' is the second main constraint, affecting, on average, 17.5 percent of all companies, with 24.4 percent of Systems and Modules producers and only 12 percent of Specialists operating in the after-market. The 'Lack of internal resources' is a constraint for 16 percent of companies, but less relevant for Subcontractors (manufacturing) and Specialists (about 13.3%). For Specialists operating in the motorsport niche, the 'Lack of knowledge about the new business solutions and technologies' is the second most critical constraint (for almost 24% of companies). The detailed picture emerging from the empirical investigation reveals the existence of very differentiated conditions that must be taken into consideration when a systemic perspective is adopted and innovation policy measures are undertaken.

Regarding the automotive supply chain in Japan, three main findings have to be underlined. They reflect the key results of the detailed empirical analysis developed by Motohashi (2019), based on in-depth interviews with 33 automotive firms. These 33 firms were identified as automotive firm suppliers (i.e. by and large producing automotive parts) and were interviewed by RIETI in the survey on big data. Although the sample is very small, some interesting comparisons can be made that lead to three key findings. The first finding is that these automotive firms showed a greater propensity to data sharing with other supply chain partners (working in the automotive value chain) than with companies working in other supply chains. In particular, it was found that automotive companies were more likely to share digital data with suppliers and customers, as compared to companies in other industries (respectively 45 and 35 percent with suppliers and 61 and 38 percent with customers). The second finding is that the internal use of digital data was larger for companies in the automotive industry compared to companies in other industries. The third finding concerns the impact of big data use: it was high mainly on cost reduction, traceability and manufacturing process improvement, but the use of big data was less relevant in enhancing product innovation and customer development.

5. Multidimensional perspective on digital transformation: two examples

Digital transformation calls for a multidimensional perspective in order to understand ongoing changes and suggest possible policy measures.

The perspective on the many interrelated dimensions of digital technology is clearly significant with regard to what is going on in China, which is targeting sustainable mobility with a shift towards electrical vehicles whose production will largely benefit from digital technologies. First of all, the size of the Chinese domestic market (not to speak of those of the African countries in which China is expanding production facilities and markets abroad) opens to the possibility to perform large scale experiments on alternative techniques to produce energy. This is important because technologies improve their performance in a cumulative way, allowing the emergence of socio-technical systems of complementary technologies, also fostered by patterns of user-producer interactions (Arthur 1983; Rosenberg, 1963 and 1996; Teece, 1986): scaling up across several alternatives would then provide great benefit to countries unable to scale up or implement several alternatives.[16] Within this framework, policy makers should leave many doors open for the emergence of complementary technologies or improvements deriving from learning (by interacting with other producers, with users and learning-by-doing) and scaling up. This seems to be the path of innovation policy that China has been undertaking: while in 2015 "Made in China 2025" focused mainly on batteries and on energy produced in nuclear plants (and with some other renewable energy sources), early in 2019 China promulgated the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles that now includes fuel cell technology and small unit production of hydrogen.[17] The combined conditions of a very large scale of production and domestic adoption might enhance the possibility of scaling up alternatives, such as batteries, hydrogen fuel cells and the decentralized small scale production of hydrogen (among those now on stage) that might have further applications in other countries. In turn, the large scale production of electric vehicles will radically change the supply of components and also the relative role of car manufacturers, whose competences were essential in designing and assembling cars with internal combustion engines.

Another example of the need to adopt a multidimensional perspective is the learning potential emerging from cross-country competence networks. Let us consider the case of an Italian company (with more than 600 employees) that leads in the segment of modular and redundant Uninterruptible Power Supplies and was European leader in the production of a telematics system for the remote control of vehicles (having a great impact on insurance companies’ performance). This company was acquired by a Chinese company aiming at becoming world leader in connectivity, extending to multiple product lines in automotive platforms. The acquisition was realized in two steps: the first was at 49%, to make explicit the strong interest in the company, without however running the risk of depriving it of the many links with the social and economic fabric in which it was embedded (a gentle acquisition). In two years, the company increased its employment in Italy by more than 100 employees engaging in a new long term project of growth: the design and implementation of a new plant in Chongqing Industrial Park where some leading car makers are located (among others, Porsche, BMW, Volkswagen, PSA), in one of the fast growing provinces of the Chinese area crossed by the Belt and Road Initiative. The investment project in Chongqing was funded by the Chinese owner Deren, who obtained a 10-year contract for the supply of PSA in France, for the production of a crucial component to be used in electrical vehicles assembled in plants in Europe for the EU market. The plant in Chongqing is designed and controlled, in remote, in collaboration with the Italian subsidiary, which in two years has become fully controlled by the Chinese ownership, reinforcing – thanks also to its positive performance - its strong embeddedness in the Emilia-Romagna region. A series of positive bootstrapping is enhanced in that cross country competence network: feedback on local competences in Italy, from design and remote control of such a plant; impact on local competences in China in relation to the strong linkages within that network of competences; feedback on the competence network in the three countries and in related business activities.

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[16] Lock-in conditions affect path-dependence of innovation processes. (Arthur, 1983).

[17] See the policy release 138/2019 (DRC, 2019).

6. Policy implications

The empirical evidence presented in this paper supports the hypothesis that the analysis of the ongoing digital transformation calls for an analytical framework that takes into account many interrelated dimensions. In particular, the analysis has to consider: new emerging actors, new competences and skills, new opportunities for mutual learning, many diverse levels of adoption of the various technologies encompassed in Industry 4.0 (within and across countries, as well as within supply chains).

These many interrelated dimensions - and the related cascade of changes in technologies, organisations and users' needs - are essential in supporting our understanding of the complex digital transformations that are still at their outset, and also for supporting policy measures that could foster the benefits deriving from digital technologies and mitigate potential divides.

With regard to the pace of transformation, the empirical evidence on Japan and Italy highlights a large disparity in the pace of transformation (i.e. adoption of Industry 4.0 technologies) in both countries. In particular, the divide between SMEs and large companies is worthy of note, but also the diversity across supply chains. If one considers that the full potential of digital technologies derives from its systemic adoption, this outcome underlines the need to reduce heterogeneities across industries and within sectors and supply chains. Companies lagging behind in the pace of their technical and organisational transformation may become marginal suppliers, i.e. barely capable of catching up with the innovative potential of digital technologies and thus losing their competitive advantage. The industrial landscape of many specialised suppliers may shrink, orienting customers towards other suppliers more aligned along the same technology pathway.

The focus on the interrelationships in the automotive global value chain in four countries (China, Japan, Germany and Italy) has made clear the need to look at the ongoing transformations in the digital economy with regard not only to complementary changes of technologies, but also to labour organisation and production. For example, the shift towards the large scale production of electric vehicles will change the supply of components and also the role of car manufacturers. Also, standards are a critical area for policy interventions: for example, the quality of digitalization in the automotive supply chain in China will impact on EU vehicles, thus demanding the setting of standards and more effective controls.

The implications of such changes for innovation policy have to consider the systemic changes in related systems of education, transport infrastructures and renewable energy production: their path of development will be strongly affected by the pace at which electric vehicles are produced, remote control is effective and standards are set.

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