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Doctoral Dissertation

Industry 4.0 and the future of manufacturing.

Theoretical base and empirical analyses

Giovanna Culot

Supervisor: Prof. Guido Nassimbeni

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ABSTRACT

A new industrial revolution – also called “Industry 4.0” – is unfolding fueled by the introduction of broadly interconnected digital technologies, including the Internet of Things, cloud computing, artificial intelligence and additive manufacturing. Many industries are witnessing the entrance of new players integrating new technologies into disruptive business models; incumbents are also urged to rethink how they operate against trends that are expected to further accelerate in the current pandemic situation.

The overarching aim of the research presented in this doctoral dissertation is to investigate to what extent Industry 4.0 represents a fundamental challenge to existing paradigms and requires researchers to modify their theoretical frameworks to approach emerging issues. With this in mind, each chapter can be seen as a step forward in journey whereby some core issues come progressively into focus. The starting point is a conceptual work analyzing the phenomenon – “Industry 4.0” and similar labels – and its underlying technological and non-technological components. As a second step – under the assumption of Industry 4.0 having paradigmatic properties comparable to previous industrial revolutions – potential new configurations of manufacturing value chains are investigated. Through a future-oriented expert study, eight scenarios are conceived identifying critical drivers to value chain configurations. Finally, one of these critical drivers – data sharing in inter-organizational relationships – is investigated through the development of a case study analysis in the automotive sector.

The contribution of this dissertation to the academic debate is at least twofold. On the one hand, the research highlights the cornerstones of the phenomenon to make sense of its overarching features and building elements. This contributes to lay solid theoretical foundations needed to advance the understanding in the field. On the other hand, my empirical investigations suggest that several barriers counterbalance the technological drivers for change, posing significant questions as for when and how the future of manufacturing will materialize. Overall, an approach focused on understanding how technologies influence the assumptions behind the current reasoning might lead at a synthesis between “old” and “new” elements in the Industry 4.0 phenomenon.

Keywords: Industry 4.0, Digital Supply Chain, Manufacturing, Value chain, information sharing, Systematic literature review, Delphi-based scenario analysis, Multiple case study analysis

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CHAPTER 1. Introduction

1.1. Doing research on Industry 4.0

The last ten years have been characterized by growing expectations about a new industrial revolution, also known as “Industry 4.0” (Schwab, 2016; OECD, 2017). The underlying assumption is that – in light of a new set of digital technologies reaching market-level maturity – the economy and society are experiencing changes comparable to previous industrial revolutions, such as those triggered by steam-powered mechanization, electricity and information and communication technologies (ICT) (Kagermann *et al.*, 2013). Policy makers, management consultants and private companies have all been intensifying their efforts in turning into reality what in the early 2010s was only an “announced” revolution. As far as manufacturing companies are concerned, data show an uptake of technological adoption; however, in most cases it is about pilot projects within the factory walls (WEF, 2019). Examples of large-scale applications – especially those related to supply chain digitalization – are instead still limited in number.

The phenomenon has been receiving considerable attention across academic disciplines (Liao *et al.*, 2017; Mariani and Borghi, 2019). Since the beginning of my doctoral studies, the number of publications on Industry 4.0 and related concepts has been growing exponentially, contributing to a sharper identification of key concepts and emerging issues. Only three years ago, in fact, the bulk of the research on the topic was technical in nature, focusing on the potential of emerging technologies and the definition of use cases. The main challenge for researchers back then was to understand the contours of the phenomenon in terms of key enabling technologies, applications, characteristics and impacts. Moreover, it was crucial to identify commonalities and differences between Industry 4.0 and previous paradigms in order to assess where existing theories could be tested (or rather challenged) in a new context. As natural, over time the debate has matured beyond these initial definitional efforts and focused on specific issues and topics, including the implementation processes of Industry 4.0 technologies, diffusion patterns, performance implications and non-technological features of the phenomenon. In parallel, the studies have been characterized by an increasing theoretical connotation and – although Industry 4.0 remains an essentially interdisciplinary phenomenon – specialization into separate research streams such as new production models, digital supply chains, servitization, just to name a few.

The development of my research activities over the last three years reflects this progressive coming into focus of Industry 4.0 core issues. My journey began as I acknowledge that – although science needs rigorous conceptual and terminological foundations – the ideas and language to describe Industry 4.0 were still extremely ambiguous and needed better articulation. However, being the phenomenon in the making (Lasi *et al.*, 2014; Drath and Horch, 2014; Hofmann and Rüsch, 2017) and technologies evolving by convergence and mutual combination (Yoo, 2012; Monostori, 2014; OECD, 2017), any definitional effort would fall short of expectations far too soon. The approach was thus to develop a systematic literature review in order to identify the building blocks of Industry 4.0 and related concepts. The main takeaway from this analysis was that Industry 4.0 should be seen as a broad socio-technical paradigm shift (Dalenogare *et al.*, 2018; Mariani and Borghi, 2019) with technological advancements representing just one side of the equation, the other one referring to concurrent changes in consumer habits, (inter)organizational processes and work organization.

Changes at the inter-organizational level seemed the most fascinating after these initial observations. Previous waves of technological innovation proved to affect – among others – economies of scale, transaction and coordination costs, asset specificity and agglomeration rents. History shows that these drivers triggered profound reconfigurations of competitive boundaries between industries, changes in vertical integration approaches and geographic dispersion of activities (Sampler, 1998; Baldwin, 2015). In perspective, these evolutionary trends can be seen as "paradigmatic" – i.e., typical of an historical period, such as the vertically integrated conglomerates of the 1920s (made possible by lower transport costs and higher production efficiency brought about by steam and electricity) and the offshoring phenomenon culminating in the 1990s (enabled by lower transaction and coordination costs derived from the adoption of information and communication technologies). Similar paradigmatic shifts in manufacturing are also expected in the context of Industry 4.0, for example in relation to the extreme flexibility of additive manufacturing (Jiang *et al.*, 2017; Baumers *et al.*, 2016, 2017) as well as considering the opportunity for seamless connectivity of products, processes and organizations (Evans and Annunziata, 2012; Strange and Zucchella, 2017). Given the still low implementation of Industry 4.0 at scale, only some hypotheses have been put forward by previous studies, the overall academic understanding still characterized by an extreme fragmentation of research topics and technological focus.

As I was looking for some answers to this through a future-oriented expert study, it became clear that – alongside some agreed-upon evolutionary trajectories emerging from my research – some dynamics seemed subject to critical uncertainties difficult to anticipate at present.

Starting from the identification of these uncertainties, the logical next step was thus to delve deeper into their characteristics bringing into the picture empirical evidence. Consistently with my purpose of investigating Industry 4.0 dynamics in inter-organizational settings, I decided to focus on (digital) supply chains studying if and how new technologies encourage higher levels of information sharing between companies. This was motivated by an apparent inconsistency between the mainstream narrative of Industry 4.0 – whereby new technologies are expected to unlock productivity and revenues through data sharing (WEF, 2020; Kagermann *et al.*, 2013; Evans and Annunziata, 2012) – and some evidence from the expert study just completed, whereby some participants suggested that data will possibly be retained at firm level even more being a source of competitive advantage: *if it is true that data are the "new oil", why would companies be willing to share*? Information sharing has a long-lived history in supply chain management research (Kembro and Näslund, 2014a; Johnsson and Myrelid, 2016); however, it has never been investigated in the context of Industry 4.0

To summarize – looking at both the development of the academic body of knowledge over the last few years and my own experience – I believe that doing research on Industry 4.0 is about the integration of "digital" into ongoing debates. A balance between interdisciplinary studies and disciplinary focus is needed to advance knowledge in the field. Technology has multiple, varied and interconnected implications at different levels, from human-machine interactions to value chain reconfigurations. Against the fascination of a "whole new world" described by Industry 4.0 proponents – and stressed even more in the wake of the COVID-19 pandemic – the main challenge is to understand the real characteristics of the phenomenon relating emerging trajectories to existing paradigms.

1.2. Aims of the research

The overarching aim of the research presented in this doctoral dissertation is to investigate to what extent Industry 4.0 represents a fundamental challenge to existing paradigms and thus requires researchers to modify their theoretical frameworks and approaches in the light of emerging issues. Under this premise – in line with the development of the academic debate and progressively building on the results of my studies (as illustrated in Section 1.1.) – I have pursued three specific research objectives during my doctoral research.

1st objective – Lay the theoretical basis for Industry 4.0 research

In light of a significant ambiguity on the conceptualization of the phenomenon, I performed a systematic literature review of almost 100 definitions of Industry 4.0 and related concepts.

The review was oriented by the following research questions: What are the key definitional elements of the upcoming industrial revolution as described by Industry 4.0 and similar concepts? (*RQ1a*); and What are the differences between Industry 4.0 and the other concepts describing the phenomenon? (*RQ1b*). The coding framework and future research directions aim at providing an initial contribution towards the operationalization of the phenomenon.

2nd objective – Investigate emerging characteristics of Industry 4.0 in manufacturing

The assumption of Industry 4.0 having paradigmatic properties comparable to previous industrial revolutions needed further investigation. I focused on the configuration of manufacturing companies. In doing this, I considered both the phenomenon's characteristics – i.e., "what practices are enabled by Industry 4.0" – and its scope – i.e., "what kind of companies will be affected". As the review of the existing literature revealed an overall picture still incomplete and not entirely coherent, I developed a future-oriented expert study following the methodological guidelines of Delphi-based scenario analyses. The following research question was explored: How will manufacturing value chains evolve in the context of Industry 4.0? (*RQ2*). The objective was not to derive a definitive forecast, but rather scenarios, meaning *"descriptions of possible futures that reflect different perspectives"* (van Notten *et al.*, 2003, p. 424). The elaborated scenarios aim to draw the attention where emerging trends needed scholarly research to focus in order to better explain the nature of manufacturing in the new context.

3rd objective – Explore the effects of Industry 4.0 on information sharing

The potential of Industry 4.0 to increasingly enable data sharing and information systems integration fit in an ongoing debate across managerial disciplines. In particular, scholars in supply chain management have often addressed the issue of inter-organizational information flows in terms of drivers, barriers, performance implications and contingency elements. Despite the number of pages written on the topic, there are still several question marks as for the real practice of information sharing due to its complexity, costs and risks (Kembro and Näslund, 2014a). Under this premise, I develop a case study analysis driven by the following research questions: How do manufacturing companies seize digital opportunities for information sharing in supply chains? (*RQ3a*) How emerging dynamics are explained through established theoretical frameworks? (*RQ3b*). In line with the overarching aim of the research presented in this doctoral dissertation, the approach was based on abductive reasoning (Ketokivi and Choi, 2014). The objective of the analysis was to identify whether new trends could be seen at the horizon that required scholars to rethink some assumptions underpinning existing frameworks.

1.3. Structure of the dissertation

Following this introduction this doctoral dissertation consists of three chapters adapted from studies already published in international journals and/or presented in international conferences. The studies were developed by myself as first author and co-authored by my supervisor (Prof. Guido Nassimbeni) and two other academics within the research group (Prof. Marco Sartor and Prof. Guido Orzes). This is in accordance with the regulations of the University of Udine for doctoral dissertations. The publisher of both journal articles (Elsevier) grants permission for the reuse of published content in dissertations without restrictions.

The three chapters reflect the research objectives outlined in the previous section (Section 1.2.). **Chapter 2**, adapted from *"Behind the definition of Industry 4.0: Analysis and open questions"*[1], presents the systematic literature review of Industry 4.0 definitions and an initial conceptualization of the main definitional elements of the phenomenon. **Chapter 3**, adapted from "*The future of manufacturing: a Delphi-based scenario analysis on Industry 4.0*"[2], includes a systematic literature review on the impact of Industry 4.0 and related technologies on the configuration of manufacturing companies in terms of competitive and operations strategy. On this basis, the Delphi-based scenario analysis is developed taking as a base year 2030, eight scenarios are formulated. **Chapter 4** illustrates the results of the case study analysis on the role of Industry 4.0 in enabling higher levels of interorganizational information sharing. Besides the literature on Industry 4.0 already included in the previous chapter, the body of knowledge on information sharing is presented. A previous version of the chapter – *"Data sharing in inter-organizational settings: emerging patterns in the context of I4.0"* – has been presented at an international conference last year[3].

The studies included in these three chapters are summarized in Fig. 1, highlighting the logical nexus linking progressively results and research questions.

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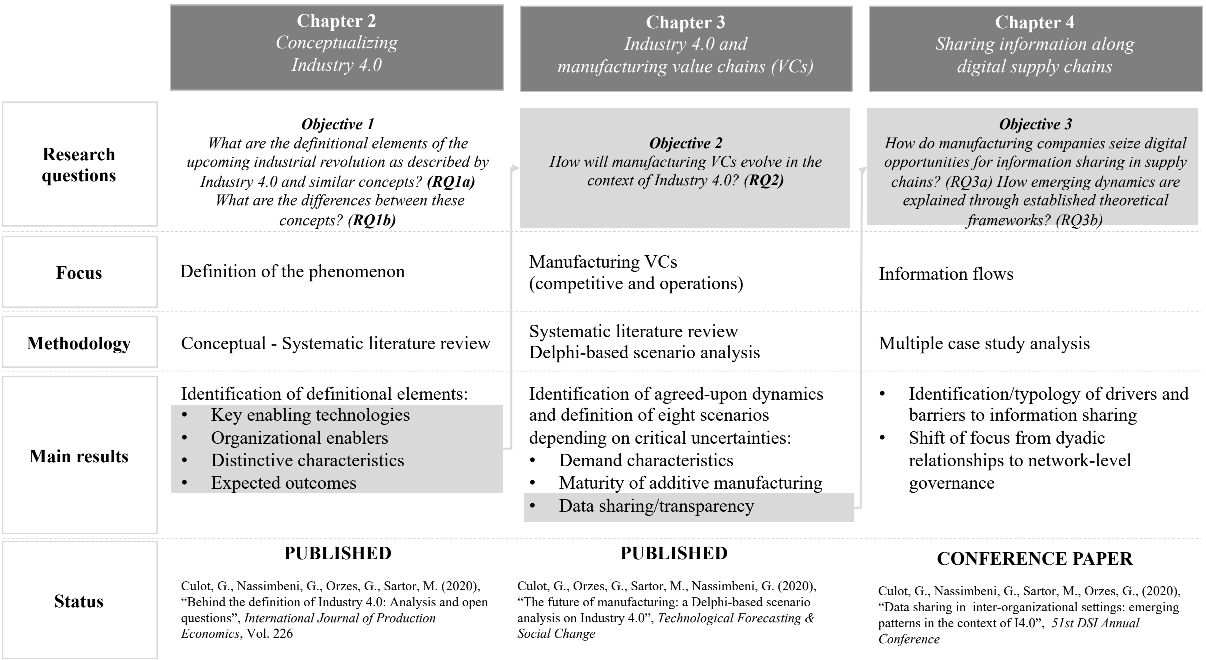
[1] Culot, G., Nassimbeni, G., Orzes, G., Sartor, M. (2020). "Behind the definition of Industry 4.0: Analysis and open questions", *International Journal of Production Economics*, Vol. 226, 10.1016/j.ijpe.2020.107617.

[2] Culot, G., Orzes, G., Sartor, M., Nassimbeni, G. (2020). "The future of manufacturing: a Delphi-based scenario analysis on Industry 4.0", Vol. 157, *Technological Forecasting & Social Change*, 10.1016/j.techfore.2020.120092.

[3] Culot, G., Nassimbeni, G., Sartor, M., Orzes, G.(2020). "Data sharing in inter-organizational settings: emerging patterns in the context of I4.0", *51st Decision Science Institute (DSI) Annual Conference, Decision Sciences in the Age of Connectivity, 21-23 November 2020.*

To conclude, **Chapter 5** summarizes the results of my doctoral research, highlighting the contribution to theory and practice, as well as limitations and future research avenues.

Figure 1. Studies included in the dissertation



	Chapter 2 *Conceptualizing Industry 4.0*	**Chapter 3** *Industry 4.0 and manufacturing value chains (VCs)*	**Chapter 4** *Sharing information along digital supply chains*
Research questions	***Objective 1*** *What are the definitional elements of the upcoming industrial revolution as described by Industry 4.0 and similar concepts?* ***(RQ1a)*** *What are the differences between these concepts?* ***(RQ1b)***	***Objective 2*** *How will manufacturing VCs evolve in the context of Industry 4.0?* ***(RQ2)***	***Objective 3*** *How do manufacturing companies seize digital opportunities for information sharing in supply chains? (RQ3a) How emerging dynamics are explained through established theoretical frameworks? (RQ3b)*
Focus	Definition of the phenomenon	Manufacturing VCs (competitive and operations)	Information flows
Methodology	Conceptual - Systematic literature review	Systematic literature review Delphi-based scenario analysis	Multiple case study analysis
Main results	Identification of definitional elements: • Key enabling technologies • Organizational enablers • Distinctive characteristics • Expected outcomes	Identification of agreed-upon dynamics and definition of eight scenarios depending on critical uncertainties: • Demand characteristics • Maturity of additive manufacturing • Data sharing/transparency	• Identification/typology of drivers and barriers to information sharing • Shift of focus from dyadic relationships to network-level governance
Status	**PUBLISHED** Culot, G., Nassimbeni, G., Orzes, G., Sartor, M. (2020), “Behind the definition of Industry 4.0: Analysis and open questions”, *International Journal of Production Economics*, Vol. 226	**PUBLISHED** Culot, G., Orzes, G., Sartor, M., Nassimbeni, G. (2020), “The future of manufacturing: a Delphi-based scenario analysis on Industry 4.0”, *Technological Forecasting & Social Change*	**CONFERENCE PAPER** Culot, G., Nassimbeni, G., Sartor, M., Orzes, G., (2020), “Data sharing in inter-organizational settings: emerging patterns in the context of I4.0”, *51st DSI Annual Conference*

1.4. Main contributions

Overall, the research presented in this doctoral dissertation contributes to the growing literature on Industry 4.0 by promoting a cross-disciplinary debate drawing from different streams of research that have investigated the issue separately so far. The dissertations links literature in operations and supply chain management with business strategy and evolutionary theories. Broad-range considerations are discussed on topics such as information sharing, manufacturing servitization, mass customization, technological platforms and multi-sided markets.

Each study included in the review, moreover, delivers some specific contributions to the debate.

First, against a definitional ambiguity and overoptimistic expectations about Industry 4.0, **Chapter 2** offers an analytical perspective to researchers in the field. The definitional dimensions and sub-dimensions characterizing the phenomenon in its technological and non-technological aspects are identified.

Second, **Chapter 3** describes the emerging paradigmatic characteristics of Industry 4.0 in manufacturing building on the assessment of expert academics and practitioners. The description confirms some dynamics highlighted in the literature, while puts into perspective other evolutionary trajectories. The individuation of crucial uncertainties behind those represents a further element of originality.

Third, in **Chapter 4** the issue of information sharing – broadly investigated in supply chain management over the years – is recontextualized with respect to Industry 4.0. Evidence from a series of case studies developed in the automotive sector shows that the impact of Industry 4.0 technologies as enablers of higher inter-organizational data sharing is uneven depending on the type of flow, the characteristics of the players involved, and network governance. As information sharing is analyzed beyond the traditionally linear (mostly dyadic) setting, new opportunities for theory development are highlighted.

As far as the contribution to the practice is concerned, the dissertation underlines the complexity and multidisciplinary nature of the phenomenon against a "plug-and-play" understanding of technology. By defining possible scenarios, managers are urged to focus and anticipate possible key trends conducive to different possible futures for manufacturing. Finally, in light of the significant expectations about Industry 4.0 optimizing inter-organizational networks, the issue of information sharing is revisited stressing potential controversial areas.

CHAPTER 2. Conceptualizing Industry 4.0

2.1. Purpose

The many scholars approaching Industry 4.0 today need to confront the lack of an agreed-upon definition, posing serious limitations to theory building and research comparability. Since its initial German conceptualization in 2011, both the technological landscape and the understanding of the Industry 4.0 have evolved significantly leading to several ambiguities. In parallel, similar concepts often used as synonyms – such as "smart manufacturing", "digital transformation", and "fourth industrial revolution" – have increased the sense of confusion around the scope and characteristics of the phenomenon. Almost 100 definitions of Industry 4.0 and related concepts were analyzed to address the issue. The chapter is adapted from *"Behind the definition of Industry 4.0: Analysis and open questions"*[4].

2.2. Positioning of the research

Conventional wisdom places the "invention" of Industry 4.0 in 2011 in Germany, when the concept was presented at the Hanover Fair by a working group on a mandate from the Research Union Economy-Science of the German Ministry of Education and Research. As described in their final report, the term Industry 4.0 was used to cover two different meanings: as a synonym for an alleged "fourth industrial revolution" – following those triggered by steam-powered mechanization, electricity and information, and communication technologies (ICT) – and also as a label for the strategic plan pursued by Germany to strengthen its international competitive position in manufacturing (Kagermann *et al.*, 2013).

Even though the German origins of the concept are seldom questioned, expectations about a technology-driven "manufacturing renaissance" were growing around the same time in many other contexts (Livesey, 2012; Mosconi, 2015; Hartman *et al.*, 2017). Similar initiatives were being launched in other geographies, as in the case of the US Advanced Manufacturing Partnership (Executive Office of the President, 2012) and the European Factories of the Future Program (European Commission, 2013). Consulting companies and major technology providers were publishing white papers on an upcoming revolution in manufacturing and beyond (e.g., McKinsey, 2012; Evans and Annunziata, 2012; Bradley et al., 2013). The academic research at the crossroad between technology and operations management was being

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[4] Culot, G., Nassimbeni, G., Orzes, G., Sartor, M. (2020). "Behind the definition of Industry 4.0: Analysis and open questions", *International Journal of Production Economics*, Vol. 226, 10.1016/j.ijpe.2020.107617.

given further impetus with the prospect of new manufacturing paradigms (e.g., Radziwon *et al.*, 2014; Tao *et al.*, 2011; Ning *et al.*, 2011; Lu *et al.*, 2013).

These governmental initiatives, practical reports, and academic studies were characterized by partially overlapping concepts and terminology. Different "labels" were used to describe the phenomenon, including "Industrial Internet" (Evans and Annunziata, 2012), "industrial revolution" (Tien, 2012), and "smart manufacturing" (Radziwon *et al.*, 2014). Among these labels, "Industry 4.0" has eventually become prevalent, and since 2013 it has attracted exponentially increasing interest from scholars across technical and managerial disciplines (Liao *et al.*, 2017; Muhuri *et al.*, 2019).

Although a clear-cut definition of the Industry 4.0 would be expected against the dramatic growth in the number of studies in the last few years, recent research papers show instead a clear omission in the conceptualization of the phenomenon. The ongoing confusion between Industry 4.0 and similar concepts is still perceived as a major hindrance for the scope and theoretical foundations of academic investigations (Osterrieder *et al.*, 2019; Rymaszewska *et al.*, 2017; Agostini and Filippini, 2019). Studies on the implementation of Industry 4.0 (Frank *et al.*, 2019; Dalenogare *et al.*, 2018; Tortorella and Fettermann, 2017; Ghombakhloo and Fathi, 2019; Dachs *et al.*, 2019) often include different sets of technologies and applications, as well as many "old" technologies such as enterprise resource planning (ERP), computer-aided-design (CAD), computer-aided-manufacturing (CAM), and electronic data interchange (EDI). The several Industry 4.0 maturity models (Trotta and Garengo, 2019; Bibby and Dehe, 2018; Ganzarain and Errasti, 2016) show similar ambiguities in terms of organizational practices and competitive configuration.

These issues are just partially explained by the origins of Industry 4.0 as – in the process of becoming the label for a global phenomenon – the initial German formulation became contaminated by the ideas and the terminology developed by other schools of thought. At the roots of these ambiguities there is in fact also the relative novelty of the phenomenon as, despite some over-optimistic view offered by the mainstream press, it is still in its infancy and characterized by uncertain developments (Lasi *et al.*, 2014; Drath and Horch, 2014; Hofmann and Rüsch, 2017). The same technological landscape is evolving very rapidly, leaving many questions open in terms of future maturity and possible application (OECD, 2017; Gartner, 2017).

In the light of uncertain evolutionary trajectories, the aim of this paper is to initiate a debate around the definition of the phenomenon in order to: (1) reduce the level of ambiguity for the benefit of both the academic and the managerial communities; and (2) introduce the foundational premises for the theoretical conceptualization of Industry 4.0 scope and characteristics.

The study thus investigates the following research questions:

RQ1: What are the key definitional elements of the upcoming industrial revolution as described by Industry 4.0 and similar concepts?

RQ2: What are the differences between Industry 4.0 and the other concepts describing the phenomenon?

We approached the issue by means of a systematic literature review (Rousseau *et al.*, 2008; Tranfield *et al.*, 2003) of academic studies providing a definition of Industry 4.0 and similar concepts. A selection of non-academic publications was also included in the analysis. The outcome is a categorization that clarifies the semantic of Industry 4.0 and its dimensions. We did not formulate a conclusive definition – which would be reductive in front of the many uncertainties and the multidisciplinary nature of the debate – but we suggest a series of research directions for the scientific community.

The difference between this work and previous literature reviews is substantial. Liao *et al.* (2017) mainly investigated the current state of research on Industry 4.0, similarly to Piccarozzi *et al.* (2018) who reviewed only managerial literature. Pereira *et al.* (2017), Lu (2017), Otmel and Gursev (2018) and Alcácer and Cruz-Machado (2019) mainly addressed Industry 4.0 technologies and their impacts; Hermann *et al.* (2016) and Ghobakhloo (2018) delved into characteristics or "design principles"; Schneider (2018) and Liboni *et al.* (2019) focused on organizational and human resource management implications; Kamble *et al.* (2018) explored Industry 4.0 at the crossroad with operations and supply chain management.

2.3. Literature review approach

Following the approach proposed by Rousseau *et al.* (2008) and Tranfield *et al.* (2003), we developed a systematic literature review – a systematic method for locating, analyzing and synthetizing existing literature – of academic contributions with an explicit and primary focus on defining Industry 4.0 and related terms. This literature has been complemented by a selection of non-academic publications to account for both the relative novelty of the topic and the influence of industry, policymakers, and other players in shaping the concept (Knopf, 2006). Both academic and non-academic papers have been analyzed for their content, following Seuring and Gold (2012) methodological recommendations. Screening and coding activities have been carried out independently by two researchers and any disagreement discussed within the team until an agreement was reached.

With respect to the academic literature, we performed a search on title, abstract and keywords on Elsevier's Scopus, the most acknowledged online scientific database. Two different sets of keywords have been utilized in a combined search (OR to combine the keywords within the two sets; AND to combine the two sets). Set 1 comprised 19 labels for the phenomenon, which have been identified through a "snowballing" approach, i.e. progressively adding the terms used as synonyms for or equivalent to Industry 4.0 in the papers we first analyzed. In line with the aims of this study (to identify the key definitional elements of Industry 4.0 and highlight the differences with other concepts describing the phenomenon), we did not include in the set keywords related to specific technologies – e.g., the "Internet of Things" of "3D printing" – but only terms describing overarching concepts. Set 2 contained 13 keywords related to the semantic fields of "definition" and "classification". The final list of keywords is shown in Table 1.

Table 1. List of keywords

Set 1 – related to Industry 4.0	**Set 2 – related to definition**
Industry 4.0	Defin*
Industrie 4.0	Concept*
Fourth Industrial Revolution	Classif*
4th Industrial Revolution	Taxonomy
Industrial Internet	Understanding
Smart manufacturing	Paradigm
Smart factory	Characteri*
Smart industry	Review
Cyber manufacturing	Overview
Digital transformation	Vision
Cyber-physical production system	Framework
Cloud manufacturing	Notion
Cloud-based design and manufacturing	Introd*
Software-defined manufacturing	
Factory of Things	
Wisdom manufacturing	
Self-organizing manufacturing	
Social manufacturing	
Smart city production system	

The research, covering the period until February 2019, resulted in 4,666 records filtered for publications written in English. Abstracts and full texts have been screened against a set of explicit exclusion and inclusion criteria. We excluded: (i) articles where Set 2 keyword did not refer to Set 1 keyword (i.e., a definition is provided but not of Industry 4.0 or related terms); and (ii) articles defining a single technology. We included articles that (i) explicitly provided a definition; (ii) introduced comprehensively the concept; or (iii) compared Industry 4.0 with one or more other terms. 137 papers have been preselected based on their abstracts, afterwards their full-text and reference list have been examined. At the end of the process, 81 academic publications have been included in the analysis.

With respect to non-academic literature, the large number of publications on the topic would have made ineffective a systematic review through a keyword search on the web. We thus first defined the list of possible sources, and then searched online for the existence of documents issued by these sources on Industry 4.0 or anyways describing similar technology-driven evolutions. We identified five relevant groups: (i) *country-specific sources* with contributions published either by administrative bodies or by initiatives receiving governmental support in the ten largest economies by manufacturing GDP (United Nations Statistics Division, 2018); (ii) *international sources* considering the main intergovernmental organizations, such as the Organization for Economic Co-operation and Development (OECD), the European Commission and the United Nations Industrial Development Organization (UNIDO), and international think tanks like the World Economic Forum (WEF); (iii) the two major *consulting firms* worldwide, i.e. McKinsey&Company and The Boston Consulting Group; (iv) *international standard-setting bodies*, including a contribution by the International Electrotechnical Commission (IEC); (v) *multinational companies* which have been cited by the selected academic papers, as General Electric and Cisco. As a result, 18 non-academic publications have been included.

Thereupon, we proceeded with the coding analysis. First, we classified each publication based on source category. Limited to academic papers, we also classified each contribution in terms of publication outlet, the geographical location of the institutions, authors' affiliation, methodology, type of contribution. Thereafter, we analyzed the content of each contribution to identify its underlying definitional elements. As authors often use different terminology or level of detail (Mittal *et al.*, 2016), we adopted an inductive approach. Individual items mentioned in each publication were clustered for similarity into six coding categories and relative sub-categories.

2.3. Characteristics of the literature

This section presents the descriptive findings first for the academic literature, thereafter for the non-academic one. The analyses are based on the data included in Table 2 and Table 3, inserted at the end of this section.

2.3.1. Academic literature

The classification brings to light several insights on the development of the Industry 4.0 concept within the scientific community.

The analysis included 42 definitions of “Industry 4.0” and 39 of other concepts. The first definition of “Industry 4.0” published in an academic outlet dates back to 2014 (Drath and Horch, 2014) and is a review by two German professionals issued in the IEEE Industrial Electronics Magazine. Most of the contributions were published in 2017 (10 papers, 23.8%) and 2018 (12 papers, 28.6%). Initially, the debate had a strong German connotation: 10 (62.5%) out of the 16 definitions published until 2016 have German authors, from 2017 onwards only one (3.8%) out of 26. Going forward, the debate was still characterized by a European imprinting, as just 13 contributions out of 42 (30.9%) do not have at least one European author. The analysis of the authors’ affiliations shows a strong prevalence of engineering disciplines with 20 (47.6%) contributions. Definitions are provided by 20 articles (47.6%), 20 conference papers (47.6%), one book chapter and one review. Out of the articles, seven are from ABS-ranked journals (ABS-Association of Business Schools, Academic Journal Guide 2017), including two from Computers in Industry (Hofmann and Rüsch, 2017; Chiarello et al., 2018) and one each from the following journals: Production Planning and Control (Fatorachian and Kazemi, 2018), International Journal of Production Economics (Frank et al., 2019), International Journal of Production Research (Xu et al., 2018), Journal of Manufacturing Technology Management (Ghobakhloo, 2018), and Journal of Intelligent Manufacturing (Oztemel and Gursev, 2018). Overall, with reference to the citation data available on Google Scholar in October 2019, the three most credited definitions so far have been Hermann *et al.* (2016) with 1,385 citations; Lasi (2014) with 1,158, and Drath and Horch (2014) with 556. In terms of methodology, most of the papers are conceptual except for three surveys (Frank *et al.*, 2019; Schmidt *et al.*, 2015; Khan and Turowski, 2014) and one paper describing a demonstration in a learning factory setting (Anderln, 2015).

Out of the 39 academic definitions of other concepts, most of the contributions included in the analysis were published in 2016 (10 papers, 25.6%), 2017 (9 papers, 23.1%), and 2018 (8 papers, 20.5%). The first definitions were two conference papers published in 2011 which refer to the concept of “Cloud manufacturing” (Ning *et al.*, 2011; Tao *et al.*, 2011). Some patterns can be observed from a geographical standpoint: definitions of “Cloud manufacturing” come mostly from Chinese institutions (5 out of 12), those of “Smart manufacturing” from US-based scholars (3 out of 7). The authors’ affiliation is largely in engineering disciplines (31 papers, 79.5%). 27 (69.2%) contributions are journal articles, 12 (30.8%) conference papers. Eight definitions have been published in ABS-ranked journals: International Journal of Production Research (Kumar, 2018; Kusiak, 2018), Computers in Industry (Boyes *et al.*, 2018), IEEE Transactions on Systems, Man, and Cybernetics: Systems (Tao and Qi, 2019), International Journal of Computer Integrated Manufacturing (Adamson *et al.*, 2017; Ren *et al.*, 2017), Journal of Manufacturing Systems (Fisher *et al.*, 2018), and International Journal of Agile Systems and Management (Yadekar *et al.*, 2016). Overall, the three most credited definitions so far refer to the concept of "Cloud manufacturing" and are Tao *et al.* (2011) with 471 citations, Zhang *et al.* (2014) with 407, and Wu *et al.* (2015) with 382. In terms of methodology, all the papers are conceptual except for one case study (Kumar *et al.*, 2016) and one simulation model (Song and Moon, 2016).

2.3.2. Non-academic sources

The review encompasses six definitions "Industry 4.0": besides the German working group report finalized in 2013 (Kagermann *et al.*, 2013), two management consulting companies' white papers published in 2015 (Rußman *et al.*, 2015; McKinsey Digital, 2015), two documents related to country-specific initiatives issued in 2016 and 2017 respectively in Italy (Ministero dello Sviluppo Economico, 2016) and in Brazil (Fiesp, 2017), and a 2017 publication by the UNIDO (UNIDO, 2017). The other 12 non-academic definitions use a variety of terms. Country-specific documents refer to industrial policy initiatives similar to the German one but named differently. These initiatives are the US "Advanced manufacturing" (Executive Office of the President, 2012), the South Korean "Manufacturing 3.0" (MOTIE, 2014), the Chinese "Made in China 2025" (State National Council, 2015), the French "Factories of the Future" (Usin du Futur, 2016), the UK "Fourth industrial revolution" (HM Government, 2017), and the Japanese "Society 5.0" (Prime Minister of Japan and His Cabinet, 2017). Documents issued by international sources include one by the European Commission referring to the "Factories of the Future" (European Commission, 2013), one book published by the WEF and written by its founder on the "Fourth industrial revolution" (Schwab, 2016), and a report by the OECD on the "Next production revolution" (OECD, 2017). Among standard-setting bodies, only the IEC published a document describing the "Factory of the Future" concept (IEC, 2015). Finally, our analysis encompasses also two white papers issued by multinational corporations introducing two further terms: GE's "Industrial Internet" (Evans and Annunziata, 2013) and Cisco's "Internet of Everything" (Bradley *et al.*, 2013). Overall, some of these non-academic definitions had a decisive impact in shaping the current understanding of the phenomenon, in particular the book published by the WEF (3,596 Google Scholar citations in October 2019), the final report by the German working group (1,091), the white paper by the Boston Consulting Group (614), and that by GE (499).

Non-academic sources are presented separately in the paper to allow the reader to assess and attach weight to the types of contribution. The main differences with academic sources have been highlighted in the analysis.

Table 2. Academic papers included in the review

Author(s), Year	Source title	Type	Country	Affiliation	Methodol	Citations
Adamson *et al.*, 2017	International Journal of Computer Integrated Manufacturing	A	Sweden / UK	Computer sciences / Engineering	C	79
Anderl, 2015	AT- Automatisierungstechnik	A	Germany	Computer sciences	E	44
Barreto *et al.*, 2017	Procedia Manufacturing	C	Spain	Business school / Telecomunications	C	103
Boyes *et al.*, 2018	Computers in Industry	A	UK	Computer sciences	C	55
Chiarello *et al.*, 2018	Computers in Industry	A	Italy	Engineering / Business	C	19
Chu *et al.*, 2016	International Journal of Precision Engineering and Manufacturing - Green Technology	A	South Korea / USA	Engineering	C	38
Cimini *et al.*, 2019	Studies in Computational Intelligence	C	Italy	Engineering	C	
Cristians and Methven, 2017	Proceedings of the International Conference on Sustainable Smart Manufacturing	C	UK	Engineering	M	
Dobos *et al.*, 2018	IOP Conference Series: Material Science and Engineering,	C	Hungary	Engineering	C	
Drath and Horch, 2014	IEEE Industrial Electronics Magazine	R	Germany	Practitioners	C	556
Dumitrache and Caramihai, 2014	IFAC Proceedings Volumes	C	Romania	Engineering	C	1
Ebert and Duarte, 2018	IEEE Software	A	Brazil	Computer sciences	C	9
Fatorachian and Kazemi, 2018	Production Planning and Control	A	UK	Business School	C	31
Fisher *et al.*, 2018	Journal of Manufacturing Systems	A	UK	Engineering	C	25
Frank *et al.*, 2019	International Journal of Production Economics	A	Brazil / France	Engineering	E	35
Ghobakhloo, 2018	Journal of Manufacturing Technology Management	A	Iran	Engineering	C	61
Havle *et al.*, 2018	Proceedings of the 2nd International Symposium on Multidisciplinary Studies and Innovative Technologies	C	Turkey	Engineering	C	1
Hermann *et al.*, 2016	Proceedings of the Annual Hawaii International Conference on System Sciences	C	Germany	Engineering / Practitioners	M	1385
Hofmann and Rüsch, 2017	Computers in Industry	A	Switzerland	Logistics management	C	354

Hozdić, 2015	International Journal of Modern Manufacturing Technologies	A	Slovenia	Engineering	C	67
Kagermann, 2015	Management of Permanent Change	BC	Germany	Other	C	278
Kamble *et al.*, 2018	Process Safety and Environmental Protection	A	India / USA	Engineering / Business	C	60
Kang *et al.*, 2016	International Journal of Precision Engineering and Manufacturing - Green Technology	A	South Korea	Engineering / Computer Sciences	C	368
Kassim *et al.*, 2017	IOP Conference Series: Materials Science and Engineering	C	Malaysia	Engineering	C	4
Khan and Turowski, 2014	Advances in Intelligent Systems and Computing	C	Germany	Computer sciences	E	57
Kirazli and Hormann, 2015	IIE Annual Conference and Expo 2015	C	Germany	Practitioners	C	6
Kubler *et al.*, 2016	Studies in Computational Intelligence	C	Luxembourg / Finland	Engineering and computer Science	C	16
Kumar *et al.,* 2016	Manufacturing Letters	A	UK	Engineering	E	15
Kumar, 2018	International Journal of Production Research	A	USA	Engineering	C	40
Kusiak, 2018	International Journal of Production Research	A	USA	Engineering	C	120
Lasi *et al.*, 2014	Business and Information Systems Engineering	A	Germany	Computer sciences / Practiotioners	C	1158
Lee *et al*., 2016	Manufacturing Letters	A	USA	Engineering	C	82
Li *et al.*, 2017	IEEE Communications Surveys and Tutorials	A	China / Canada	Computer sciences	C	94
Lom *et al.*, 2016	2016 Smart Cities Symposium Prague	C	Czech Republic	Transportation Science	C	77
Lu *et al*., 2013	Journal of Industrial Information Integration	C	New Zeland	Engineering	C	8
Lu, 2017	Journal of Industrial Information Integration	A	USA / UK	Engineering	C	475
Maynard, 2015	Nature Nanotechnology	S	USA	Risk sciences	C	77
Mittal *et al*., 2016	IFIP Advances in Information and Communication Technology	A	USA / Mexico	Engineering	C	8
Muhuri *et al.,* 2019	Engineering applications of Artificial Intelligence	A	India / USA	Computer sciences	C	30
Neugebauer *et al.*, 2016	Procedia CIRP	C	Germany	Applied research	C	44
Ning *et al.*, 2011	Proceedings: 2011 IEEE International Conference on Cloud Computing and Intelligence Systems	C	China	Computer sciences / Practiotioners	C	34
Ojra, 2019	Advances in Intelligent Systems and Computing	C	UK	Engineering / Business	C	1
Oztemel and Gursev, 2018	Journal of Intelligent Manufacturing	A	Turkey	Engineering	C	35
Pereira and Romero, 2017	Procedia Manufacturing	C	Portugal	Engineering	C	80
Piccarozzi *et al.*, 2018	Sustainability	A	Italy	Management	C	34

Pires *et al.,* 2018	IEEE International Symposium on Industrial Electronics	C	Portugal	Engineering	C	3
Postranecky and Svitek, 2017	2017 Smart Cities Symposium Prague, SCSP 2017 - IEEE Proceedings	C	Czech Republic	Practitioners	C	7
Preuveneers and Ilie-Zudor, 2017	Journal of Ambient Intelligence and Smart Environments	A	Belgium / Hungary	Computer sciences	C	39
Qin *et al.*, 2016	Procedia CIRP	C	UK	Engineering	C	292
Radziwon *et al.*, 2014	Procedia Engineering	C	Denmark	Mechatronics / Innovation	C	259
Raja Sreedharan and Unnikrishnan, 2017	International Journal of Pure and Applied Mathematics	A	India	Management	C	5
Ren *et al.*, 2015	Enterprise Information Systems	A	China	Engineering	C	161
Ren *et al.*, 2017	International Journal of Computer Integrated Manufacturing	A	China / Sweden	Engineering	C	160
Roblek *et al.*, 2016	SAGE Open	A	Slovenia	Management / Policy making	C	293
Rödder *et al.*, 2016	2016 IEEE International Conference on Big Data	C	Germany	Engineering / Computer Sciences / Business	C	6
Rojko, 2017	International Journal of Interactive Mobile Technologies	A	Germany	Applied research	C	109
Saldivar *et al.*, 2015	2015 21st International Conference on Automation and Computing	C	UK / China	Engineering	C	59
Santos *et al.*, 2017	Procedia Manufacturing	C	Portugal / Spain	Engineering	C	49
Schmidt *et al,* 2015	Lecture Notes in Business Information Processing	C	Germany	Computer sciences	E	238
Schuh *et al.*, 2014	Procedia CIRP	C	Germany	Engineering	C	83
Sissini *et al.*, 2018	IEEE Transactions on Industrial Informatics	A	Italy / USA / Sweden	Engineering / Computer Sciences	C	75
Song and Moon, 2017	International Journal of Advanced Manufacturing Technology	A	USA	Engineering	M	23
Suacedo-Martìnez *et al*, 2018	Journal of Ambient Intelligence and Humanized Computing	A	Mexico / Malaysia	Engineering / Computer Sciences	C	48
Tao and Qi, 2019	IEEE Transactions on Systems, Man, and Cybernetics: Systems	A	China	Engineering	C	73
Tao *et al.*, 2011	Proceedings of the Institution of Mechanical Engineers	C	China / USA	Engineering	C	471
Thames and Schaefer, 2016	Procedia CIRP	C	USA / UK	Practitioner / Engineering	C	104
Thoben *et al.*, 2017	International Journal of Automation Technology	A	Germany / USA	Engineering	C	218
Tien, 2012	Journal of Systems Science and Systems Engineering	A	USA	Engineering	C	55

Vaidya *et al.*, 2018	Procedia Manufacturing	C	India	Engineering	C	129
Wan *et al.*, 2015	Proceedings of 2015 International Conference on Intelligent Computing and Internet of Things	C	China	Engineering	C	103
Wang *et al.*, 2017	Advances in Manufacturing	A	UK / Norway / China	Business / Engineering	M	40
Wu *et al.*, 2015	CAD Computer Aided Design	A	USA / Sweden	Engineering	C	382
Xiong *et al.*, 2018	IEEE/CAA Journal of Automatica Sinica	A	China / Finland / USA	Engineering	C	7
Xu *et al.*, 2018	International Journal of Production Research	A	USA	Information technologies	C	225
Yadekar *et al.*, 2016	International Journal of Agile Systems and Management	A	UK	Engineering	C	13
Yao and Lin, 2015	International Journal of Advanced Manufacturing Technology	A	China / USA	Engineering	C	48
Yao *et al.*, 2017	Proceedings - 2017 5th International Conference on Enterprise Systems: Industrial Digitalization by Enterprise Systems	C	China / Switzerland	Engineering	C	15
Zhang *et al.*, 2014	Enterprise Information Systems	A	China	Engineering	C	407
Zheng *et al.*, 2018	Frontiers of Mechanical Engineering	A	New Zeland	Engineering	C	75
Zhong *et al.*, 2017	Engineering	A	New Zeland / Germany / UK	Engineering	C	308
Zhou *et al.*, 2015	12th International Conference on Fuzzy Systems and Knowledge Discovery	C	China	Engineering	C	277

Notes:
Type of contribution: A (Article); C (Conference Paper); B (Book Chapter); R (Review); S (Survey)
Citation count: Google Scholar, October 2019

Table 3. Non academic contributions included in the review

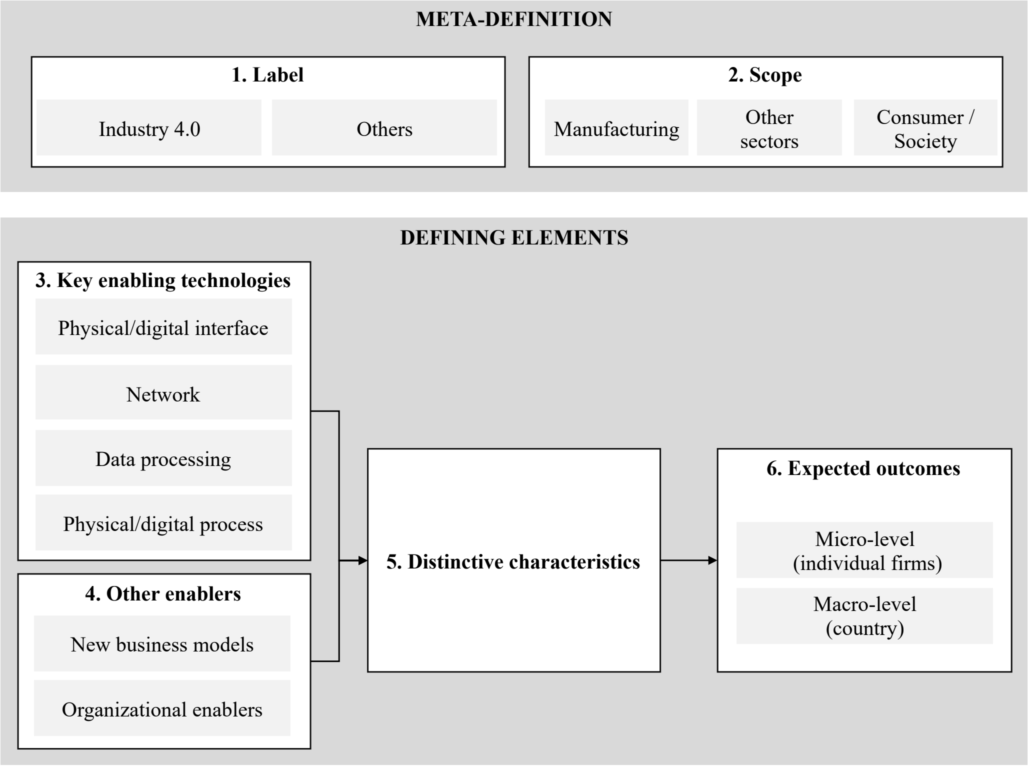
Type of non-academic source	**Author(s), Year**	**Citations**	**Program title**
A. Governmental sources	Executive Office of the President, 2012	26	Advanced manufacturing
A. Governmental sources	Fiesp, 2017a/b	n.a.	Indùstria 4.0
A. Governmental sources	HM Government, 2017	26	Industrial strategy / Fourth industrial revolution
A. Governmental sources	Kagermann *et al.*, 2013	1091	Industrie 4.0
A. Governmental sources	Ministrero dello Sviluppo Economico, 2016	2	Impresa 4.0
A. Governmental sources	MOTIE, 2014	n.a.	Manufacturing innovation 3.0
A. Governmental sources	Prime Minister of Japan and His Cabinet, 2017	n.a.	Society 5.0
A. Governmental sources	State National Council, 2015	30	Made in China 2025
A. Governmental sources	Usine du Futur, 2016	n.a.	Usine du Futur
B. International sources	European Commission, 2013	15	Factories of the Future
B. International sources	OECD, 2017	20	Next production revolution
B. International sources	Schwab, 2016	3596	Fourth industrial revolution
B. International sources	UNIDO, 2017	3	Industry 4.0
C. Consulting firms	McKinsey Digital, 2015	80	Industry 4.0
C. Consulting firms	Rußmann *et al.*, 2015	614	Industry 4.0
D. Standard-setting bodies	IEC, 2015	5	Factory of the Future
E. Other MNCs	Bradley *et al.*, 2013	184	Internet of Everything
E. Other MNCs	Evans and Annunziata, 2012	499	Industrial Internet

Notes:
Citation count: Google Scholar, October 2019

2.4. Thematic findings

In this section commonalities and differences among the various definitions of Industry 4.0 and related concepts are presented. Results are reported according to six coding categories (Fig. 2). The categories and relative sub-categories have been derived from an analysis of the themes and language emerging from individual publications.

Figure 2. Classification framework



The first two coding categories relate to the *meta* dimension of each definition, i.e. describe the features of the definition. These are: (*i) label for the phenomenon* – “Industry 4.0” or other terms; *ii) scope* – the field of reference and applicability of the definition.

The other four coding categories refer to constituting elements of the phenomenon in terms of: (*iii) key enabling technologies* – the main technological innovations supporting the change; (*iv) other enablers* –what else is required to unfold the potential of technology, especially in terms of organization and business models; (*v) distinctive characteristics* – properties that are peculiar and distinguishing of Industry 4.0; *(vi) possible outcomes* – the foreseeable impact on performance dimensions at firm or country level[5]. The full coding tables are included in Appendix.

2.4.1. Label of the phenomenon

The label “Industry 4.0” suggests a new phase in manufacturing (“Industry”) through ICT-driven innovation (“4.0”). Areas where similar technologies also have an impact – such as climate, mobility, healthcare, and security – were considered by the German Government in other initiatives that together composed the federal program High-Tech Strategy 2020 (Federal Ministry of Education and Research, 2014). In the report, the term “Industry 4.0” is described as the “fourth stage of industrialization” (Kagermann *et al*., 2013, p. 13) or as “fourth industrial revolution” (p. 20). Although the concept of “revolution” was used by other sources (e.g., OECD, 2017; Maynard 2015; Tien, 2012), the term “Industry 4.0” became *de facto* the label for the phenomenon. This is also the label attracting more definitional efforts among the examined contributions (see Table 4).

The vast majority of other labels used in the academic literature resonate with the idea of a new paradigm in manufacturing, highlighting however specific aspects. “Cloud manufacturing” transposes the key characteristics of cloud computing from ICT to the industry describing a model whereby manufacturing capabilities become encapsulated and servitized in the cloud (Adamson *et al.*, 2017; Ren *et al.*, 2017). “Smart manufacturing” extends the common meaning of the word “smart” – i.e., “an object that was enhanced by additional features that increased its ability” (Radziwon *et al.*, 2014, p. 1188) – to a connected manufacturing environment. Along the same lines, the adjective “intelligent” is applied in continuity with the “Intelligent manufacturing” concept as it developed since the 1990s (Kusiak, 2017). “Cyber” places attention on the cyber space where data from interconnected systems are processed into operations decisions (Lee *et al.*, 2016). The ideas suggested by labels related to “Social” and “Smart city” manufacturing refer to the opportunity to engage directly with consumers through social networks (Xiong *et al.*, 2018; Yao *et al.*, 2017) in order to meet the needs of urban contexts (Kumar *et al.*, 2016; Lom *et al.*, 2016).

Besides labels more strictly related to manufacturing, two other concepts have been mentioned in the academic literature: one is “digital transformation” which stresses the

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[5] In the final report of the German working group (Kagermann *et al.,* 2013), which we regarded as key reference, it is possible to trace information about each of the coding categories at the following pages: *ii) key enabling technologies*: pp. 13-14, p. 20, p. 42; *iii) other enablers*: pp. 22-23; *iv) scope*: p. 14; *v) distinctive characteristics*: pp. 20-21; *vi) potential outcomes*: pp. 15-16.

implications for strategy and business model innovation (Ebbert and Duarte, 2018; Rödder *et al.*, 2018), the other is the “Industrial Internet”, a term often considered as the US equivalent of “Industry 4.0” (Boyes *et al.*, 2018).

Table 4. Label of the phenomenon

Label	**Number**	**References**
Academic sources		
Industry 4.0 (or Industrie 4.0)	*42*	Anderl, 2015; Barreto *et al.*, 2017; Chiarello *et al.,* 2018; Cimini *et al.*, 2019; Cristians and Methven, 2017; Dobos *et al.*, 2018; Drath and Horch, 2014; Fatorachian and Kazemi, 2018; Frank *et al.*, 2019; Ghobakhloo, 2018; Havle *et al.*, 2018; Hermann *et al.*, 2016; Hofmann and Rüsch, 2017; Hozdić, 2015; Kagermann, 2015; Kamble *et al.*, 2018; Khan and Turowski, 2014; Kirazli and Hormann, 2015; Lasi *et al.*, 2014; Lu, 2017; Muhuri *et al.*, 2019; Neugebauer *et al.*, 2016; Ojra, 2019; Oztemel and Gursev, 2018; Piccarozzi *et al.*, 2018; Pires *et al.,* 2018; Pereira and Romero, 2017; Preuveneers and Ilie-Zudor, 2017; Qin *et al.*, 2016; Raja Sreedharan and Unnikrishnan, 2017; Roblek *et al.*, 2016; Rojko, 2017; Saldivar *et al.*, 2015; Santos *et al.*, 2017; Schmidt *et al.*, 2015; Schuh *et al.*, 2014; Suacedo-Martinez *et al.*, 2018; Vaidya *et al.*, 2018; Wan *et al.,* 2015; Wang *et al.*, 2017; Xu *et al.*, 2018; Zhou *et al.*, 2015
Cloud manufacturing (or Cloud-based manufacturing and design)	*12*	Adamson *et al.*, 2017; Fisher *et al.,* 2018; Kassim *et al.*, 2017; Kubler *et al.*, 2016; Lu *et al.*, 2013; Ning *et al.*, 2011; Ren *et al.*, 2015; Ren *et al.*, 2017; Tao *et al.*, 2011; Wu *et al.*, 2015; Yadekar *et al.*, 2016; Zhang *et al.*, 2014
Smart manufacturing (or Smart factory, or Service-oriented smart manufacturing)	*7*	Kang *et al.*, 2016; Kumar, 2018; Kusiak, 2018; Mittal *et al.*, 2016; Radziwon *et al.*, 2014; Tao and Qi, 2019; Zheng *et al.*, 2018
Smart city production system (or Smart city near to 4.0 or Smart city Industry 4.0)	*3*	Lom *et al.*, 2016; Kumar *et al.*, 2016; Postranecky and Svitek, 2017
Social manufacturing (or Socio-cyber-physical system-based manufacturing or Wisdom manufacturing)	*3*	Xiong *et al.*, 2018; Yao and Lin, 2015; Yao *et al.,* 2017
Industrial Internet (or Industrial Internet of Things)	*3*	Li *et al.,* 2017; Boyes *et al.*, 2018; Sissini *et al.*, 2018
Cyber manufacturing (or cyber manufacturing systems)	*2*	Lee *et al.*, 2016; Song and Moon, 2017
Fourth / Next industrial revolution	*2*	Maynard, 2015; Tien, 2012
New intelligent manufacturing (or Intelligent cyber enterprise)	*2*	Dumitrache and Caramihai, 2014; Zhong *et al.*, 2017
Digital transformation	*2*	Ebert and Duarte, 2018; Rödder *et al.*, 2016
Other labels (Manufacturing for Design, Software-defined cloud manufacturing for Industry 4.0; Smart manufacturing and Industrie 4.0)	*3*	Chu et al., 2016; Thames and Schaefer, 2016; Thoben et al., 2017
Non-academic sources		
Industry 4.0 (or Industrie 4.0, Industria 4.0 or Impresa 4.0)	*6*	Kagermann *et al.*, 2013; Fiesp, 2017a/b; Ministero dello Sviluppo Economico, 2016; UNIDO, 2017; Rußmann et al., 2015; McKinsey Digital, 2015)
Other labels (Made in China 2025, Usine du Futur, Society 4.0, Manufacturing innovation 3.0, Fourth / Next industrial revolution, Advanced manufacturing, Factories of the Future, Industrial Internet, Internet of Everything)	*12*	State National Council, 2015; Usine du Futur, 2016; Prime Minister of Japan and His Cabinet, 2017; MOTIE, 2014; HM Government, 2017; Executive Office of the President, 2012; European Commission, 2013; OECD, 2017; Schwab, 2016; IEC, 2015; Bradley et al., 2013; Evans and Annunziata, 2012

Considering non-academic sources, the labels also refer to manufacturing (or “factories”, “made in”) and future developments (“2025”, “future”) driven by progress in Internet-related technologies. Differences in the wording are meant to stress the role of the proposing subject, especially in the case of government-backed initiatives and MNC's white papers.

2.4.2. Scope

The concept of Industry 4.0 was originally meant to describe the impact of emerging technologies "in the realm of manufacturing" (Kagermann *et al.*, 2013, p. 13). As shown in Table 5, the focus on *manufacturing* is no longer so distinct. Several definitions encompass *other economic sectors*, in a context where industry boundaries are fading as smart products blur the line between goods and services (e.g. Lasi *et al.*, 2014; Wan *et al.*, 2015; Roblek *et al.*, 2016).

Table 5. Scope of the definitions, number of occurrences by label
(heatmap: color intensity based on total number of definitions per label)

2. SCOPE			
Academic sources	Manufacturing	Other sectors	Consumer / society
Industry 4.0	42	8	9
Cloud manufacturing	12		6
Smart manufacturing	7	1	
Smart city production system	3	2	3
Social manufacturing	3		3
Industrial Internet	3	2	
Cyber manufacturing	2		1
Fourth / Next industrial revolution	2	2	
New intelligent manufacturing	2		
Digital transformation	2	2	1
Other labels	3	1	
Total of Academic definitions	**81**	**22**	**18**
Non-academic sources			
Industry 4.0	6	1	1
Other labels	12	8	5
Total of non-academic definitions	**18**	**9**	**6**

By the same token, Industry 4.0 is often seen in relation with deep transformations in *consumer* behaviors and the *society* at large (Oztemel and Gursev, 2018). Consumers are expected to participate in shaping products and services thanks to smart devices, digital platforms, and the spread of additive manufacturing technologies (Pereira and Romero, 2017; Ghombakhloo, 2018; Kamble *et al.*, 2018).

These dynamics are often discussed in the papers defining labels other than “Industry 4.0”. The concept of “Digital transformation” underlines the impact of emerging technologies on business models and, in turn, the rise of cross-industry ecosystems such as “mobility” and “smart home” (Rödder *et al.*, 2016). “Social manufacturing” and “Smart city production systems” build specifically on the opportunities for higher involvement of the final customer (Xiong *et al.*, 2018; Yao and Lim, 2015).

2.4.3. Key enabling technologies

The technological aspect of the phenomenon is covered by all the examined contributions, although with some differences in what is included and the level of detail of the description.

The landscape is extremely vast and heterogeneous. A recent attempt to map the technological components of Industry 4.0 identified 1,211 single elements referring to 30 disciplinary fields (Chiarello *et al.*, 2018). Industry 4.0 is in fact not about a single breakthrough invention but comprises several “tech ingredients” that are still evolving into new enabling technologies by convergence and mutual combination (e.g., Drath and Horch, 2014; Monostori, 2014; OECD, 2017). We mapped their occurrence in Table 6 adopting the terminology and level of detail used in other non-technical studies and influential non-academic reports (e.g., Mittal *et al.*, 2016; Cristians and Methven, 2017; Kusiak, 2018; OECD, 2017; Rußmann et al., 2015). We also added a residual sub-category (*technological generics*) for papers referring to unspecified technological innovation.

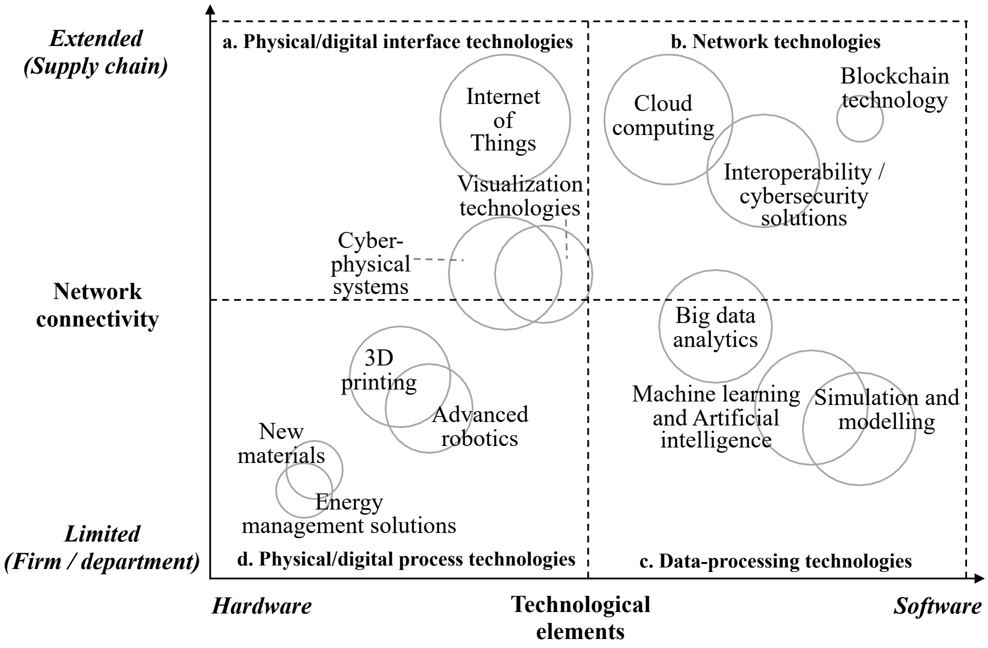
Some studies have argued for a managerial-oriented categorization of applications stemming from these key enabling technologies in order to facilitate analytical efforts and decision-making. Zhou *et al.* (2015) divided plant-specific solutions, called “smart factory”, from “intelligent production and management” applications along the supply chain and with the consumer. Cimini *et al.* (2019) approached the issue based on four phases in the supply chain – i.e., procurement, production, distribution and logistics, service and delivery. Frank *et al.* (2019) developed a conceptual framework of four “front-end” technologies which are “smart manufacturing”, “smart working”, “smart supply chain”, and “smart products”. Neugebauer *et al.* (2016) identified ten clusters of technologies in relation to the different phases in the production process.

Table 6. Key enabling technologies, number of occurrences by label
(heatmap: color intensity based on total number of definitions per label)

	3. KEY ENABLING TECHNOLOGIES													
	a. Physical / digital interface technologies			*b. Network technologies*			*c. Data processing technologies*			*d. Digital / physical process technologies*				
Academic sources	Internet of Things	Cyber-physical systems	Visualization technologies	Cloud computing	Interoperability and cybersecurity solutions	Blockchain technology	Simulation and modelling	Machine learning and artificial intelligence	Big data analytics	3D printing	Advanced robotics	New materials	Energy management solutions	Technological generics
Industry 4.0	38	38	20	33	25	5	21	25	29	19	17	1	3	20
Cloud manufacturing	12	2	2	12	9		11	7	4	2				1
Smart manufacturing	6	5	5	5	5		5	5	5	5	3	3	1	3
Smart city production system	2	2	1	2	1		3	2	1	1				1
Social manufacturing	3	2	1	3	1		2	3	2	2				1
Industrial Internet	3	2	1	2	1		1	1	1	1				2
Cyber manufacturing	2	2	1	2	1		2	2	2	1				
Fourth / Next industrial revolution	1			2	1		1	2	1	2	2	2	1	1
New intelligent manufacturing	1	2	1	1			2	2	1	1	1			
Digital transformation	1		1	2	1	2	1	1		1	1			1
Other labels	1	1		2	1			1	1	2	1			3
Total of Academic definitions	**70**	**56**	**33**	**66**	**46**	**7**	**49**	**51**	**47**	**37**	**25**	**6**	**5**	**33**
Non-academic sources														
Industry 4.0	5	3	5	5	5	1	6	4	5	5	5	2	2	4
Other labels	9	4	9	10	11	3	8	9	11	9	9	9	9	7
Total of non-academic definitions	**14**	**7**	**14**	**15**	**16**	**4**	**14**	**13**	**16**	**14**	**14**	**11**	**11**	**11**

In order to better understand the technological drivers of Industry 4.0, however, we considered a different categorization based on the nature of the technological innovation. The 13 sub-categories of key enabling technologies appear in fact to be characterized by two common trends: *(i.)* integration between the physical world and the digital one (e.g. Evans and Annunziata, 2012; Fatorachian and Kazemi, 2018); and *(ii.)* connectivity both locally and with universal direct networking, as the introduction of the new Internet protocol IPv6 exponentially increased the number of addresses available (e.g. Kagermann *et al.*, 2013, Qin *et al.,* 2016). Considering these two trends, we developed a 2x2 matrix framework (see Fig. 3). The x-axis maps each technology along a hardware / software continuum based on the nature of its composing elements. The y-axis considers the kind of connectivity structurally implied by each technology from limited or local to extended or global, thus mirroring its potential to be applied at a broad supply chain level. With the aim of gaining a better understanding of the relevance of these two trends in shaping the phenomenon, we performed a qualitative assessment placing the key enabling technologies on the matrix. The assessment was based on our literature review complemented with papers providing a detailed definition of individual technologies.

Figure 3. Key enabling technologies (matrix)
(bubble size proportional to the number of occurrences in the examined definitions)



Each of the four quadrants identifies a cluster:

a. *Physical-digital interface technologies* (high share of hardware components / extended network connectivity) bridge the cyber-space with the reality of machines, products and people at work. The cluster includes *cyber-physical systems* (Lee *et al.*, 2015), the similar concept of the *Internet of Things* (Lee and Lee, 2015; Atzori *et al.*, 2017) and *visualization technologies* such as augmented, virtual and mixed reality (Chryssolouris *et al.*, 2009).

b. *Network technologies* (high share of software components / extended network connectivity) provide online functionalities, as in the case of *cloud computing* (Armbrust *et al.*, 2010), *interoperability and cybersecurity solutions* (Anderln, 2015; Kagermann, 2015) and the *blockchain technology* (Ahram *et al.*, 2017).

c. *Data-processing technologies* (high share of software components / low level of connectivity) support the analysis of data and provide information-driven input for control and decision making. These technologies refer to *simulation and modelling*, including the “digital twin” (Chryssolouris *et al.*, 2009)*, machine learning and artificial intelligence* (Wüst, *et al.*, 2016; Yao *et al.*, 2017; Brödner, 2018), and *big data analytics* (Chen *et al.*, 2014). Although data-processing technologies can be operated locally, they are increasingly delivered through cloud computing platforms.

d. *Physical-digital process technologies* (high share of hardware components / low level of connectivity) include equipment used in production such as *3D printing* (Laplume *et al.*, 2016) and *advanced robotics* like co-bots (Ezell, 2006; Hermann *et al.*, 2016; Kumar, 2018). Other technologies mentioned less frequently in the literature are intuitively physical, such as *new materials* or *energy management solutions*, but in recent years have become more and more entwined with digital technologies (Bowles and Lu, 2014; OECD, 2017).

Today, these technologies are usually reported separately, however they are deeply interdependent in their application. Many of the analytical capabilities implied by cyber-physical systems and the Internet of Things are provided by data processing technologies, often offered as service applications delivered through cloud computing (Lee and Lee, 2015; Lee *et al.*, 2015; Atzori *et al.*, 2017). Interoperability and cybersecurity solutions ensure the opportunity to extend their application within the company and with business partners (Kagermann *et al.*, 2013; Anderln, 2015; Li *et al.*, 2017). New materials and 3D printable designs are developed through advanced simulation and modelling solutions (OECD, 2017; Kusiak, 2017). Advanced robotics leverage machine learning and artificial intelligence (Yao *et al.*, 2017).

Overall, the *Internet of Things* and *cloud computing* are the technologies most often mentioned and thus characterize the phenomenon together with the cluster of *data-processing technologies*, which also appears very frequently across the different labels. The definitions of the label “Industry 4.0” refer extensively to *cyber-physical systems* and *interoperability and cybersecurity solutions*, which emerge repeatedly also in connection with “Smart manufacturing” and “Cloud manufacturing”. *3D printing* and *advanced robotics*, even though still relevant, appear to a lesser extent. The *blockchain technology* has been included only in papers published after 2017 (e.g., Hofmann and Rüsch, 2017; Muhuri *et al.*, 2019). *New materials* and *energy storage solutions* are hardly mentioned by academic contributions, whereas they appear more frequently in non-academic definitions.

2.4.4. Other enablers

Non-technological enablers, i.e., *organizational enablers* and *new business models*, have also been reported in the examined literature, albeit with significantly lower frequency and level of detail (see Table 7). Consistently with the sociotechnical system theory and the competence-based view (Imran and Kantola, 2019), it has been claimed that technology does not normally offer ready-to-use solutions and no major productivity gain can be expected unless changes in business processes and work practices are jointly implemented (Schuh *et al.*, 2014; Brynjolfsson *et al.*, 2017).

Table 7. Other enablers, number of occurrences by label
(heatmap: color intensity based on total number of definitions per label)

4. OTHER ENABLERS		
Academic sources	Organizational enablers	Business Model Innovation
Industry 4.0	21	13
Cloud manufacturing	2	11
Smart manufacturing		
Smart city production system	1	1
Social manufacturing	1	1
Industrial Internet		
Cyber manufacturing	1	
Fourth / Next industrial revolution		
New intelligent manufacturing	1	
Digital transformation	2	2
Other labels	1	1
Total of academic definitions	**30**	**29**
Non-academic sources		
Industry 4.0	5	4
Other labels	11	9
Total of non-academic definitions	**16**	**13**

As for *organizational enablers*, the definitions address three main points. First, organizational design should pursue higher inter- and intra-organization linkages (Lee *et al.*, 2016; Lu, 2017; Schuh *et al.*, 2014). Second, organizational structures should flatten out to accommodate distributed decision making (Hofmann and Rüsch, 2017; Roblek *et al.*, 2016) consistently with lean management practices (Barreto *et al.*, 2017; Usin du Futur, 2016; Hofmann and Rüsch, 2017). Third, digital and strategic capabilities will be needed at all levels within the organization (e.g., Hermann *et al.*, 2016; Schwab, 2016; Kamble *et al.*, 2018).

Regarding *business model innovation*, two main aspects emerge from the examined literature. The first is related to the increasing spread of smart products, whereby data-driven services integrate or replace traditional product sales (e.g., McKinsey Digital, 2015; Rußman *et al.*, 2015; Saldivar *et al.*, 2015; Schmidt *et al.*, 2015). The other is related to new forms of production. 3D printing makes it possible to manufacture some simpler products at home. Crowdsourcing practices enable companies to obtain services from a large collaborative group of individuals, rather than from employees or traditional suppliers (IEC, 2017). Digital platforms may become new market spaces for manufacturing activities sold "by the hour" (Pereira and Romero, 2017; Kagermann, 2015). This last point has been mostly raised by Cloud manufacturing definitions (e.g., Adamson *et al.*, 2017; Ren *et al.*, 2015; Yadekar *et al.*, 2016).

2.4.5. Distinctive characteristics

Some authors have pursued an understanding of the phenomenon based on the identification of its *distinctive characteristics*. These are descriptions of "how to do" Industry 4.0 resulting from the application of key enabling technologies and the evolution of non-technological enablers; elsewhere have been referred to as "design principles" (Hermann *et al.*, 2016; Ghobakloo, 2018; Kamble *et al.*, 2018; Pires *et al.*, 2018) or "functionalities" (Radziwon *et al.*, 2014). Building on these studies, we mapped all the definitions included in our analysis (see Table 8). Very few differences have been identified between the different labels, with the exception of the strong focus of "Cloud manufacturing" on the servitization of manufacturing capabilities.

Process integration, *real-time information transparency*, *virtual representation of the real world,* and *autonomy* stand out as core characteristics of the phenomenon. Process integration refers to the impact of interoperability solutions in unifying product and process data within and across organizational boundaries (e.g., Kagermann *et al.*, 2013; Kagermann, 2015; Fatorachian and Kazemi, 2018). *Real-time information transparency* and *virtual representation of the real world* are typical functionalities of physical-digital interface technologies as advanced connectivity ensures data acquisitions from machines and information feedback from the cyber-space (e.g., Lee *et al.*, 2015; Vaidya *et al.*, 2018). *Autonomy* implies that manufacturing systems – machines and people – can decide for themselves and react to novel situations without external guidance; it has been mainly related to artificial intelligence (Frank *et al.*, 2019), but also to organizational changes in terms of structure and control mechanisms (Hermann *et al.,* 2016).

Characteristics related to the servitization trend have also been reported but to a lesser extent, essentially in relation to new business models based on *product servitization* (Schmidt *et al*., 2015; Pereira and Romero, 2017, Xu *et al*., 2018) and the *servitization of manufacturing capabilities* (Zhang *et al*., 2014; Adamson *et al*., 2017; Kamble *et al*., 2018).

Finally, *predictability* and *modularity and reconfigurability* were also consistently mentioned across the various labels albeit with less frequency. Predictability mainly refers to the application of big data analytics and simulation techniques such as the digital twin to monitor the performance of machines and connected products, opening up opportunities for predictive maintenance (e.g., Dobos *et al*., 2018). *Modularity and reconfigurability* apply to a dynamic configuration of the various elements of business processes (Fatorachian and Kazemi, 2018) as well as to production lines thanks to interconnected programmable machines with mobile agents and robots (Roiko, 2017).

Table 8. Distinctive characteristics, number of occurrences by label
(heatmap: color intensity based on total number of definitions per label)

	5. DISTINCTIVE CHARACTERISTICS							
	Process Integration	Real-time information transparency	Virtual representation of the real world	Autonomy	Product servitization	Servitization of manufacturing capabilities	Predictability	Modularity and reconfigurability
Academic sources								
Industry 4.0	33	31	31	30	19	12	16	18
Cloud manufacturing	12	7	12	3	2	12	2	1
Smart manufacturing	5	5	4	6		4	5	1
Smart city production system	2	2	2	3	1	2	1	3
Social manufacturing	2	2		1	1	1	1	
Industrial Internet	2	3	2	2	2	1	1	1
Cyber manufacturing	1	1	1	2		1	2	
Fourth / Next industrial revolution	1	1	1		1			1
New intelligent manufacturing	2	2	2	2		1		
Digital transformation		1			1		1	
Other labels	2	1	2	1	1	1	1	1
Total of Academic definitions	**62**	**56**	**57**	**50**	**28**	**35**	**30**	**26**
Non-academic sources								
Industry 4.0	5	5	5	5	6	2	5	5
Other labels	9	9	3	6	8	4	5	3
Total of non-academic definitions	**14**	**14**	**8**	**11**	**14**	**6**	**10**	**8**

2.4.6. Possible outcomes

The vast majority of definitions have mentioned possible impacts of the phenomenon (see Table 9). Literature typically tackles the topic from two angles: *micro- (individual firms)* and *macro-level (country)*. The latter has been proportionally more addressed by non-academic definitions as they include several government-backed initiatives.

Table 9. Possible outcomes, number of occurrences by label

(heatmap: color intensity based on total number of definitions per label)

	6. POSSIBLE OUTCOMES								
	a. Micro-level (individual firms)							*b. Macro-level (country)*	
	Productivity	Flexibility	Mass customization	Environmental sustainability	Time and cost to market	Quality	Lead time	Economic growth	Employment
Academic sources									
Industry 4.0	27	28	29	13	20	13	13	3	3
Cloud manufacturing	11	10	8	5	8	3	5		
Smart manufacturing	5	5	5	5	2	5	3	1	
Smart city production system	2	3	2	2	1		1		
Social manufacturing	2	3	3	1	1				
Industrial Internet	2	1	1	3	1		1		
Cyber manufacturing	2	1		1	1	1	2		
Fourth / Next industrial revolution	1	1	1	1				2	1
New intelligent manufacturing	2	2	2	1		2			
Digital transformation			1					1	
Other labels	2	3	2	2		2	1		
Total of Academic definitions	**56**	**57**	**54**	**34**	**34**	**26**	**26**	**7**	**4**
Non-academic sources									
Industry 4.0	6	6	4	5	4	5	4	3	2
Other labels	11	7	9	11	9	8	6	10	6
Total of non-academic definitions	**17**	**13**	**13**	**16**	**13**	**13**	**10**	**13**	**8**

Possible outcomes at firm-level have emerged consistently in the examined papers, with no major difference between "Industry 4.0" and other labels. All the classic performance dimensions of operations may potentially be affected by Industry 4.0 technological and organizational levers (e.g., McKinsey Digital, 2016; Kagermann *et al.*, 2013). The most common expectations concern improvements in *productivity* and *flexibility* to the point of *mass customization / personalization* (e.g., Kagermann *et al.*, 2013; Fatorachian and Kazemi, 2018). These expectations appear to be in line with a scenario characterized by increasingly fragmented and volatile demand (Tien, 2012; Lasi *et al.*, 2014) and decreasing labor costs differential between low- and high-income countries (Ben-Daya *et al*., 2019). Still extensively mentioned, albeit to a lesser extent, are *environmental sustainability* in terms of energy savings and reduced transportation emissions (e.g., Fisher *et al*., 2018; UNIDO, 2017) and *time- and cost-to-market* (e.g., Rojko, 2017). Vice versa, *quality* and *lead-time* have not attracted significant attention so far, even though there are many technological solutions related to these two performance objectives in terms, for example, of visualization technologies and real-time production planning and control (e.g., Kamble *et al*., 2018; Oztemel and Gursev, 2018).

A few contributions, mainly non-academic ones, have tackled *system-/country-level potential outcomes*. Consistently with the notion of "industrial revolution", it has been argued that the result of the process will be overall *economic growth*, essentially measured in terms of GDP (Evans and Annunziata, 2012; Qin *et al*., 2016; Neugebauer *et al.,* 2016). Some definitions mentioned a possible impact on *employment*. Even though technological advances will increase the scope and rate of automation (Schwab, 2016; Ghombakloo, 2018), most of the definitions retain a positive outlook in view of historical evidence about the positive effects of innovation on the labor market (OECD, 2017).

2.5. Directions towards a conceptualization of the Industry 4.0 phenomenon

The review of the literature categorized the definitional elements of the upcoming industrial revolution (RQ1) through six coding categories (Figure 2). We identified a series of commonalities among the definitions of Industry 4.0 and other concepts in terms of:

- *Key enabling technologie s*– the landscape is characterized by increasing digitalization and connectivity due to physical-digital interface, network, and data-processing technologies. Most definitions agree on the key role played by the Internet of Things and cloud computing;
- *Distinctive characteristics* – common characteristics are consistent with the properties of the most frequently mentioned technologies in terms of virtualization, real-time information sharing, and autonomy. Higher process integration is also expected within and across the boundaries of the firm in line with interoperability and cybersecurity solutions;
- *Possible outcomes* – expectations are mostly related to higher productivity and flexibility, up to the point of making mass customization / personalization possible.

The analysis underlined how very few differences among definitions can actually be explained by the label used to describe the phenomenon (*RQ2*). "Cloud manufacturing" definitions display a stronger focus on new business models and on the servitization of manufacturing capabilities. “Social manufacturing” and “Smart city production system” explicitly broaden their scope including consumers and society. These definitional elements, however, appear under the label “Industry 4.0” as well.

The differences in the enumeration of *key enabling technologies* depend on various factors. The focus of some authors on managerial aspects of the definition (e.g., Hermann *et al.*, 2016; Piccarozzi *et al.*, 2018) resulted in a less detailed presentation of the technological elements. More recent developments such as the blockchain technology (Ahram *et al.*, 2017) have been included only after 2017. New materials, whose maturity is overall lower (OECD, 2017), have only been marginally included. Technologies showing fewer interdependencies with the Internet of Things in their evolutionary trajectories have been cited to a lesser extent, as in the case of 3D printing and advanced robotics, mentioned by only half of the definitions. By the same token, as modularity and reconfigurability are typically related to physical-digital process technologies, they are the least represented among *distinctive characteristics*.

Today, in front of this definitional ambiguity, it is common practice for scholars to structure their research around their own definitions of Industry 4.0 (e.g., Dalenogare *et al*., 2018; Tortorella and Fettermann, 2017; Ghombakhloo and Fathi, 2019). Although this approach is effective in supporting the analysis, the lack of an agreed-upon framework might blur the scope of the research, hinder the comparison of studies, and pose serious limitations to theory development and testing.

Similar challenges are not unusual for academic research tackling multi-dimensional concepts, as in the case of Lean Manufacturing (LM) and Supply Chain Management (SCM). In the 1990s LM was introduced in the West as an umbrella term for a set of different consolidated practices in connection with similar concepts such as the “Toyota production system” and “World Class manufacturing”. At the beginning of the 1980s consultants shaped SCM as a free-floating idea which was only later substantiated by academic research. In both cases, scholars have progressively converged on the key pillars and defining dimensions, adapting over time in line with emerging approaches (e.g., Alfalla-Luque and Medina-Lopez, 2009; Pounder *et al.*, 2013; Bhamu and Sangwan, 2014; Carter, Rogers and Choi, 2015).

Today the multi-dimensional nature of Industry 4.0 highlighted in our analysis suggests the opportunity to engage in similar convergence efforts. The constituent dimensions of the phenomenon ought to be captured through shared operationalizations and consequent measures which, however, necessarily leave the door open to new developments in technology and business practices.

2.5.1. Preliminary step: the operationalization of Industry 4.0

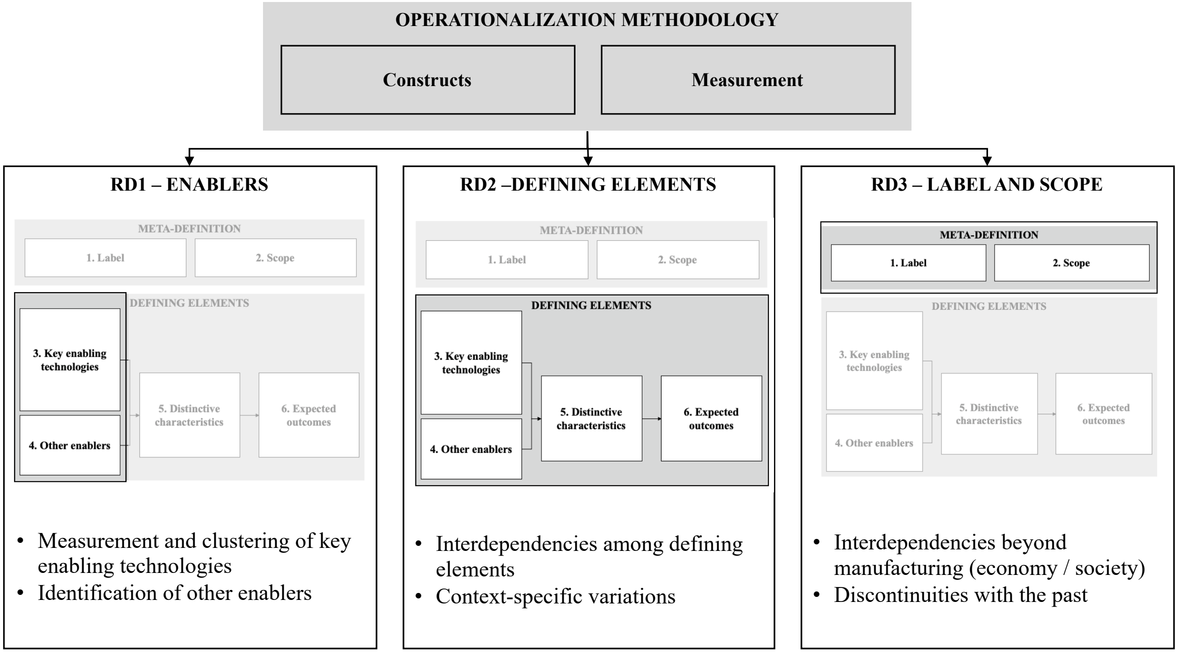
A prerequisite for research to have a theoretically solid approach to Industry 4.0 is to agree on representative constructs and respective measurements. Some initial attempts in this direction have been made by the assessment tools – maturity models and readiness indexes – which identify incremental levels of Industry 4.0 adoption considering technology and, in some cases, organizational dimensions (for a review: Mittal *et al.*, 2018). Notwithstanding the benefits of these tools for awareness-raising and benchmarking, there are several methodological limitations. The design is based on the assumption of a best way of sequential stages to reach final maturity where no further development is possible (Wendler, 2012). However, not only do contextual factors affect the "best way" companies approach Industry 4.0, but it is also virtually impossible to define a "final stage" as the phenomenon is still rapidly evolving. Moreover, the measurement scales utilized by these assessment tools neglect that Industry 4.0 is itself on an evolutionary trajectory where linear developments may be followed by sudden disruptive changes.

Against this backdrop, it is crucial for academics to first align on the methodology to segment the overarching Industry 4.0 concept into its components, for which measurable constructs need to be defined, and then investigate their interrelationships. Based on the findings of our literature review, we posit three directions for future research (Figure 4).

2.5.2. Research direction 1 – Industry 4.0 enablers

The first step is to identify the antecedents of Industry 4.0 in terms of technological and non-technological enablers. Concerning key enabling technologies, they give raise to a long list of solutions requiring frequent updates including industry-specific and even proprietary applications. From a research point of view, there is value in defining the appropriate level of detail, clustering criteria, and measurement modes in order to assess different technological intensities among companies. These efforts should ensure comparability across industries and over time.

Figure 4. Research directions



In terms of other enablers, our analysis underlined how they do not play a central role in the current understanding of Industry 4.0. Further research is needed first to map emerging business models and organizational practices, then to test their relevance in the context of Industry 4.0. History makes the case for taking a greater account of these aspects. Internet companies needed to innovate their business models in the 1990s as they were struggling to capture value against customer expectations for free services (Teece, 2010). The benefits of electrification were reaped only several decades after its commercial introduction as factory layouts were reorganized independently from the constraints of a central stream engine (David, 1990).

2.5.3. Research direction 2 – Interrelations among Industry 4.0 defining elements

Measurable constructs around Industry 4.0 enablers are a precondition to posit and test interrelations among Industry 4.0 defining elements. Future studies should shed light on how different combinations of technological applications, business models, and organizational enablers are related to Industry 4.0 distinctive characteristics and their impact on performance (i.e., expected outcomes). Looking at processes or activities, research might systematically identify use cases of Industry 4.0 (e.g., Bauer, Pokorni and Findeisen, 2018). Taking the firm as the unit of analysis, taxonomies of homogeneous profiles in Industry 4.0 implementation might be developed (e.g., Frank *et al.*, 2019). This approach has been largely adopted since the 1990s in relation to advanced manufacturing technologies (AMTs), leading to a bulk of cross-sectional and longitudinal studies on investment patterns and performance implication (Cheng *et al.*, 2018).

Research into such interrelations should also analyze context-specific variations of the phenomenon. Scholars and non-academic experts have already profiled the existence of a different model of Industry 4.0 in developing countries as compared with advanced economies (e.g., McKinsey Digital, 2015; UNIDO, 2017; Frank *et al.*, 2019; Castelo-Branco *et al.*, 2019). The industrial policies included in this literature review also show different approaches based on respective economic, societal, and geopolitical situations, as, for example, Japan's efforts to mitigate the impact of a reverse age pyramid (Prime Minister of Japan and His Cabinet, 2017) and China's focus on product quality to close the gap with advanced economies (State Council of China, 2015). Moreover, preliminary evidence indicates differences among industries, for instance, the adoption of cyber-physical systems in sectors demanding high flexibility, 3D printing for small batches of customized products, and visualization technologies in applicative contexts with high quality standards (Rußman *et al.*, 2015; Mittal *et al.*, 2016). Firm size, strategy, and position along the value chain are also expected to play a role (Moeuf *et al.*, 2017; Bauer, Pokorni and Findeisen, 2018).

2.5.4. Research direction 3: Industry 4.0 label and scope

The last research direction refers to the focus of Industry 4.0 on the manufacturing sector.

"Industry 4.0" refers to a new paradigm in manufacturing, however technology is triggering similar evolutions in other economic sectors and has deep implications at the societal level (Lightfoot *et al.*, 2013; Bustinza *et al.*, 2017). The history of previous industrial revolutions has shown the relevance of these interdependencies – e.g., the Fordist paradigm implied profound transformations also in consumption patterns and cultural models (de Grazia, 2006). A deeper understanding of these dynamics – for example, consumer behavior and workforce evolution – might support policymakers at the national level and orient the debate on important global issues.

Further research is also needed to understand to what extent Industry 4.0 represents a new phase in the history of manufacturing. It is not unusual to think of history as a series of different phases, each with unique specific characteristics and defining moments marking the line. New phases are often identified in relation to technological advances – even though the exact number of revolutions is a matter of debate as this has been seen as the third one (Evans and Annunziata, 2012), the fifth one (Ezell, 2016) and the sixth one (Reischauer, 2018). In order to identify technological discontinuities, some scholars have pointed to the idea of General Purpose Technologies (GPTs) as discussed by Bresnahan and Trajtenberg (1995) and Jovanovic and Rousseau (2005). Today's artificial intelligence, cloud computing, and cyber-physical systems seem to be GPTs (Brynjolfsson *et al.*, 2010; 2017) but further evidence is needed to substantiate these ideas. Moreover, many defining elements of Industry 4.0 are not a pure novelty. Several key enabling technologies have been developing for at least the last 20 years – e.g., first applications of artificial intelligence date back to the 1950s, 3D printing to the 1980s, the Internet of Things to the 1990s (Li *et al.*, 2017). Organizational practices strongly echo LM methodologies (Bauer, Strandhagen and Chen, 2018) and emerging business models such as ecosystems have a long history prior to digitalization (Jacobides *et al.*, 2016). The most frequently mentioned distinctive characteristics of Industry 4.0 – autonomy, real-time information transparency, and process integration – emerged as early as the 1980s within the Computer-integrated manufacturing paradigm (Brödner, 2018; Chryssolouris *et al.*, 2009; Cagliano and Spina, 2000), the same ideas have repeatedly been discussed with the advent of the Internet (Yusufa *et al.*, 1999; Montreuil *et al.*, 2000).

Measurable constructs related to Industry 4.0 defining elements – not limited to the technological ones – should allow for a better understanding of the discontinuities of Industry 4.0 against previous phases. This would provide solid foundations for testing the applicability of existing theories or justify the need to conceive new ones.

2.5.5. Going forward in Industry 4.0 research and practice

The challenge for the scientific community is primarily methodological at this stage. As research progresses in this direction, we also believe that scholars, policymakers, and the business community should align on three important implications stemming from our study.

First, *Industry 4.0 requires a context-specific approach*. Industry 4.0 is an umbrella concept for a broad range of technologies and applications to be implemented in relation with different characteristics and performance objectives. Different variations of Industry 4.0 are emerging depending on the specific context of each country, industry, and company, which should increasingly be analyzed in scholarly research. Along the same lines, governmental initiatives should consider country-related drivers, barriers, and strategic goals in supporting Industry 4.0 implementation. A good example of this is the progressive streamlining of the French initiative

(Digital Transformation Monitor, 2017). Originally it had a scope of 34 “industrial plans”, now focuses on nine “industrial solutions” which appear to be more in line with the country’s infrastructure and industrial base (e.g., smart objects, digital trust, smart food production, sustainable cities, eco-mobility, medicine of the future).

Second, *Industry 4.0 requires a multi-disciplinary approach*. As the scope of Industry 4.0 outreaches industrial operations, scholarly research, companies, and institutional stakeholders need to consider a broad range of issues. These include cultural and social factors (e.g., privacy and sustainability concerns), the legislative environment (e.g., intellectual property protection at national and international level), demographics (e.g., aging population), education (e.g., new skills and capability), and infrastructure (e.g., mobility and energy). In academia some efforts have been made to move past disciplinary silos. We believe, however, that there are further opportunities to engage in broader research projects across and beyond managerial disciplines, including sociology, psychology and law as well as urban planning. A similar cross-fertilization is also required in policymaking and in the industry, where manufacturing companies need to integrate competences from the service sector.

Finally, *Industry 4.0 technological landscape is still in a state of flux*. This means that academic investigations should be careful not to follow to the letter any closed list of key enabling technologies, as most recent developments – e.g., the blockchain technology – are often not included. Academic journals might lag behind due to the time needed for the publication process, but several other sources might provide timely information on which technologies are reaching maturity for industrial application, including conference proceedings, patent analysis, management consulting and industry reports, technological maturity surveys (e.g., Gartner, 2017), and thematic initiatives’ websites (e.g., the German Plattform Industrie 4.0, the US-based Industrial Internet Consortium). On the other hand, practitioners should be parsimonious in using the label “Industry 4.0” for marketing “old” technologies as this increases the misunderstandings about the nature and complexity of the phenomenon.

CHAPTER 3. Industry 4.0 and manufacturing value chains

3.1. Purpose

Industry 4.0 is expected to impart profound changes to the configuration of manufacturing companies with regards to what their value proposition will be and how their production network, supplier base and customer interfaces will develop. The literature on the topic is still fragmented. The chapter analyze the evolutionary trajectories of manufacturing companies assuming a value chain perspective. We developed a Delphi-based scenario analysis involving 76 experts from academia and practice. The results highlight the most common expectations as well as controversial issues in terms of emerging business models, size, barriers to entry, vertical integration, rent distribution, and geographical location of activities. Eight scenarios provide a concise outlook on the range of possible futures. These scenarios are based on four main drivers which stem from the experts' comments: demand characteristics, transparency of data among value chain participants, maturity of additive manufacturing and advanced robotics, and penetration of smart products. The chapter is adapted from "*The future of manufacturing: a Delphi-based scenario analysis on Industry 4.0*"[6],

3.2. Positioning of the study

The technological landscape is evolving rapidly around digitalization, connectivity, and automation, fueling enthusiasm about a new industrial revolution, also referred to as Industry 4.0 (Kagermann et al., 2013; Hermann et al., 2016). Significant changes are expected in the economic system as well as in the social sphere inducing a series of research challenges (Mariani and Borghi, 2019; Caviggioli and Ughetto, 2019). Central to this growing body of literature is the assumption that Industry 4.0 has paradigmatic properties that make it comparable to previous industrial revolutions (e.g., Steenhuis and Pretorius, 2017; Li et al., 2018; Yin et al., 2018; Kim, 2018). The nature of these properties is however still questioned against ongoing technological uncertainties, early implementation examples, and late macro-economic indicators (Brynjolffson and McAffee, 2016; OECD, 2017).

In this paper we investigate the nature of the Industry 4.0 paradigm with respect to the configuration of manufacturing companies. We consider both the phenomenon's

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[6] Culot, G., Orzes, G., Sartor, M., Nassimbeni, G. (2020). "The future of manufacturing: a Delphi-based scenario analysis on Industry 4.0", Vol. 157, *Technological Forecasting & Social Change*, 10.1016/j.techfore.2020.120092.

characteristics – i.e., “what practices are enabled by Industry 4.0” – and its scope – i.e., “what kind of companies will be affected”.

Despite the ever-growing research interest in Industry 4.0 and related technologies, the overall picture is still incomplete and not entirely coherent. Operations and Supply Chain Management research has focused on the geographies and scale of production (e.g., Srai et al., 2016; Ancarani et al., 2019). Strategy and Industrial Sociology scholars have argued also that additive manufacturing technologies (AMTs) will affect the competitive landscape with prospects of players’ consolidation (D’Aveni, 2015; 2018) as opposed to manufacturing “democratization” (e.g., Birtchnell et al., 2017; Gress and Kalafski, 2015). The Internet of Things (IoT) has mostly been investigated by research on business model innovation. Closer relationships between manufacturers and broad ecosystems of software developers, technology and service providers have been posited (e.g., Rogers et al., 2016; Ehret and Wirtz, 2017; Rymaszewska et al., 2017) together with increasing commoditization of physical products and falling industry boundaries (e.g., Porter and Heppelmann, 2014; 2015; Iansiti and Lakhani, 2014). Supply chain management research has more recently focused on the blockchain technology and its disintermediation effects (e.g., Chang et al., 2019; Wang et al., 2019a).

Whereas some possible characteristics emerge from the literature, it is still unclear whether they can be considered “paradigmatic”. This is only partially motivated by the rapid transformative developments characterizing Industry 4.0 today (Drath and Horch, 2014; Frank et al., 2019a); other reasons lie the way the issue has been approached so far. First, Industry 4.0 technologies have been mostly analyzed individually; this focus – although beneficial for isolating initial hypotheses – does not reflect their aggregate effects (e.g., Chiarello et al., 2018; Mariani and Borghi, 2019; Culot et al., In Press). Second, the literature has been developing within specific streams of research, largely neglecting the long-debated interdependencies between competitive strategy and operations configuration (e.g., Skinner, 1969; Hayes and Wheelwright, 1984; Chen and Paulraj, 2004). Third – with few exceptions – impacts have been investigated from the perspective of the focal company and its first-tier relations, whereas evolutionary phenomena are characterized by the embeddedness of individual decisions and outcomes in larger networks of business relations (e.g., Granovetter, 1985; Gulati et al., 2000; Choi et al., 2001; McFarland and Payan, 2008; Pagani and Pardo, 2017).

The time has come for academia to question the scope of emerging trajectories. As an ongoing revolution, Industry 4.0 is bound to represent a challenge to many existing theories; it is crucial today to anticipate where the depth and breadth of changes require scholarly research in order to draw attention to explaining the nature of the configuration decisions made by manufacturing companies in this new context. This is particularly relevant as – in front of extraordinary technological opportunities – business leaders may risk making hasty decisions overseeing long-term dynamics beyond single technology applications and industry boundaries.

In this study we approach the issue with a broad focus in terms of technology, configuration dimensions and analytical perspective, starting from the concept of the value chain (VC). We believe that the future of Industry 4.0 can be understood only by considering the various emerging technologies with respect to their impact on multi-tier supplier-customer relations and parallel evolutions in adjacent industries – e.g., platform-based intermediaries, digital players entering the manufacturing space and AMTs bringing in non-manufacturing producers. VC analysis has often proved effective in the literature to investigate recurring patterns and interdependencies in the configuration of intra- and extra-industry players (Gereffi and Fernandez-Stark, 2016; Hernández and Pedersen, 2017; Raikes et al., 2000).

Under this premise, the following research question is addressed:

RQ2: How will manufacturing VCs evolve in the context of Industry 4.0?

We developed an expert study structured as a Delphi-based scenario analysis (Nowack et al., 2011; Bokrantz et al., 2017). This exploratory research methodology was selected because of the interdisciplinarity and complexity of the issue, which made the case for an involvement of qualified academics and professionals able to provide an informed opinion on current trends. The analysis was based on the principles of interpretative research (Smith, 1983; Prasad and Prasad, 2002).

3.3. Literature background

This study fits into the growing debate on Industry 4.0 and related technologies. The relevant literature is presented in three subsections. In the first (Section 3.3.1.) provides an overview of the main research issues on the phenomenon. The literature more closely related to the scope of this study is then summarized in Section 3.3.2. (impacts of Industry 4.0 on manufacturing companies) and in Section 3.3.3. (impacts of Industry 4.0 on other players involved in manufacturing VCs). Finally, limitations of the literature and research gaps are outlined in Section 3.3.4.

The papers presented in Sections 3.3.2. and 3.3.3. were identified through a systematic approach. We performed a combined keyword search on Scopus with two sets of keywords:

the first was related to Industry 4.0, similar concepts (e.g., “fourth industrial revolution”, “smart manufacturing”, “digital transformation”) and underlying technological components (e.g., “Internet of Things”, “cloud computing”, “artificial intelligence”, “additive manufacturing”, “blockchain”); the second set of keywords included those related to the VC and other similar analytical perspectives (e.g., “supply chain”, “ecosystem”, “industry”, “business model”) as well as specific configuration dimensions (e.g., “shoring”, “sourcing”, “internalization”). 7,115 journal articles written in English were identified when the query was first submitted in April 2019; abstracts and full texts were then examined. We considered articles on Industry 4.0 as a whole as well as on single technologies; impacts from a competitive and operations strategy point of view. The search was complemented through a backward/forward approach – following Webster and Watson’s (2002) recommendations – and updated until February 2020.

3.3.1. Industry 4.0: concept and research issues

Today, Industry 4.0 appears to be an umbrella construct – as per Hirsch and Levin (1999) – and is broadly used to account for various emerging technologies and related practices in manufacturing and beyond (Oesterreich and Teutemberg, 2016; Mariani and Borghi, 2019). “Digital transformation”, “smart manufacturing”, and the “fourth industrial revolution” are other terms also commonly used to describe the phenomenon.

Several studies have attempted to define Industry 4.0 and related terms (e.g., Nosalska *et al.*, In Press; Fatorachian and Kazemi, 2018; Xu, 2018); to clarify single technological paradigms such as the IoT (e.g., Lu *et al.*, 2018b), AMTs (e.g., Gardan, 2016) and the blockchain technology (e.g., Pournader *et al.*, In press); and to conceptualize specific underlying constructs such as the “smart factory” (e.g., Osterrieder *et al.*, 2020) or the “digital supply chain” (e.g., Schniederjans *et al.*, 2020; Garay-Rondero *et al.*, In press). Overall, however, there is still no agreed-upon definition either of the phenomenon or of its constituent elements.

Industry 4.0 is commonly understood as a broad socio-technical paradigm (Dalenogare *et al.*, 2018; Mariani and Borghi, 2019). In its original German conceptualization (Kagermann *et al.*, 2013) the scope of the phenomenon was limited to manufacturing, but the distinction became less sharp in the light of technology-driven transformations across economic sectors (e.g., Simchi-Levi and Wu, 2018; Caro and Sadr, 2019; Mariani *et al.*, 2018) as well as in the public and social sphere (e.g., Nicolescu *et al.*, 2018; Ossewaarde, 2019; Pauget and Dammak, 2019).

The Industry 4.0 phenomenon at large and individual key enabling technologies have been at the center of a growing interest across managerial disciplines; detailed overviews can be found in recent literature reviews and bibliometric analyses (e.g., Strozzi *et al.*, 2017; Gagliati and Bigliardi, 2019; Mariani and Borghi, 2019; Wagire *et al.*, 2020; Mahlmann Kipper *et al.*, In Press). Overall, four broad research foci are at the core of the ongoing debate: *implementation process characteristics*, *emerging adoption patterns*, *possible impacts*, and *non-technological features* of the phenomenon.

As regards the first – i.e., *implementation process characteristics* – the literature has explored drivers and barriers (e.g., Chatzoglou and Michailidou, 2019; Yeh and Chen, 2018; Ghombakhloo, In Press); initial disadvantages of small and medium enterprises (e.g., Horváth and Szabó, 2019; Moeuf *et al.*, 2020; Arcidiacono *et al.*, 2019) and developing countries (e.g., Kamble *et al.*, 2018; Raj *et al.*, In press); best-practice implementation processes (e.g., Mellor *et al.*, 2014; Svan *et al.*, 2017; Zangiacomi *et al.*, 2020; Tortorella *et al.*, 2020; Veile *et al.*, In press); ideal maturity stages (e.g., Bibby and Dehe, 2018; Pacchini *et al.*, 2019); and governance modes in specific geographical and institutional contexts (e.g., Reynolds and Yilmaz, 2018; Sung, 2018; Kummitha and Crutzen, 2019; Fukuda, 2020).

The second focus – i.e., *emerging adoption patterns* – revolves around the current situation and possible typologies of Industry 4.0 technologies. This topic has been explored with firm-level surveys (e.g., Akhtar *et al.*, 2018; Dalenogare *et al.*, 2018; Frank *et al.*, 2019a; Ferreira *et al.*, 2019; Chiarini *et al.*, In Press) as well as secondary data analysis (Ancarani et al., In Press; Castelo-Branco *et al.*, 2019), expert studies (Lu and Weng, 2018) and case research (Calabrese *et al.*, In press). Several articles have also investigated consumers' adoption and attitudes towards smart products and AMTs (e.g., Caputo *et al.*, 2018; Mittal *et al.*, 2018; Halassi *et al.*, 2019; Baudier *et al.*, 2020).

The third broad topic refers to the *possible impacts* of the phenomenon. Research has been tackling the effects of one or more technologies on single performance metrics (e.g., Kunovjanek and Reiner, 2020), operational performance expectations (e.g., Frank *et al.*, 2019a; Büchi *et al.*, 2020), stock market returns (Lam *et al.*, 2019), and overall firm competitiveness (e.g., Niaki and Nonino, 2017). Scholars have also warned against unintended social consequences of the phenomenon (e.g., Kaplan and Haenlein, 2020; Kovacs, 2018; Ossewaarde, 2019), with empirical investigations mainly related to job market impacts (e.g., Dengler and Matthes, 2018; Balsmeier and Woerter, 2019).

The last overarching research issue concerns – under the assumption of Industry 4.0 as a socio-technical paradigm – the *non-technological features* of the phenomenon. Academics have delved into the profile and skills of human resources (e.g., Jarrahi, 2019; Liboni *et al.*, In Press; Wright and Schultz, 2018; Candi and Beltangui, 2019); organizational design and processes (e.g., Falkenreck and Wagner, 2017; Osmonbekov and Johnston, 2018); organizational capabilities, culture, and mindset (e.g., Hasselblatt *et al.*, 2018; Matthyssens, 2019; Frisk and Bannister, 2017); and entrepreneurial processes and outcomes (e.g., Nambisan, 2017; Nambisan *et al.*, 2018; Elia *et al.*, 2020). Several studies have also argued for a strong relationship between Industry 4.0 and lean manufacturing (e.g., Totorella and Fettermann, 2017; Pagliosa *et al.*, 2019; Rosin *et al.*, 2020) as well as with circular economy practices (e.g., Lopes de Sousa Jabbour *et al.*, 2018; Rosa *et al.* 2020; Kouhizadeh *et al.*, In Press). Within this last broad focus, emerging configuration trajectories of manufacturing companies have also been addressed, as illustrated in larger detail in the following two subsections.

3.3.2. Industry 4.0: impacts on manufacturing companies

Academic research has started to approach the impact of new technologies on manufacturing configuration; an overview of the most relevant literature is presented in Table 10. The literature is characterized by a fragmentation of research interest and single technology focus. Few studies have addressed the whole set of Industry 4.0 technologies so far, and only focus on specific impacts, e.g., the reshoring phenomenon. From a methodological perspective, conceptual studies and case research are prevalent. Several articles have investigated the manufacturing sector as a whole; others refer only to specific industries.

Overall, it is possible to derive a series of emerging impacts of Industry 4.0 on the configuration of manufacturing in relation to: (1) new *value offering*, (2) *location* decisions, (3) *governance* of activities, and (4) *size* of manufacturing companies.

Change in the (1) *value offering* of manufacturing companies has been mainly addressed within research on technology-driven business models. Academics have been focusing on three main trends: the first is related to increasing mass-customization (Bogers *et al.*, 2016), the second to higher sustainability (Nascimento *et al.*, 2019), the third to a progressive dematerialization from physical products to digital designs (e.g., D'Aveni, 2015; Jiang *et al.*, 2017) and services (e.g., Ehret and Wirtz, 2017; Ardolino *et al.*, 2018; Frank *et al.*, 2019b). The literature has been developing in two concurrent streams, one with a focus on IoT-driven digital services and non-ownership models (e.g., Porter and Heppelmann, 2014; Rymaszewska *et al.*, 2017; Boehmer *et al.*, 2020), the other on AMTs' potential for new forms of production. These refer to digital platforms simplifying access to manufacturing capabilities (e.g., Rogers *et al.*, 2016; Ryan *et al.*, 2017), on-site printing by retailers and logistics operators (e.g., Jia *et al.*, 2015; Durach *et al.*, 2017) and private 3D printers installed in homes or community centers (e.g., Birtchnell and Urry, 2013; Halassi *et al.*, 2019).

The impact of technology on (2) *location* decisions has likewise been at the center of significant academic debate. Several studies have suggested a relationship between Industry 4.0 and reshoring – i.e., the decision to bring those production activities back home or to neighbouring countries, which had previously been offshored due to lower labor intensity and higher digital maturity in developed countries (Morandlou and Tate, 2018; Barbieri *et al.*, 2017). These hypotheses have found initial empirical confirmation in Fratocchi (2018), Ancarani *et al.* (2019), Dachs *et al.* (2019) and Stentoft and Rajkumar (2019). The increasing applicability of AMTs has imparted new impetus to research on redistributed manufacturing – i.e., a model of localized production involving many small or micro-scale manufacturing facilities (e.g., Rauch *et al.*, 2017; Hannibal and Knight, 2018). The model is currently being piloted in specific segments, such as 3D-printed spare parts (e.g., Cherukov et al., 2018).

The issue of (3) *governance* has attracted lower academic interest so far. Reported trends point in the direction of direct sales, disintermediation of service networks, and increasing internalization of technology and data-related activities (Pagani and Pardo, 2017; Subramanian *et al.*, 2019; Rymaszewska *et al.*, 2017). The impact on production activities, on the other hand, is not clear. Outsourcing might increase because of easier digital coordination with suppliers (Strange and Zucchella, 2017), the need to access specialized capabilities for customization purposes (Gress and Kalafski, 2015; LaPlume *et al.*, 2016), and digital platforms providing ready access to manufacturing capabilities (Berman, 2012; Rehnberg and Ponte, 2018). These expectations, however, have been supported only by limited empirical evidence so far and more internalization of production has also been observed (Fratocchi *et al.*, 2018; Rayna and Striukova, 2016; Kohtamäki *et al.,* 2019).

Table 10. Relevant literature for Industry 4.0 implications of VC

							Topics addresses								
Author(s). year	**Technologies**	**Perspective**	**Methodology**	**Industry focus**	**Time horizon**	**Main topics**	(1) Value offering	(2) Location	(3) Governance	(4) Size	(5) Suppliers and partners	(6) Customers	(7) Intermediaries	(8) Competitors	(9) Relational dynamics
Ancarani *et al*., 2019	Industry 4.0	Firm	Secondary data analysis	Manufacturing	*Present*	*Relationship between reshoring, Industry 4.0 adoption, and performance objectives.*		x							
Ardolino *et al*., 2018	IoT, cloud computing, analytics	Business model	Multiple case study	Industrial goods	*Present*	*Role of technology in enabling servitization and emerging models.*	x								
Athanasoupoulou *et al*., 2019	IoT, energy solutions	Business model	Expert study	Automotive	*Future*	*Technology-driven services impacting automotive business models.*	x								
Arnold *et al*., 2016	IoT	Business model	Multiple case studies	Automotive, Machinery and Equipment, Electronics, ICT, Medical	*Present*	*Industry-differences in IoT-driven business models in manufacturing.*	x		x		x	x			
Barbieri *et al*., 2017	Industry 4.0	Firm	Conceptual	Manufacturing	*Present*	*Review extant research on manufacturing reshoring.*		x							
Bessière *et al*., 2019	IoT, Big Data	Industry	Expert study	Consumer goods	*Future*	*Challenges, opportunities, and research questions on redistributed manufacturing.*	x	x							
Berman, 2012	AMTs	Not specified	Conceptual	Manufacturing	*Future*	*Characteristics and applications of AMTs in the light of mass customization.*	x	x	x		x	x	x		
Bertola and Teunissen, 2018	Industry 4.0	Industry	Illustrative cases	Apparel and Footwear	*Present/Future*	*Product characteristics and approaches to operations and supply chain.*	x	x	x	x		x			
Birtchnell and Urry, 2013	AMTs	Economy/society	Conceptual	Manufacturing	*Future*	*Future applications and spread of AMTs.*	x	x	x	x		x			
Birtchnell *et al*., 2017	AMTs	Economy/society	Multiple case study	Manufacturing	*Present*	*Involvement of tertiary institutions in AMTs.*	x	x	x	x	x	x			
Boehmer *et al*., 2020	IoT	Business model	Multiple case study	Automotive, Machinery and Equipment	*Present*	*Pathways to servitizing the business model through IoT implementation.*	x				x				x
Bokrantz *et al*., 2017	Industry 4.0	Function	Expert study	Machinery and equipment	*Future*	*Future developments of the maintenance function.*	x				x				
Bogers *et al*., 2016	AMTs	Supply chain	Conceptual	Consumer goods	*Future*	*Interdependent evolution of business models and supply chain geographical configuration.*	x	x				x			
Braziotis *et al*., 2019	AMTs	Supply chain	Conceptual	Manufacturing	*Present*	*Supply chain geographical configuration and adoption of AMTs in the light of different performance objectives.*	x	x							

Cenamor *et al*., 2017	IoT	Firm	Multiple case studies	Automotive, Machinery & Equipment	*Present*	*Role of platform approach in the implementation of advanced service offerings in manufacturing firms.*	x		x		x	x	x		x
Chang *et al*., 2019	Blockchain	Supply chain	Conceptual	Manufacturing	*Future*	*Impact of the blockchain technology and smart contracts on supply chain process design.*			x				x		
Cole *et al*., 2019	Blockchain	Supply chain	Conceptual	Manufacturing	*Present*	*Potential applications of blockchain technology in the context of operations and supply chain management.*	x		x				x		
Coreynen *et al*., 2017	Digital technologies	Business model	Multiple case study	Manufacturing	*Present*	*Servitization pathways of manufacturing SMEs*	x								
Culot *et al*., 2019	Industry 4.0	Value chain	Illustrative cases	Manufacturing	*Present*	*Vertical integration dynamics and scale advantage with regards to emerging business models.*	X	x	x	x					x
Dachs, *et al.,* 2019	Industry 4.0	Firm	Survey	Manufacturing	*Present*	*Relationship between reshoring, Industry 4.0 adoption, and performance objectives.*		x							
D'Aveni, 2015	AMTs	Firm/Ecosystem	Illustrative cases	Manufacturing	*Future*	*Future applications of AMTs and strategic implications for managers.*	x	x	x	x	x	x	x	x	x
D'Aveni, 2018	AMTs	Firm	Illustrative cases	Manufacturing	*Future*	*Typology of AMT implementation models and competitive implications.*	x							x	
Durach *et al*., 2017	AMTs	Supply chain	Expert study	Manufacturing	*Future*	*Emerging applications of AMTs, barriers, and timeline of adoption.*	x	x							
Ehret and Wirtz, 2017	IoT	Business model	Conceptual	Manufacturing	*Present*	*Conditions for non-ownership business models and their characteristics.*	x								
Ferràz-Hernández *et al*., 2017	Autonomous driving	Industry	Secondary data analysis	Automotive	*Present*	*Characteristics of the companies involved in the shared and self-driven electric vehicles segment.*				x				x	
Frank *et al*., 2019b	Industry 4.0	Business model	Conceptual	Manufacturing	*Present*	*Interplay between servitization, and Industry 4.0 in product firms.*	x								
Fratocchi, 2018	AMTs	Firm	Multiple case study	Manufacturing	*Present*	*Relationship between reshoring, AMTs adoption, motivation and sourcing.*		x	x						
Gress and Kalafski, 2015	AMTs	Global production networks	Conceptual	Manufacturing	*Future*	*Spatial ramification of suppliers of AMTs machinery and materials; future impacts in terms of geographies and scale in production.*	x	x		x	x				
Hakanen and Rajala, 2018	IoT/new materials	Business model/Ecosystem	Multiple case study	Steelmaking	*Future*	*Role of smart materials on business models and industry-wide ecosystems.*	x				x	x		x	
Halassi *et al*., 2019	AMTs	Not specified	Survey	Manufacturing	*Present*	*Emergence of "prosumers" designing and printing at home.*	x					x			
Hamalainen and Karjalainen, 2017	AMTs	Business model	Multiple case study	Manufacturing	*Present*	*Nature of technology-driven business models based on firm-individual collaboration.*			x		x	x			
Hannibal and Knight, 2018	AMTs	Global factory	Conceptual	Manufacturing	*Future*	*Industry and product characteristics driving the localization of production.*	x	x							
Holmström *et al*., 2016	AMTs	Supply chain	Conceptual	Manufacturing	*Present/Future*	*Impact of AMTs on production operations and supply chain structure.*	x	x	x		x				x
Iansiti and Lakhani, 2014	IoT	Business model	Illustrative cases	Manufacturing, Services	*Future*	*Impact of IoT and digital transformation on business models and competition.*	x							x	x
Jia *et al*., 2015	AMTs	Business model	Simulation	Food and Beverages	*Present*	*Implications on marginality on two alternative business models for AMTs: production carried out by manufacturers or by retailers.*	x	x	x				x		x
Jiang *et al*., 2017	AMTs	Economy/society	Expert study	Manufacturing	*Future*	*Impact of AMTs on firms, supply chains, the economy and the society by 2030.*	x	x	x			x	x	x	
Kapetaniou *et al*., 2018	AMTs	Firm/Industry	Secondary data analysis	Manufacturing	*Present*	*Differences between industries and firms in the application of AMTs.*	x		x	x		x	x	x	
Katsikeas *et al*., In press	Cloud computing, big data analytics	Firm	Conceptual	Manufacturing, Services	*Future*	*Impact of digital technologies on foreign market selection and entry decisions.*		x					x	x	
Kiel *et al*., 2017	IoT	Business model	Multiple case study	Manufacturing	*Present*	*Impact of IoT on manufacturing business models.*	x				x	x	x		
Kohtamäki *et al*., 2019	IoT	Ecosystem	Conceptual	Manufacturing	*Present*	*Theory-based analysis on the interdependencies between individual firms' business models and the business models of other firms within the ecosystem.*	x		x		x		x		x

Kotarba, 2018	Various digital technologies	Business model	Conceptual	Manufacturing, Services	*Present*	*Changes in the morphology of business models due to increasing digitalization.*	x				x	x	x		
Kumar et al. 2016	IoT, Big data, AMTs	Supply chain	Conceptual	Manufacturing	*Future*	*Role of smart cities in supply chain design.*		x	x	x	x	x	x		
Langley *et al.*, 2020	IoT	Business model/Ecosystem	Conceptual	Manufacturing, Utilities, Services	*Future*	*Impact of IoT on business models from a networked/ecosystem perspective.*	x		x	x		x		x	
LaPlume *et al.*, 2016	AMTs	Global value chains (GVCs)	Conceptual	Manufacturing	*Future*	*Impact of AMTs on GVCs (production) across different industries.*	x	x	x	x	x	x			
Leminen *et al.*, 2020	IoT	Business model/Ecosystem	Conceptual and illustrative cases	Automotive, Machinery & Equipment	*Future*	*Types of IoT-enabled servitized business models.*	x		x		x				
Montes and Olleros, 2019	AMTs, various digital technologies	Firm	Conceptual	Manufacturing	*Present*	*Enablers and implications of the micro-factory model.*	x	x	x		x	x			
Morandlou and Tate, 2018	AMTs	Firm	Survey	Manufacturing	*Present*	*Relationship between reshoring, AMTs adoption, and postponement.*		x							
Morkunas *et al.*, 2019	Blockchain	Business model	Conceptual	Manufacturing, Services	*Future*	*Effects of blockchain technologies on the business models of non-financial firms.*	x		x		x	x	x		
Müller *et al.,* 2018	Industry 4.0	Business model	Multiple case study	Manufacturing	*Present*	*Business model evolution of manufacturing SMEs in the context of Industry 4.0.*	x				x	x	x		
Nascimento *et al.*, 2019	Industry 4.0	Business model	Expert study	Manufacturing	*Future*	*Integration of Industry 4.0 and circular economy practices.*	x				x				
Öberg and Shams, 2019	AMTs	Supply Chain	Multiple case study	Manufacturing	*Future*	*Effects of AMTs on individual firms' position and role along the supply chain.*			x						
Opresnik and Taisch, 2015	Big Data	Business model	Conceptual	Manufacturing	*Future*	*Role of big data as enabler of servitization strategies.*	x					x			
Pagani and Pardo, 2017	Various digital technologies	Business network	Multiple case study	Automotive, Chemicals, Food and Beverage, Healthcare, Insurance	*Present*	*Types of digitalization of inter-company relationships.*	x		x				x		
Petrick and Simpson, 2013	AMTs	Not specified	Conceptual	Manufacturing	*Future*	*Future disruptions triggered by AMTs on manufacturing.*	x	x	x	x	x	x		x	
Porter and Heppelman, 2014	IoT	Industry	Illustrative cases	Manufacturing	*Present/Future*	*Impact of smart products on industry structure and the nature of competition.*	x		x	x	x	x	x	x	x
Potstada and Zybura, 2014	AMTs	Economy/society	Expert study	Consumer electronics	*Future*	*Science fiction prototyping for home fabrication in 2033.*	x	x	x		x	x			
Rauch *et al.,* 2017	Industry 4.0	Manufacturing networks	Conceptual	Manufacturing	*Present/Future*	*State of the art and future developments of redistributed manufacturing.*		x	x			x	x		
Rayna and Striukova, 2016	AMTs	Firm/ecosystem	Conceptual	Manufacturing	*Present*	*Impact of AMTs on business model configuration and innovation.*	x	x	x	x	x	x	x	x	x
Rehnberg and Ponte, 2018	AMTs	Global value chains (GVCs)	Conceptual	Manufacturing	*Future*	*Impact of AMTs on GVCs considering two alternative scenarios (complementarity with traditional production technologies or substitution).*	x	x	x	x	x				x
Roden *et al.*, 2016	Big Data	Firm	Multiple case study	Manufacturing	*Present*	*Role of Big Data in transforming firms' operation models.*	x				x	x			
Rong *et al.*, 2015	IoT	Ecosystem	Multiple case study	Automotive, Media	*Present*	*Parallel evolution of individual firms' business models and their ecosystems.*	x				x	x			

Roscoe and Blome, 2019	AMTs	Supply chain	Multiple case study	Pharmaceuticals	*Future*	*Reconciliation of efficiency and flexibility targets in redistributed manufacturing.*		x	x	x					
Ryan *et al.*, 2017	AMTs	Supply chain	Conceptual	Manufacturing	*Present/Future*	*Existing scenarios and future opportunities for AMTs.*	x	x				x			
Rymaszewska *et al.*, 2017	IoT	Value chain	Multiple case study	Machinery and Equipment, Energy, Electronics	*Present*	*Value creation dynamics in IoT-driven servitization.*	x		x						
Sandström, 2016	AMTs	Industry	Multiple case study	Medical devices	*Present*	*Developments of AMTs in the hearing aid industries between 1989-2008.*	x			x			x		x
Sklylar *et al.*, 2019	Various digital technologies	Ecosystem	Multiple case study	Machinery and Equipment	*Present*	*Organizational change in service ecosystem due to digital servitization.*	x				x				
Srai *et al.*, 2016	AMTs, various digital technologies	Supply chain	Expert study	Manufacturing	*Future*	*Challenges and opportunities for redistributed manufacturing.*	x	x		x	x	x	x		
Stentoft and Rajkumar, 2019	Industry 4.0	Firm	Survey	Manufacturing	*Present*	*Drivers and barriers related to Industry 4.0 in the location decision process.*		x							
Strange and Zucchella, 2017	Industry 4.0	Global value chains (GVCs)	Conceptual	Manufacturing	*Future*	*Future impact of emerging technologies on GVCs.*	x	x	x						x
Subramanian *et al.*, 2019	IoT	Ecosystem	Conceptual	Manufacturing, Services	*Future*	*Impact of the emergence of digital ecosystems on firms' strategy.*	x								
Sun and Zhao, 2017	AMTs	Industry	Conceptual	Apparel and Footwear	*Future*	*Impacts and challenges of AMTs.*	x	x	x		x		x		
Suppatvech *et al.*, 2019	IoT	Business model	Conceptual	Manufacturing	*Present*	*Types of IoT-enabled servitized business models.*	x								
Tziantopoulos *et al.*, 2019	AMTs	Supply chain	Conceptual	Manufacturing	*Present*	*Decision-making process model for supply chain reconfiguration.*	x	x			x	x	x		
Vendrell-Herrero *et al.*, 2017	Various digital technologies	Supply chain	Secondary data analysis/Simulation	Publishing	*Present*	*Effects of servitization and digitalization on power and marginalities upstream and downstream the supply chain.*	x				x		x		x
Verboeket and Krikke, 2018	AMTs	Supply chain	Conceptual	Manufacturing	*Future*	*Impact of AMTs on supply chain design and performance.*		x	x		x	x			
Wang *et al.*, 2016	AMTs	Not specified	Survey	3D printing	*Present*	*Characteristics of the early adopters of home-based 3D printing systems.*						x			
Wang *et al.*, 2019a	Blockchain	Supply chain	Conceptual	Manufacturing	*Future*	*Impact of blockchain technologies on supply chain structure and practices.*	x		x				x		
Weller *et al.*, 2015	AMTs	Industry	Conceptual/Simulation	Manufacturing	*Future*	*Impact of AMTs on industry, based on industry characteristics.*				x				x	X
Yun *et al.*, 2016	Robotics, autonomous driving	Industry	Multiple case study	Automotive, Machinery and Equipment	*Future*	*Interdependencies among technology, business models and industry structure.*	x			x					
Yun *et al.*, 2019	Robotics, autonomous driving	Industry	Multiple case study	Automotive, Machinery and Equipment	*Present*	*Role of technology and business model innovation in converted and emerging industries.*	x								
Zaki *et al.*, 2019	Big data	Firm	Secondary data analysis/Multiple case studies	Consumer goods	*Present*	*Influence of big data in the implementation of redistributed manufacturing models.*	x	x							

The effects of Industry 4.0 on the (4) *size* of manufacturing firms are equally unclear. Whereas product innovation is triggering the entrance of new players across several manufacturing industries, in the future a higher concentration is to be expected due to technological standardization (Yun *et al.*, 2016). Different speculations have been made as regards to production activities. On the one hand, consolidation trends seem to be supported by the need to guarantee higher service levels because of mass customization, by AMTs cutting out component suppliers and contract manufacturers and also by the pursuit of cost synergies in the light of the increasing price transparency of online sales channels (Tziantopoulos et al., 2019; Rehnberg and Ponte, 2018; Holmström et al., 2016). On the other hand, it has been argued that AMTs and digital coordination technologies will provide more opportunities to small and medium enterprises (SMEs) to network with large players for mass customization, spare parts and localized production (Braziotis *et al.*, 2019; Gress and Kalafski, 2015).

Along these dimensions, several studies have suggested industry-specific variations because of different levels of technological applicability (e.g., LaPlume *et al.*, 2016; Athanasoupoulou *et al.*, 2019), standards and regulation requirements (e.g., Weller *et al.*, 2015; Hannibal and Knight, 2018; Braziotis *et al.*, 2019), as well as current industry characteristics and inertia to change (e.g., Bertola and Teunissen, 2018; Kapetaniou *et al.*, 2018; Sun and Zhao, 2017).

3.3.3. Industry 4.0: impacts on other players involved in manufacturing VCs

As shown in Table 11, several papers have investigated emerging configurations of manufacturing companies within their broader networks of business relations. Research has mostly focused on focal firms' first-tier interfaces, e.g., investigating how companies shape their business models, orchestrate resources within their ecosystem or redesign their supply chains. Few studies – mainly conceptual (e.g., Porter and Heppelman, 2014; LaPlume *et al.*, 2016; Sun and Zhao, 2017) – have approached the issue considering whole industries or VCs. These are mostly from a geographical point of view; very few contributions have considered the interplay between the economic and societal level.

From this literature it is possible to identify some evolutionary dynamics:

> (5) an increasing dependency from *suppliers* of IoT technologies and data providers, as well as the emergence of broad networks of collaborative *partners* in software development and product design supported by modularization and platform-based governance (e.g., Iansiti and Lahkani, 2014; Kiel et al., 2017; Rong et al., 2015; Cenamor *et al.*, 2017);

(6) final customers turning into prosumers that co-create products and services with companies through the Internet and 3D print directly at home (e.g., Wang *et al.*, 2016; Hamalainen and Karjalainen, 2017; Halassi et al., 2019);

(7) traditional *intermediaries* in both the consumer and business segment being challenged by the spread of digital platforms (e.g., Durach et al., 2017; Jiang et al., 2017; Halassi et al., 2019), blockchain technologies automating several "middle-man" activities (e.g., Cole et al., 2019; Chang *et al.*, 2019; Morkunas *et al.*, 2019), smart cities becoming increasingly relevant (e.g., Kumar *et al.*, 2016);

(8) *competitors* from adjacent sectors, digital players, and technology providers operating in broader cross-industry market ecosystems (e.g., Culot et al., 2019, Frank *et al.*, 2019b; Hakanen and Rajala, 2018); and

(9) overall deep changes in the *relational dynamics and configuration drivers* that determine opportunities and constraints for individual companies along manufacturing VCs. These refer to: changes in the economies of scale and scope in production (e.g., Bogers *et al.*, 2015); a shift in the sources of competitive advantage and new barriers to entry in relation to control over data and proprietary technologies (e.g., Porter and Heppelman, 2014; Weller *et al.*, 2015; Vendrell-Herrero *et al.*, 2017); a redistribution of value towards services and data-related activities or rather towards production (e.g., Durach *et al.*, 2017; Jia *et al.*, 2015; Rehnberg and Ponte, 2018).

In order to provide a comprehensive overview of the configuration trajectories affecting manufacturing VCs, three further streams of literature should also be mentioned. The first one is related to the growing academic interest around technological platforms. The current debate on Industry 4.0 in manufacturing has only partially been influenced by the "economic perspective" of platform research so far (Gawer, 2014; McIntyre and Srinivisan, 2017), the main focus being on manufacturers sponsoring technological platforms to engage with third-party complementors. The increasing prevalence of platform-based approaches raises, however, further questions concerning demand dynamics (e.g., Bryonlfsson *et al.*, 2010), cross-industry consolidation trends (e.g., Eisenmann *et al.*, 2011; Ruutu *et al.*, 2017) as well as potential direct competition between platforms and manufacturers (e.g., Zhu and Liu, 2018). The second stream of research is related to data management for value creation in the era of big data (e.g., Davenport, 2017; Iansiti and Lahkani, 2020; Hagiu and Wright, 2020; Spiekermann and Korunustovska, 2017). In these studies, attention has been placed on understanding how different types of data represent a source of competitive advantage, an issue that has been tackled only marginally in the research investigating IoT-enabled business models in manufacturing. The third and last stream is also related to the data issue, where some studies have also investigated emerging business models and concentration dynamics of technology providers in the IoT (Metallo *et al.*, 2018; Basaure *et al.*, In press) and in the big data industries (e.g., Urbinati *et al.*, 2019; Nuccio and Guerzoni, 2019).

3.3.4. Summary and research gaps

A key question within the growing literature on Industry 4.0 is related to its non-technological features under the assumption of a new socio-technical paradigm. Within this broad research focus, the configuration of manufacturing companies has been addressed from a competitive and an operations strategy perspective. Various methodologies have been employed aiming, on the one hand, at understanding how companies are currently shaping their approaches and, on the other, at deriving future general trends. Some characteristics have been highlighted in terms of manufacturing companies' value offering, location, governance and size; many questions do, however, remain on the specific implications. Several studies have also addressed possible impacts within the manufacturing companies' network of business relations, even though they mostly consider focal companies' first-tier interfaces. Potential changes refer to suppliers and partners, customers, intermediaries, competitors and relational dynamics across the various players along manufacturing VCs.

Overall, the current understanding of the paradigmatic properties of Industry 4.0 is still unclear and – to a certain extent – ambivalent. Part of the issue is related to the fact that, today, researchers are clearly confronted with mostly exemplary cases of large-scale technology implementation (e.g., Hofmann and Rüsch, 2017; OECD, 2017; World Economic Forum, 2019) and business model innovation (Bughin and van Zeebroeck, 2017; Weking *et al.*, In Press). Academics investigating how companies – usually the most advanced ones – are configuring for Industry 4.0 have identified emerging trajectories and provided managers with insights on actual opportunities, but inevitably failed to describe the nature of the new paradigm and thus to make explicit the range of options and implications. Moreover, business models, ecosystems and supply chains analyzed from the point of view of focal firms did not consider the implications of parallel transformative evolutions in upstream and downstream manufacturing industries as well as in adjacent sectors. Although some scholars have approached the issue with broader analytical scope and greater future orientation (e.g., Jiang *et al.*, 2017; Opresnik and Taisch, 2015; Hannibal and Knight, 2018), there still remain significant knowledge gaps. The main gap is probably related to the narrow focus of these studies: it is still not possible to fully grasp cross technological effects and the interdependencies between competitive and operations strategy (e.g., Skinner, 1969; Hayes and Wheelwright, 1984; Chen and Paluraj, 2004) as technologies and specific impacts have been examined separately so far.

In conclusion, even if some possible configuration trajectories emerge from the literature, there is still confusion around the big picture. As Industry 4.0 is still in its early stages, we believe that a worthwhile academic endeavor is to initiate a broader debate that – starting from the learnings of previous research on specific technological and thematic issues – could anticipate the most crucial challenges in the configuration of manufacturing companies in the long term.

3.4. Methodology

Under the assumption that – similar to previous industrial revolutions – Industry 4.0 will result in a paradigm shift in the configuration of manufacturing companies, we approached the current knowledge gap through a future-oriented and interdisciplinary research. Drawing from the literature review on the definition of Industry 4.0 and similar concepts (Chapter 2), four main clusters of technologies were considered: *physical/digital interface technologies* bridging the cyber-space with the reality of machines, products, and people at work (i.e., the IoT, cyber-physical systems, and visualization technologies); *network technologies* providing online functionalities (i.e., cloud computing, interoperability and cybersecurity solutions, and the blockchain technology); *data-processing technologies* supporting analysis and providing information-driven input for decision making (i.e., simulation, machine learning and artificial intelligence, big data analytics); and *physical-digital process technologies* (i.e., AMTs, advanced robotics, new materials and energy management solutions). We assumed that our analysis should be stretched beyond individual companies' boundaries and dyadic relationships. As system-level construct, the VC seemed the most apt as it includes both manufacturing and non-manufacturing players, encompasses different stages along the value creation process, and allows for syncretic analyses.

In line with a well-established tradition across managerial disciplines (Meredith et al., 1989; Ramirez *et al.*, 2015), we developed an expert study approached through the lenses of interpretative research (Smith, 1983; Prasad and Prasad, 2002). The underlying assumption was that:

- qualified academics and professionals with heterogenous backgrounds were in a position to provide an informed opinion on the issue in its different facets;

- a structured collection and analysis of these opinions could inform the formulation of hypotheses on the future of Industry 4.0;
- these hypotheses would not provide a definitive forecast as the elicitation of expert opinion is necessarily contextualized and bounded by available information;
- through the adoption of interpretative research as epistemological stance – i.e., through the analysis of how the future is construed and conceptualized – we could highlight the most crucial uncertainties

Under this premise the study was structured as a Delphi-based scenario analysis. This methodology enables the formulation of a series of scenarios – i.e., *"descriptions of possible futures that reflect different perspectives"* (van Notten *et al.*, 2003, p. 424) – starting from the collective understanding of a panel of experts engaged in multiple-round questionnaires. This approach has been deployed consistently since the 1990s to enhance the objectivity of scenario planning (Nowack et al., 2011; Saritas and Oner, 2004). Compared with other expert opinion elicitation methodologies, the Delphi technique minimizes the social difficulties related to status or personality traits in interacting groups while fostering social learning (Rowe *et al.*, 1991). First, experts respond individually to a questionnaire, then the aggregated results are fed back to the group allowing participants to revise their original answers and provide further comments (Linstone and Turoff, 1975). The process was reiterated until the group has reached either consensus or stability in the results (von der Gracht, 2012; Linstone, 1978).

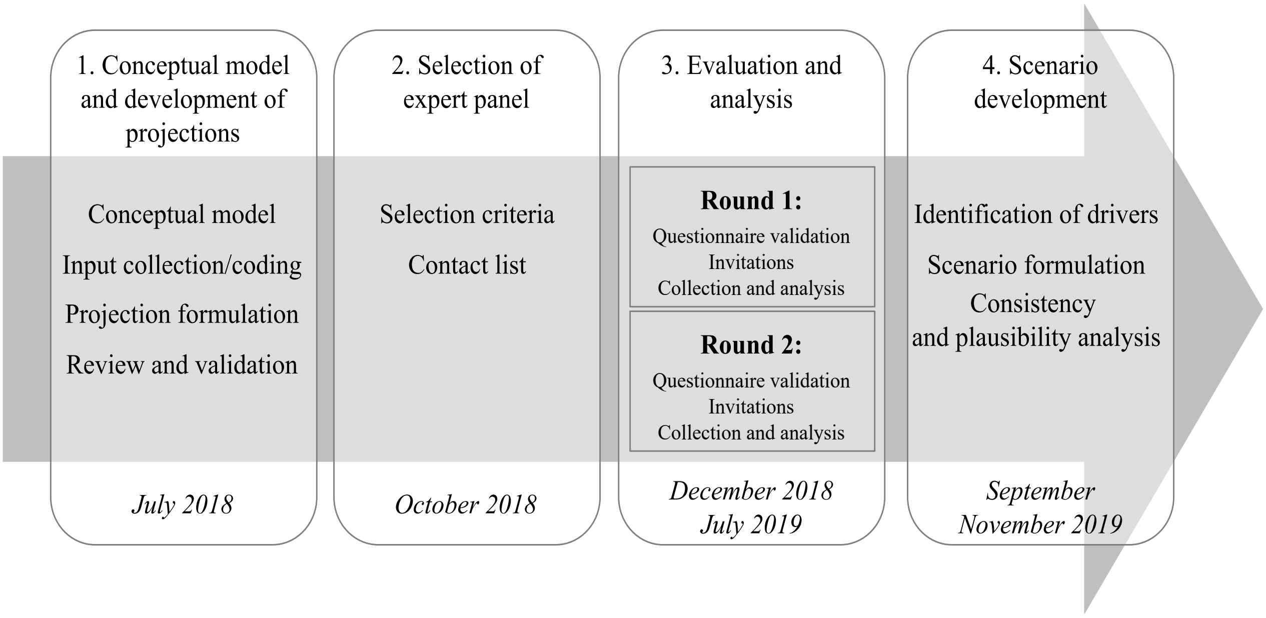
Following Nowack *et al.* (2011) methodological recommendations and the example of similar works (e.g., Bokrantz *et al.*, 2017; Jiang *et al.*, 2017; Roßmann *et al.*, 2018; Durach *et al.*, 2016; von der Gracht and Darkow, 2010), we engaged the experts in the assessment of a set of projections – i.e., short future theses – defined beforehand by the research team through a structured process. The reference year for the assessment was set to be 2030, consistently with the typical 10-15 years forecasting horizon of similar studies.

The experts were divided into three industry subpanels to account for the industry-specific dynamics highlighted in the literature (e.g., LaPlume *et al.*, 2016; Ferràz-Hernández *et al.*, 2017; Braziotis *et al.,* 2019). The first criterion was technological intensity, measured as direct research and development (R&D) intensity and R&D embodied in intermediate and investments goods (Galindo-Rueda and Verger, 2016). The second criterion was the end-use category. The two criteria were combined to select industries with diverse characteristics leveraging on the classification of economic activities developed by the Organization for Economic Co-operation and Development (OECD). We included Apparel and Footwear (low technological intensity - non-durable consumer goods), Automotive (medium-high technological intensity - durable consumer/capital goods), and Machinery and Equipment (medium-high technological intensity - capital goods).

The study was conducted in collaboration with the Boston Consulting Group (BCG). As a global leader in management consulting, BCG has been working consistently on Industry 4.0 over the past few years in relation to both client projects and knowledge creation and dissemination, often in collaboration with research institutions, governments, and international think-tanks. The collaboration involved the identification of the research question, several brainstorming and validation sessions, and the selection of industry experts. The analysis of the results was performed exclusively by the research team.

The research process and timeline are illustrated in Fig. 5. The four main phases are described in detail in the following paragraphs.

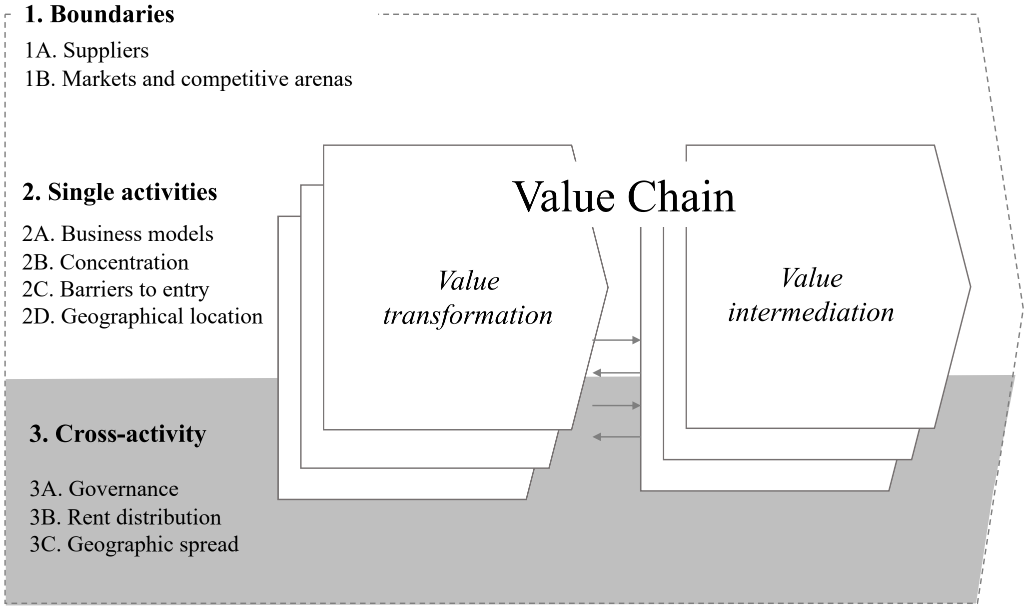
Figure 5. Research process



3.4.1. Conceptual model and development of projections

Our first step was to develop a conceptual model of the VC (Fig. 6) that would enable the analysis – across multiple dimensions – of recurring patterns in the configuration of the various players involved in the full range of activities needed to bring a product from its conception to its final use (Gereffi and Fernandez-Stark, 2016; Raikes *et al.*, 2000). Building on the ideas and terminology of various schools of thought, our conceptual model is structured on three levels of analysis.

Figure 6. Conceptual model



The first level refers to VC *boundaries (1)* that define the scope of the analysis. We leveraged on the concept of "extended value chain" (Kaplinsky, 2000; Kaplinsky and Morris, 2000) to include new suppliers and partners (1A) and borrowed from industry structure analysis (e.g., Porter, 1979; Bell, 1981; Scherer and Ross, 1990; Sampler, 1998) the idea of "industry boundaries" to investigate the evolution of markets and competitive arenas (1B).

Once the boundaries are defined, the conceptual model breaks down the VC into its building blocks, or *single activities (2)*. The single activities vary by industry and are normally identified through the analysis of a VC input-output structure as individual firms are producers/users of inputs to/from other firms (Hopkins and Wallerstein, 1994). Activities typically included are research and development, raw material and technology supply, upstream and downstream manufacturing, distribution, marketing and sales. In line with well-established concepts in the study of supply chains (e.g., Hayes and Wheelwright, 1984; Lambert *et al.*, 1998; Choi *et al.*, 2001; Carter *et al.*, 2015), we considered both physical and support activities. The two inner boxes in the conceptual model specifically differentiate activities related to *value transformation* – i.e., the production of physical goods and related services – from those involving *value intermediation* – i.e., the transfer of value between different stages of the VC and ultimately to the consumer. At this level of analysis, we adopted the typical lenses of industrial organization (IO) economy as it developed from its early days (e.g., Mason, 1939; Bain, 1956). We considered business models and new entrants (2A), the level of concentration

(2B), and the barriers to entry (2C). Moreover, because reshoring and redistributed manufacturing emerged as key topics in the literature, we also included the geographical location (2D) of activities as a topic for investigation.

The third level of analysis considers *cross-activity (3)* dynamics and examines the way in which single activities are linked together by VC participants. The reasoning is grounded again in the IO economics tradition, as well as in the concepts of global commodity chains (GCCs), global value chains (GVCs) and global production networks (GPNs), concepts that originated to explain the geographies and governance of activities in the context of the globalization phenomenon (e.g., Raikes *et al.*, 2000; Gereffi *et al.*, 2005; Coe *et al.*, 2008; Gibbon *et al.*, 2009; Hernández and Pedersen, 2017). At this level of analysis, we took into account governance modes on a market-hierarchy continuum (3A), rent distribution (3B) and the degree of geographical dispersion (3C).

The set of projections was developed on the basis of the available knowledge on the topic. As suggested by von der Gracht and Darkow (2010) and Bokrantz *et al.* (2017), we resorted to multiple sources for collecting inputs:

(1) a literature review of academic studies (Table 11) investigating the impact of Industry 4.0 and related technologies on manufacturing VC;
(2) a literature review of non-academic sources, including white papers published by management consulting firms, multinational companies, governmental bodies, and other international organizations;
(3) a workshop with four academics and two BCG consultants experienced in Industry 4.0. The workshop was structured as an initial brainstorming session on the conceptual model (Fig. 6), comments were transcribed;
(4) a thematic industry round table with eight senior professionals actively involved in Industry 4.0 implementation. The panel included three technology providers and five industry executives; three out of the five were also involved in thematic initiatives promoted by industry associations and government agencies. Participants were asked to share their experience and views on the topic and their comments were transcribed.

The data from these four sources were thoroughly analyzed. Following well-established practices in qualitative research (Mayring, 2008; Seuring and Gold, 2012; Miles, Huberman and Saldana, 2014), both the literature and the transcripts were coded deductively. The coding categories were determined according to the conceptual model illustrated in Fig. 6. Two researchers were involved independently in the process, any disagreement was discussed within the team until agreement was reached.

The coding activity resulted in an initial list of 97 possible impacts. As the quality of Delphi studies is affected by the effort and time required for compiling the questionnaire (Linstone and Turoff, 1975; Landeta, 2006; Rowe *et al.*, 1991), this initial list of possible impacts was significantly rationalized. Redundancies were ruled out and similar themes across different analytical dimensions were combined following the Jiang *et al.* (2017) example.

The final list included 43 projections phrased in English according to established practices for the length and number of elements in each sentence (Mitchell, 1991), the definition of technological concepts (Johnson, 1976) and the avoidance of ambiguity and conditional statements (Rowe and Wright, 2001; Loveridge, 2002). Two external researchers and three consultants independently analyzed the full list of projections for content and face validity (Salancik *et al.*, 1971).

The final list of 43 projections is presented in Table 11. The projections are clustered according to the level of analysis and the main topics of the conceptual model in Fig. 6. The final questionnaire is based on the same structure.

Table 11. Final list of projections

No	Projection
1. BOUNDARIES	
1A. Suppliers and partners	
1.	Players in the **additive manufacturing** value chain provide machines and materials for manufacturing activities.
2.	Digital players **provide** individual-level **customer-. product- or process- data** needed for activities (e.g., production, service provision, intermediation) within the value chain.
3.	**Rare natural resources** are needed in manufacturing activities and in the product itself (e.g., rare metals for batteries).
4.	**Players in the waste management value chain** provide inputs for manufacturing activities (e.g., disassembly and routing of components/materials back into production).
1B. Markets and competitive arenas	
5.	End-markets are characterized by broad **cross-industry ecosystems** where companies from traditionally different industries compete for similar customer needs (e.g., from “automotive” to “mobility solutions”).
6.	Consumers are **producing directly at home** products and components thanks to additive manufacturing technologies.
7.	Individual-level customer- process- and product-**data generated within the industry value chain are sold** to players in the data management value chain.
2. SINGLE ACTIVITIES	
2A. Business models and new entrants	
Value transformation (manufacturing / services)	
8.	**Small scale workshops** (e.g., fab labs, small factories) produce physical products (final or intermediate goods) for a variety of customers.
9.	**Digital players offer (e.g., via software applications) services** meeting demand previously addressed by traditional manufacturing and service companies.
10.	**Substitutes** (materials, products, services) leveraging emerging technologies are manufactured/provided by players traditionally not belonging to the industry value chain (e.g., in the past: MP3 and streaming services developing outside the traditional record music value chain).
11.	Companies manufacture physical products without owning any production facility (in a **virtual manufacturing** setting).
Value intermediation (sales and distribution)	
12.	Intermediaries adopting a **platform business model** match demand and supply of products, components, and services along the value chain.
13.	**Pure-play digital players** perform intermediation activities previously offered by traditional "brick-and-mortar" companies (i.e., with physical shops or distribution network).
14.	Customers are offered **product usage instead of product ownership**, leveraging on time-based or performance-based payment schemes.
15.	Public administration at the local/city level match demand and supply of products and services within a **smart city** context.

2B. Concentration
Value transformation (manufacturing / services)
16. Activities related to sourcing of **raw materials are concentrated** with a limited number of global suppliers.
17. Activities related to the **manufacturing of intermediate goods are concentrated** with a limited number of global suppliers.
18. Activities related to the **manufacturing of final products are fragmented** with the participation of a large number of small and medium enterprises.
19. Activities related to **design (product and software) are fragmented** with the participation of a large number of small and medium enterprises and micro-companies.
20. Activities related to **data management are concentrated** with a limited number of global players.
21. Activities related to the **provision of services** (including services via software applications) **are fragmented** with the participation of a large number of small and medium enterprises and micro-companies.
Value intermediation (sales and distribution)
22. **Intermediation** activities (e.g., sales and distribution, platforms) are **concentrated** with a limited number of global players.

2C. Barriers to entry
Value transformation (manufacturing / services)
23. New players can **easily enter manufacturing** activities as barriers to entry are low (e.g., due to asset-light business models, limited need for personnel, declining cost of technology…).
24. New players can **easily enter service provision** activities as barriers to entry are low (e.g., due to asset-light business models. limited need for personnel, declining cost of technology…).
Value intermediation (sales and distribution)
25. New players can **easily enter intermediation activities** (e.g., sales. distribution. platforms) as barriers to entry are low (e.g., asset-light business models, limited need for personnel, declining cost of technology…).

2D. Geographical location
Value transformation (manufacturing / services)
26. **Production** and related operations of manufacturing companies are located in **Western Europe, the United States and Japan**.
27. Production is performed in small-scale factories/workshops operating **closer to products' point-of-sale/point-of-use**.
Value intermediation (sales and distribution)
28. **Customer interactions (e.g., marketing and sales) are managed centrally** with limited resource commitment in local affiliates.

3. CROSS-ACTIVITY
3A. Governance
29. **Manufacturing** companies have **internalized production activities** from intermediate goods to final product assembly.
30. **Manufacturing** companies have **internalized service provision** activities in relation to their products.
31. **Manufacturing** companies have **internalized end-of-life product management**, including remanufacturing. refurbishment and recycling.
32. **Manufacturing** companies have **internalized intermediation activities** (e.g., sales, distribution, platforms) related to their products and services.
33. **Manufacturing** companies have **internalized data management** activities in relation to their **products, services, and customers**.
34. **Manufacturing** companies have **internalized data management** activities in relation to their supplier base with direct access and control over suppliers' data (e.g., real-time production capacity, machine status).
35. **Intermediaries** (distributors, retailers, platforms), **logistics operators and after-sales service** providers (e.g., maintenance network) **produce final products or components**.
36. **Intermediaries** (distributors, retailers, platforms) develop their **own offering** of products and services.
37. **Major digital players** (e.g., Google, Amazon, Apple) **develop their own offering** of products and services.
38. **Large companies** develop **in-house proprietary technology** (e.g., algorithms, robotics, blockchain...).

3B. Rent distribution
39. Activities related to the **provision of services** display the **highest margins** along the value chain.
40. Activities related to the **management of data** display the **highest margins** along the value chain.
41. Activities related to the **production of physical products** display margins comparable to pre-production (e.g., product development) and post-production (e.g., marketing and sales) activities.

3C. Geographic spread
42. The several activities along the value chain are **dispersed globally** across multiple locations according to differential locational advantages.
43. **Integrated regional supply chains** (e.g., North America, Europe, Far East...) serve the needs of their respective markets.

3.4.2. Selection of the expert panel

A rigorous selection of the experts is a precondition for the reliability of a Delphi study (Hasson and Keeney, 2011; Landeta, 2006). Previous research shows significant differences in the number of experts involved – with studies featuring from 10-20 participants (e.g., MacCarthy and Atthirawong, 2003) up to several hundred (e.g., Fundin *et al.*, 2018) – and also in their heterogeneity in terms of professional background, age, gender, and nationality (Loo, 2002; Yaniv, 2011). These differences are mostly explained by the topic and the aims of each study.

In line with the explorative nature of our research and the cross-disciplinary nature of the debate, we opted for a panel size of at least 60 experts – minimum of 20 for each industry subpanel – with heterogeneous professional backgrounds. Heterogeneity was pursued in terms of academia/practice and – within each group – discipline/function, consideration of operations and supply chain management as well as strategy, marketing, and general management. Selection criteria were built to ensure that experts were knowledgeable and had global visibility on the phenomenon.

Consistent with previous studies, academics were identified on the basis of the publications in the domain by means of scientific databases (e.g., Scopus) and personal networking. Professionals were selected taking into account individuals with at least manager-level responsibility in the industries in scope or their employment with digital players, technology providers, digital advisory boutiques as well as management consultants. They were scouted searching the alumni directories of the academic institutions involved in the study, professional social networks (such as LinkedIn) as well as the global industrial practice network, the alumni database and the client base of BCG. Industry executives were first selected in the above-mentioned databases through a keyword search on their current industry of employment, thereafter each profile was carefully examined. This approach led to an initial list of 303 individuals, 77 of whom agreed to take part in the Delphi study. In order to further ensure rigor in the selection process (Landeta, 2006), the questionnaire included three self-rating questions on the perceived level of knowledgeability, i.e., familiarity with the specific industry (Apparel and Footwear, Automotive, Machinery and Equipment), with Industry 4.0, and with VC configuration issues. One respondent was excluded because of overall poor scores. The final panel was composed of 76 experts in the first round, only 8 experts dropped out in the second round.

The characteristics of the three subpanels are illustrated in Table 12. We firmly believe that the profiles of the experts are outstanding, both from a scientific point of view and regarding the variety of backgrounds and professional experiences.

Table 12. Composition of the subpanels

	Apparel and Footwear n=21	**Automotive n=24**	**Machinery and Equipment n=31**	***Total***
Respondent category				
Industry executives	12	13	20	*45*
Academics	5	6	4	*15*
Digital executives	2	3	2	*7*
Management consultants	2	1	3	*6*
Digital consultants/entrepreneurs	-	1	2	*3*
Years of experience				
5-10	8	5	5	*18*
11-20	10	11	16	*37*
>20	3	8	10	*21*
Self-rated familiarity (5=high; 1=low) Median (Interquartile range)				
Specific subpanel industry	4.0 (1.0)	4.0 (1.0)	4.0 (0.5)	
Industry 4.0 technologies	3.0 (1.0)	4.0 (1.0)	4.0 (1.0)	
Value chain configuration	3.5 (1.0)	4.0 (2.0)	3.0 (1.0)	
Geography (location of home institution/company)				
Europe				
Austria	-	1	-	*1*
Belgium	-	-	1	*1*
Denmark	-	1	-	*1*
Finland	-	-	1	*1*
France	2	-	1	*3*
Germany	2	8	5	*15*
Hungary	-	1	-	*1*
Italy	6	4	9	*19*
Spain	1	-	-	*1*
Sweden	-	-	3	*3*
Switzerland	-	-	1	*1*
The Netherlands	-	1	-	*1*
UK	-	1	1	*2*
Total Europe	***11***	***17***	***22***	***50***
Americas				
Trinidad and Tobago	1	-	-	*1*
US	5	7	7	*19*
Total Americas	***6***	***7***	***7***	***20***
Asia				
China	1	-	1	*2*
Japan	1	-	-	*1*
Singapore	-	-	1	*1*
Saudi Arabia	1	-	-	*1*
Thailand	1	-	-	*1*
Total Asia	***4***	***-***	***2***	***6***
Home institution/company				
Industry executives	*Adidas, Bottega Veneta, Calzedonia, Ermenegildo Zegna, Esprit, Geox, Guess, Hanky Panky, Kering, LVMH, Mango, Nike*	*Audi, Aptiv, Automotive Lighting (x2), BMW (x2), CNH Industrial, FCA, Intercable, Magneti Marelli, McLaren, Schaeffer Technologies, Volkswagen*	*ABB (x2), Atomat, Bonfiglioli, Bosch (x2), Danieli, EOS, Fincantieri, Flex, General Electic (x2), Johnson&Johnson, Leonardo (x2), Nystar, Solari, Thermokey, Veolia, Wärtsila*	
Academics	*Chiang Mai University (TH), Kansai University (JP), Polytechnic University of Milan (IT), Prince Sultan University (SA), University of the West Indies (TT)*	*Aallborg University (DK), Corvinius University (HU), Free University of Bolzano-Bozen (IT), Hawai'i Pacific University (US), Jade Hochschule (DE), Michigan State University (US)*	*ETH Zurich (CH), Lund University (SE), University of Stuttgart (DE), University of Catania (IT)*	
Digital executives	*Amazon, Google*	*Cisco, Google, Microsoft*	*IBM, Microsoft*	
Management consultants, digital consultants, entrepreneurs	*Others (2)*	*BCG (1), Others (1)*	*BCG (1), Others (4)*	

Overall, the study features strong participation of practitioners, including executives from some of the most renowned firms within each industry and managers from leading digital companies (e.g., Amazon, Google, IBM, Cisco); however, the panel is skewed towards industry incumbents as it features a low number of digital consultants and entrepreneurs. Years of experience – 58 out of 76 respondents (76%) have more than 10 years of professional experience – and self-rated familiarity with the topics of the study further confirm the level of expertise of the panel. In terms of gender, the Apparel and Footwear subpanel is well balanced, whereas the other two are mainly composed of male respondents. From a geographical perspective, the main manufacturing countries in Europe – Germany and Italy – and the United States are well represented; however, other relevant manufacturing economies in Asia – China, India, and Japan – have only a limited number of respondents.

3.4.3. Evaluation and analysis

The questionnaire was developed starting from the list of 43 projections (Table 11). Both the first- and the second-round questionnaires were pretested with five external academics and practitioners following standard methodological practices (Blair, Czaja and Blair, 2013; Forza, 2002).

The experts were asked to evaluate the projections based on how well they were providing a correct description of the present situation ("Magnitude in 2019") and of the future in 2030 ("Magnitude in 2030"). The assessments were performed on an ordinal five-point Likert-type scale (1: Very low, 5: Very high). The experts were also invited to provide a rationale for their evaluation in an open textbox; 1,218 comments were collected in the first round and a further 313 in the second, attesting to the high commitment of the participants.

The first round lasted five weeks, starting at the end of January 2019. An interim analysis was performed and thereafter separately for each industry subpanel. In line with the nature of the data, the median as a measure of central tendency and the interquartile range (IQR) for answer dispersion were calculated for all the Likert items; items with $IQR \leq 1$ were considered to have reached consensus in the expert evaluation (von der Gracht, 2012; Schmidt, 1997). The qualitative data were approached through a content analysis resulting in a list of arguments supporting high and low future magnitude for each projection (Miles, Huberman and Saldana, 2014).

Starting with the results of the interim analysis we developed the second-round questionnaire. Each expert received a form including – for each projection – the statistics, arguments, and his/her original assessment from the first round. The participants were asked to confirm or revise their original answers in view of this information. The second round lasted six weeks starting in mid-April 2019. The analysis was approached consistently with the first round. The results of the first and the second round were compared and analyzed in terms of stability – i.e., “the consistency of responses between successive rounds of a study” (Dajani *et al.*, 1979, p. 84) – calculating the Spearman’s rank-order correlation coefficient (ρ) (von der Gracht, 2012; DeLeo, 2004). After the second round, the assessments of all Likert-type items reached either consensus ($IQR \leq 1$) or stability ($\rho \geq 0.75$) in each subpanel, thus making further iterations of the questionnaire with the experts superfluous.

3.4.4. Scenario development

The results of the Delphi study served as a basis to elaborate on eight scenarios for manufacturing VCs in 2030. We first identified the four most recurring elements of uncertainty in the expert comments. The impact of different future states of these elements of uncertainty (e.g., “high” or “low” future states) on the affected projections were then analyzed.

The projections served as a basis to formulate consistent scenarios, following a plausibility and internal consistency analysis (Lehr *et al.*, 2017; Johansen, 2018). This approach is in line with the backwards logic method in scenario planning as the driving forces are inferred from future states (Derbyshire and Wright, 2014; Wright and Cairns, 2011; Wright and Goodwin, 2009).

The results were shared with the 76 experts involved in the study, who received the full article draft together with a 6-minute video illustrating the main messages of the paper. The experts were encouraged to share their comments with the research team, the feedback confirmed that the research was able to adequately capture the initial opinions of the experts and the debate developed throughout the Delphi study.

3.5. Results

This section presents the results of the Delphi study. First, we outline the descriptive statistics for the two rounds (section 3.5.1), thereafter we illustrate the content analysis of the experts’ comments and present a conclusive narrative for each projection (Section 3.5.2).

3.5.1. Delphi statistics

The analysis of the Likert items is presented in Table 13. The median values of “Magnitude in 2019” and “Magnitude in 2030” were calculated for the two rounds whereby the three industry subpanels were considered separately; the values in brackets indicate items with low subpanel consensus (IQR≤1). In order to provide a synthetic overview, the table also includes the median values calculated for the whole panel in the second round ("Total"). In addition, the IQR for the second round and the stability between rounds (Spearman's ρ) is presented.

All projections except for two (#6 and #35) have a median "Magnitude in 2030" of 3 or higher in at least one industry subpanel, confirming the relevance of the issues identified through the research process. The results show an increasing convergence of opinions through the iteration of the questionnaire. After the first round, out of 86 items (43 projections in two points in time, "Magnitude in 2019" and "Magnitude in 2030"), 46 reached consensus for Apparel and Footwear (53%), 35 for Automotive (41%) and 44 for Machinery and Equipment (51%). After the second round, the items reaching consensus were respectively 60 (70%), 70 (81%) and 76 (88%). These values indicate the effectiveness of the social learning process and are in line with previous studies (Bokrantz *et al.*, 2017). As expected, the "Magnitude in 2019" items display a higher level of agreement than the "Magnitude in 2030" ones in both rounds.

A comparison of the results of the three subpanels reveals several industry specificities. The median values differ across subpanels for 56 out of 86 items (65%); for 46 items (53%) consensus was reached in all subpanels. The analysis of the Spearman's ρ highlights relatively more stability in the Machinery and Equipment subpanel.

3.5.2. Content analysis and conclusive narratives

The following sections present the results of the content analysis of the experts' comments collected over the two rounds (Tables 14-16). For each projection, the tables include:

- the median values in the second round of "Magnitude in 2019" and "Magnitude in 2030" for the whole expert panel (Table 13, column "Total");
- arguments for high and low magnitude and industry-specific elements emerging from the content analysis of the experts' comments;
- a conclusive narrative presenting the forecast for 2030.

The results are presented according to the three levels of analysis included in the conceptual framework underpinning our study (Fig. 5).

Table 13. Delphi study descriptive statistics

	Magnitude (Median)														**Level of agreement (IQR)**						**Stability (Spearmann's ρ)**					
	Round 1						**Round 2**								**Round 2**						**Round 2 vs. Round 1**					
	Apparel & Footwear n=21		*Automotive n=24*		*Machinery Equipment n=31*		*Apparel & Footwear n=18*		*Automotive n=21*		*Machinery Equipment n=29*		***Total n=68***		*Apparel & Footwear n=18*		*Automotive n=21*		*Machinery Equipment n=29*		*Apparel & Footwear n=18*		*Automotive n=21*		*Machinery Equipment n=29*	
	2019	2030	2019	2030	2019	2030	2019	2030	2019	2030	2019	2030	**2019**	**2030**	2019	2030	2019	2030	2019	2030	2019	2030	2019	2030	2019	2030
1. Boundaries																										
1A. Suppliers and partners																										
1. AMTs suppliers	3	4	1.5	3	2	4	2	4	1	3	1	4	**2**	**4**	1	1	1	1	1	1	0.946	1.000	0.977	1.000	1.000	1.000
2. Data bought	3	5	2	4	2	5	3	5	2	4	2	5	**2**	**5**	1	0.75	0	1	1	1	0.803	1.000	1.000	1.000	0.955	1.000
3. Rare resources suppliers	3	(3)	2	4	3	(4)	(3)	3	2	4	3	3	**3**	**3**	1.75	1	1	1	1	1	0.980	0.799	1.000	1.000	0.869	0.794
4. Waste management suppliers	2	4	(2)	(3)	(2)	(4)	2	4	2	3	2	4	**2**	**4**	0	1	1	1	1	1	0.958	1.000	1.000	0.797	0.826	0.849
1B. Markets and competitive arenas																										
5. Cross-industry ecosystems	2	(4)	(2)	(4)	2	4	2	4	(2)	(4)	2	4	**2**	**4**	0	1	2	2	1	1	0.581	0.794	0.873	0.912	1.000	0.946
6. 3D printing at home	1	(2)	1	2	1	(2)	1	(2)	1	2	1	2	**1**	**2**	0	2	0	1	0	1	0.791	0.896	1.000	1.000	0.769	0.751
7. Data sold	3	4	2	(4)	2	(4)	3	4	2	3	2	3	**2**	**4**	1	1	1	1	1	1	1.000	1.000	0.931	0.882	0.956	0.873
2. Single activities																										
2A. Business models and new entrants																										
8. Micro-factories	2	(3)	2	(3)	(2)	(3)	2.5	3	1	3	2	(3)	**2**	**3**	1	1	1	1	1	2	0.979	0.876	1.000	0.918	0.863	0.764
9. Digital services	2	(4)	2	(4)	(2)	(4)	2	(4)	2	4	2	(4)	**2**	**4**	1	1.75	0	1	0	2	0.799	0.877	0.823	0.751	0.819	0.943
10. Technology substitutes	(2)	3	2	3.5	2	4	2.5	3	2	4	2	4	**2**	**4**	1	1	1	1	1	1	0.820	0.951	0.949	1.000	1.000	1.000
11. Virtual manufacturing	(3)	(4)	1	(2)	2	4	3	(4)	1	2	2	4	**2**	**3**	0	2	1	1	1	1	0.845	0.886	1.000	0.856	0.965	0.984
12. Digital platforms	2	(4)	(2)	(4)	(2)	(4)	2	(4)	2	4	2	4	**2**	**4**	0.75	2	1	1	1	1	0.893	0.761	0.898	0.851	0.846	0.919
13. Pure-play online	3	5	2	(3)	2	(4)	3	5	2	3	2	4	**2**	**4**	1	1	0	0	1	1	0.952	0.976	0.911	0.781	0.961	0.881
14. Products "as a service"	1	(4)	2	4	2	(4)	1	(3)	2	4	2	4	**2**	**4**	1	2	0	1	1	1	0.777	0.829	1.000	1.000	0.940	0.697
15. Smart cities	1	(2)	1	(3)	1	(3)	1	2	1	3	1	3	**1**	**3**	0	0.75	1	1	1	1	0.483	0.621	1.000	0.815	1.000	0.770
2B. Size																										
16. Raw concentration	3	(4)	(3)	(4)	(3)	(4)	3	3.5	3	4	3	(4)	**3**	**4**	0.75	1	1	1	1	2	0.957	0.794	0.863	0.893	0.932	0.977
17. Intermediate concentration	3	4	2	3	3	3	3	4	2	3	3	3	**3**	**3**	0.75	1	1	1	1	1	1.000	0.983	1.000	1.000	1.000	0.969
18. Final fragmentation	(3)	(3)	(2.5)	(2.5)	3	(4)	3	(3)	(2)	2	3	4	**3**	**3**	1	1.75	2	1	1	1	0.717	0.976	0.976	0.945	0.963	0.942
19. Software/design fragment.	2	(3)	(2.5)	(3)	(3)	3	2	3.5	3	3	3	4	**3**	**3**	1	1	1	1	1	1	0.965	0.927	0.743	0.766	0.945	0.927
20. Data concentration	3	(4)	2.5	(3)	(3)	(4)	(3)	4	2	(3)	3	4	**3**	**4**	1.75	1	1	2	1	1	0.963	0.857	1.000	0.968	0.839	0.836
21. Service fragmentation	3	(3)	2	(3)	3	3	3	(2.5)	2	3	3	3	**3**	**3**	1	1.75	1	1	1	1	0.923	0.887	1.000	0.924	0.988	0.894
22. Intermediaries concentration	3	4	(2.5)	(3)	3	(3)	3	4	2	(3)	3	3	**3**	**3**	1	1	1	2	1	1	1.000	0.961	0.828	0.725	0.999	0.907
2C. Barriers to entry																										
23. Low barriers manufacturing	2	(3)	(2)	(2)	2	(3)	2.5	(3)	(2)	2	2	3	**2**	**3**	1	2	2	1	1	1	0.908	0.924	0.927	0.756	0.952	0.809
24. Low barriers services	3	4	2.5	3	3	(4)	(3)	3.5	3	3	3	4	**3**	**3**	1.5	1	1	1	1	1	1.000	1.000	1.000	1.000	1.000	0.853
25. Low barriers intermediation	(2)	(3)	2	(3)	(2)	3	2	3	2	3	2	3	**2**	**3**	1	1	1	1	0	1	0.947	0.910	1.000	0.787	0.704	0.976
2D. Location																										
26. Production in HCCs	(2)	(2)	(3)	2	(3)	(3)	(2)	(2)	(3)	2	3	(3)	**3**	**2.5**	1.75	1.75	2	1	1	2	0.858	0.911	0.945	0.971	0.848	0.862
27. Redistributed manuf.	2	(3)	1.5	(2)	2	(3)	2	3	1	2	2	3	**2**	**3**	1	1	1	0	0	1	0.509	0.912	0.790	0.824	0.890	0.874
28. No local marketing/sales	(3)	3	(2)	(3)	3	3	3	(3)	(2)	3	3	3	**3**	**3**	1	1.75	2	1	1	1	0.949	1.000	0.962	1.000	0.983	0.926
3. Cross-activity dynamics																										
3A. Governance																										
29. Upstream internalization	2	(3)	3	(3)	3	(3)	2	(3)	3	3	3	(3)	**3**	**3**	0.75	2	1	1	1	2	0.753	0.922	0.894	0.835	0.948	0.762
30. Service internalization	3	(3)	2	(3)	3	(3)	3	(3.5)	2	3	3	3	**3**	**3**	1	1.75	1	1	1	1	0.821	0.898	0.945	0.665	0.896	0.789
31. End-of-life internalization	2	(2)	(2)	(3)	2	(3)	2	2.5	2	(3)	2	(3)	**2**	**3**	1	1	1	2	1	2	0.952	0.786	0.882	0.902	0.953	0.897
32. Disintermediation	3	(4)	(2.5)	(3)	3	3	3	(3)	(3)	(3)	3	3	**3**	**3**	0	1.75	2	2	1	1	1.000	0.907	0.641	0.796	0.979	1.000
33. Customer data internalization	(3)	(3)	(3)	(3)	(3)	(3)	3	(3)	3	(3)	3	3	**3**	**3**	0.75	1.75	1	2	1	1	0.914	0.849	0.929	0.903	0.914	0.894
34. Supplier data internalization	2	(3)	(2)	(4)	2	4	(2)	(4)	2	4	2	4	**2**	**4**	1.75	1.75	1	1	1	1	1.000	0.907	0.914	0.694	0.914	0.803
35. Intermediaries production	1	(2)	1	(2)	(2)	3	1	(2)	1	2	2	2	**1**	**2**	1	1.75	1	1	1	1	0.984	0.918	0.895	0.782	0.791	0.913
36. Intermediaries own offering	(2)	(3)	1.5	(3)	(2)	(3)	2	(3)	2	3	2	(3)	**2**	**3**	1	2	1	1	0	2	0.935	0.935	0.895	0.945	0.827	0.911
37. Digital own offering	2	(4)	(2)	(3)	2	(4)	2	4	2	3	2	(4)	**2**	**4**	0	1	1	1	1	2	0.737	0.921	0.982	0.927	0.913	0.935
38. Captive technology	2	4	(3)	(4)	(3)	(3)	2	4	3	4	(3)	3	**3**	**4**	0	1	1	0	2	1	0.937	1.000	0.734	0.613	0.871	0.897
3B. Margin distribution																										
39. Service marginality	3	4	2	(4)	3	(4)	3	4	2	(4)	3	4	**3**	**4**	0	1	1	2	1	1	1.000	1.000	1.000	0.912	0.970	0.954
40. Data marginality	(3)	4	(2)	3	2	4	(3)	4	(2)	3	2	4	**2**	**4**	1.75	1	2	1	1	1	0.892	1.000	0.802	0.962	0.979	1.000
41. Production marginality	3	(3)	3	(2)	2	(3)	3	(2.5)	2	(2)	2	(3)	**2**	**2**	1	1.75	1	2	1	3	0.946	0.941	1.000	0.966	0.991	0.901
3C. Geographic spread																										
42. Global value chains	4	(5)	4	(4)	(3)	(3)	4	(4.5)	4	4	3	3	**3**	**4**	0.75	1.75	1	1	1	1	0.719	0.964	0.989	0.922	0.927	0.926
43. Regional supply chains	(3)	(3)	(3)	(4)	3	3	(3)	3.5	(3)	4	3	3	**3**	**4**	1.5	1	2	1	1	1	0.963	0.933	0.853	0.767	1.000	0.986

Note: In brackets, results with no consensus among panelists (IQR > 1).

Boundaries

The projections related to the first level of analysis – the redefinition of the boundaries of manufacturing VCs – are presented in Table 14.

In terms of *Suppliers and partners* (*1A*), the Delphi study confirms the increasing relevance of AMTs in future VCs (Projection **#1**). AMTs will be broadly applied for customization purposes (Comment #1b), although with different penetration due to process/product characteristics. Suppliers of data will also grow in importance (**#2**) as data becomes a crucial factor of production in both marketing and supply chain operations (#2a) and regulation clarifies open issues (#2d/e). Rare natural resources (**#3**) are presumed to be a major concern mostly in the Automotive industry because of batteries for electric vehicles (#3e). The relevance of players in waste management services (**#4**) is also expected to grow, although with possible differences across geographies (#4d/e).

As far as *Markets and customers* (*1B*) are concerned, the results indicate strong expectations towards future cross-industry ecosystems (**#5**) driven by the increasing prevalence of smart products (#5a/e) and by companies broadening their offering to extract more value from the same customer group (#5d). As for the mobility ecosystem in specific, the experts have raised doubts concerning consumers' buy-in and industry incumbents' retaliation strategies (#5g/h). New forms of home fabrication (**#6**) are instead anticipated to have marginal relevance besides recreational use or market niches (#6c/d). Finally, the sale of data to third parties appeared as a clear trend (**#7**) although it is presumed that companies will still prefer to internally retain data considered a potential source of competitive advantage (#7f).

Table 14. Boundaries projections - Content analysis and final conclusive narrative

		Level of analysis - **Projection -** Associated arguments
	No.	***1A. Suppliers and partners***
Median magnitude: 2019: 2 → 2030: 4	**1.**	**Players in the additive manufacturing value chain provide machines and materials for manufacturing activities.**
Comments for high magnitude	a.	AMTs will have reached maturity in terms of scope of application, performance and cost accessibility.
	b.	AMTs will be needed to increase flexibility and to support product customization.
	c.	AMTs will be integrated into current manufacturing processes or as Centers of Excellence alongside traditional plants.
Comments for low magnitude	d.	AMTs will not apply to many production processes.
	e.	Traditional production technologies will still be more effective for high volumes, customization will be limited.
	f.	Gaps in AMT-related design capabilities will prevent large scale applications.
	g.	Manufacturers will not shift to AMT due to significant legacy investments in traditional technologies.
Industry comments	H	*Automotive* - Product complexity as well as safety and homologation requirements might hinder broad applications.
Conclusion		*Manufacturing companies will be more dependent on suppliers of AMTs. The relevance of AMTs will be high for customization purposes depending on the characteristics of the product/process.*
Median magnitude: 2019: 2 → 2030: 5	**2.**	**Digital players provide individual-level customer-, product- or process- data needed for activities (e.g., production, service provision, intermediation) within the value chain.**
Comments for high magnitude	a.	Manufacturing companies will need data as a "factor of production" in marketing, sales, and operations.
	b.	Data from external sources will be needed in relation to data-driven services for smart products.
	c.	Internet-based players (e.g., marketplaces, social networks) will sell their data as part of their revenue model.
	d.	Data sale/purchase will be subject to specific regulations that will clarify data-related opportunities.

Comments for low magnitude	e.	Privacy-related regulation will limit sales and purchase of individual-level consumer data.
Industry comments	f.	*Machinery and Equipment* - Players in the industrial sector will be slower to realize the relevance of data.
Conclusion		*Manufacturing companies will be more dependent on external data provided by digital players/marketplaces for targeted offerings and data-driven services. Regulation will play an important role as a driver/barrier.*
Median magnitude: 2019: 3 → 2030: 3	**3.**	**Rare natural resources are needed in manufacturing activities and in the product itself (e.g., rare metals for batteries).**
Comments for high magnitude	a.	New materials will not compensate for the exponentially increasing need for natural resources.
Comments for low magnitude	b.	Natural resources will be replaced by synthetic materials that are reaching maturity for industrial applications.
	c.	Recycling and circular economy practices will reintroduce rare natural resources into the process.
Industry comments	d.	*Apparel and Footwear* - Organic fibers will become a “rare resource” as a consequence of increasing demand due to rising consumer environmental concerns.
	e.	*Automotive* - Rare metals will be increasingly needed for batteries in electric vehicles.
Conclusion		*Overall, the relevance of rare natural resources in manufacturing will be in line with today’s situation. Their scarcity will be offset by circular economy practices and new materials reaching maturity. The increasing prevalence of electric vehicles will raise issues in Automotive.*
Median magnitude: 2019: 2 → 2030: 4	**4.**	**Players in the waste management value chain provide inputs for manufacturing activities (e.g., disassembly and routing of components/materials back into production).**
Comments for high magnitude	a.	Sustainability practices will be driven by increasing public opinion concerns and reputational advantages.
	b.	Environmental regulations and standards will support the spread of recycling and circular economy practices.
	c.	The increasing scarcity of natural resources will result in more recycling of raw materials.
Comments for low magnitude	d.	Sustainability will still not be a major concern in many areas of the world.
	e.	Environmental regulations will evolve very slowly.
	f.	It will be difficult to ensure end-to-end supply chain collaboration as needed in circular economy practices.
Industry comments	g.	*Automotive / Machinery and Equipment* - Tracing and tracking technologies will support the routing of components back into production.
	h.	*Automotive / Machinery and Equipment* - AMTs will support product repair and repurposing.
Conclusion		*Increasing public opinion environmental concerns coupled with stricter regulation will drive recycling and circular economy practices, further supported by tracing and tracking technologies and AMTs. The development will be uneven in different areas of the world.*
		1B. Markets and customers
Median magnitude: 2019: 2 → 2030: 4	**5.**	**End-markets are characterized by broad cross-industry ecosystems where companies from traditionally different industries compete for similar customer needs (e.g., from “automotive” to “mobility solutions”).**
Comments for high magnitude	a.	Smart products and product-as-a-service approaches will blur the boundaries between manufacturing and services.
	b.	The rise of ecosystems will be supported by the development of intellectual property and data-related regulation clarifying roles and responsibilities.
Comments for low magnitude	c.	Regulation (e.g., anti-trust, data-specific regulation) will preserve traditional industry boundaries.
Industry comments	d.	*Apparel and Footwear* - Cross-industry ecosystems will emerge in the high-end segment where brands will develop experience-based value propositions (e.g., major apparel brands offering furniture and investing in hospitality).
	e.	*Apparel and Footwear* - Ecosystems will emerge only in relation to smart products in the sportswear segment.
	f.	*Automotive* - The vast majority of individuals will not accept the idea of sharing rather than owning; mobility solutions will be adopted only by new generations with limited impact on the automotive industry as a whole.
	g.	*Automotive* - Incumbents in the automotive industry will fight back to maintain the status quo.
Conclusion		*End-markets will evolve towards cross-industry ecosystems as a consequence of smart product penetration, availability of data on the same customer group, and companies looking for new revenue pools. Regulation will play an important role as a driver/ barrier.*
Median magnitude: 2019: 1 → 2030: 2	**6.**	**Consumers are producing directly at home products and components thanks to additive manufacturing technologies.**
Comments for high magnitude	a.	Desktop applications of AMTs will be broadly available on the market.
	b.	Individual consumers will use AMTs to produce customized and personalized products.
Comments for low magnitude	c.	Printers for domestic production will have lower applicability/quality performance than industrial applications.
	d.	Consumers prefer to be served, rather than to produce themselves, applications will be limited to recreational use.
Industry comments		-
Conclusion		*End-markets will not be characterized by individual prosumers (i.e., consumers producing products). Home fabrication will show moderate growth only in relation to specific applications.*
Median magnitude: 2019: 2 → 2030: 4	**7.**	**Individual-level customer-, process- and product-data generated within the industry value chain are sold to players in the data management value chain.**
Comments for high magnitude	a.	More opportunities for data monetization will arise because of their increasing relevance for running business operations.
	b.	Data will be purchased/sold through data marketplaces, some of them already emerging today.

	c.	Technologies for storing and processing data (e.g., cloud computing/advanced analytics) will have reached maturity and be available to all players involved in manufacturing VCs.
	d.	Intellectual property and data-related regulations will evolve to support data monetization.
Comments for low magnitude	e.	Regulation and growing privacy concerns will hinder the emergence of data marketplaces.
	f.	Data will be retained at the company level as they are a source of competitive advantage.
Industry comments	g.	*Machinery and Equipment* - Players in the industrial sector will be slower in realizing the relevance of data.
Conclusion		*Manufacturing companies will sell their data to other players as long as these data do not provide a source of competitive advantage. Data marketplaces will emerge. Regulation will play an important role as a driver/barrier. Some industries might be slower to adapt.*

Single activities

Table 15 shows the analysis and the conclusive narratives for the second level of analysis, i.e., single activities along the VC. All the projections concerning *Business models and new entrants* (*2A*) were judged as increasingly relevant. The respondents were moderately positive towards micro-factories serving multiple clients (**#8**), a model that – supported by new production and digital coordination technologies (#8a/e) – could be more effective for flexibility and customization purposes (#8b/h). The same arguments support the prospect of a slight increase in virtual manufacturing approaches (**#11**) – i.e., the full outsourcing of production activities – despite possible limitations for complex products (#11m). Business models based on digital services substituting traditional offerings (**#9**) are foreseen as one of the key features of future manufacturing VCs and seem supported by the spread of smart products, non-ownership approaches, and the digitalization of business services (#9a/b/d/h). A similar substitution effect is envisaged for product innovation and new materials driving the entrance of new players (**#10**).

As regards new intermediaries, despite growing concerns over the control of customer data (#12f/g), the study confirms the trend towards platform-based business models in consumer sales, smart product applications, and business services (**#12**b/c/d). The applicability of cloud manufacturing platforms – i.e., platforms intermediating the access to manufacturing capabilities – has, on the contrary, mostly been questioned across subpanels (#12h/j). Overall, online channels (**#13**) appear to be increasingly relevant within an omnichannel approach determined by industry-specific elements, such as product complexity and the presence of legacy sales networks (#13b/f/g). Whenever feasible, products will increasingly be offered as-a-service (**#14**) following customer expectations and the spread of smart products (#14a/c/d/e/g/i). Smart cities are expected to gain relevance in this context (**#15**), e.g., in the emerging mobility ecosystem (#15c).

In the case of *Size* (*2B*), clear concentration dynamics are envisaged for raw material suppliers (**#16**) and data management (**#20**). In data management, consolidation seems driven by the presence of scale advantages (#20a/b), IoT technology standardization (#20c) and a lack of specific capabilities (#20f). The other projections referring to players' size actually seem subject to contrasting trends. The ongoing consolidation of intermediate goods manufacturers across industries (**#17**) might be counterbalanced by new production technologies supporting small-scale production (#17e). The same applies to final good manufacturing (**#18**): small players could be increasingly involved in customized production as a result of new technologies (#18a, b), but large companies might also prefer production internalization to capture the higher margins of customized products (#18g). New technologies are also bringing about opportunities for small firms in product design and software programming (**#19**), as digital tools simplify the coordination of a large number of suppliers and even single professionals (#19b/d). These opportunities, however, came out as strongly industry-dependent (#19e/f/g). Regarding the concentration levels in service provision (**#21**) and intermediation activities (**#22**), the analysis of the experts' comments highlights the assumption that digital services and online channels might be subject to consolidation trends due to data-related advantages and network effects (#21b, #22a/b). On the other hand, services requiring on-site presence and physical channels might still be managed by small local players (#21d/g).

The results for *Barriers to entry* (*2C*) are consistent with the picture illustrated so far. Barriers to entry are expected to partially decrease in manufacturing (**#23**) whenever production shifts towards small-scale models enabled by flexible equipment (#23a). Digitalization of service provision (**#24**) and intermediation activities (**#25**) could be linked to lower start-up costs (#24a, #25a), but the experts believed relevant data and technological capabilities not to be accessible to new players (#24d/e; #25b/d) and customer lock-in strategies to be amply pursued (#24c, #25c).

Finally, as far as the *Location* of activities is concerned (*2D*), the statistics seem to exclude production reshoring (**#26**), even though the content analysis suggests this might be a relevant trend for specific products and market segments (#26c/h). Along the same lines, the results for point-of-sale/point-of-use production (**#27**) are explained by small-scale production for customization and spare parts (#27c/h). The location of marketing and sales activities (**#28**) appears unaffected.

Table 15. Single activities projections - Content analysis and final conclusive narrative

		***Level of analysis* - Projection -** Associated arguments
	No.	***2A. Business models and new entrants***
Median magnitude: ***2019: 2 → 2030: 3***	**8.**	**Small-scale workshops (e.g., fab labs, small factories) produce physical products (final or intermediate goods) for a variety of customers.**
Comments for high magnitude	a.	Small-scale production will be possible thanks to the application of AMTs and advanced robotics.
	b.	Production will be externalized to small suppliers to increase flexibility and product customization/personalization.
	c.	Large manufacturers will engage micro-factories through cloud manufacturing platforms; these platforms will ensure visibility, price transparency, standard contracting.
	d.	Small-scale local production will emerge due to protectionism and to limit the environmental footprint of operations.
	e.	Digital coordination technologies will enable the coordination of a large number of small suppliers.
Comments for low magnitude	f.	Small workshops will not meet the quality standards needed to enter structured supply chains.
	g.	The minimum efficient scale of production technologies will be high representing a barrier to entry for small players.
	h.	Customized products will represent a market niche: there will be no need for large companies to massively involve local/small-scale suppliers.
	i.	Thanks to customization technologies (e.g., AMTs, advanced robotics) available on the market, large companies will internalize late-stage production to capture higher margins.
	j.	Large companies have several biases in including small players in their supply chain.
Industry comments	k.	*Apparel and Footwear* - Demand will become even more unpredictable due to online sales and new forms of small-scale local production will be needed.
	l.	*Apparel and Footwear* - The industry is increasingly characterized by large full-package suppliers, only market niches will be available to small players.
	m.	*Automotive* - Small specialized suppliers will not be needed: with cars being shared rather than owned, there will be no need to customize physical products.
	n.	*Automotive* - The increasing complexity of electric vehicles will represent a high barrier to entry for small suppliers.
	o.	*Automotive / Machinery and Equipment* - Products and processes will become simpler due to modularization and platform thinking.
Conclusion		*Small-scale suppliers supported by new production technologies will be increasingly involved for customization purposes, whenever production internalization will not be possible/convenient.*
Median magnitude: ***2019: 2 → 2030: 4***	**9.**	**Digital players offer (e.g., via software applications) services meeting demand previously addressed by traditional manufacturing and service companies.**
Comments for high magnitude	a.	Smart products will create new space for digital services.
	b.	Digital players will enter whenever product ownership is substituted by product-as-a-service approaches.
	c.	The ownership of customer data will enable digital players to develop targeted software applications substituting traditional services.
	d.	Business services (e.g., accounting, legal, design) will be provided over the Internet as digital services.
Comments for low magnitude		-
Industry comments	e.	*Apparel and Footwear* - Smart products and digital services will have a limited application, e.g., in sportswear.
	f.	*Automotive* - Digital services and software applications will be the main source of profit in the new mobility ecosystem.
	g.	*Automotive* - Mobility services will be appealing only to new generations.
	h.	*Automotive / Machinery and Equipment* - Digital services will augment physical services (e.g., preventive maintenance).
Conclusion		*Digital services will be developed for smart products and product-as-a-service business models. Business services will go digital.*
Median magnitude: ***2019: 2 → 2030: 4***	**10.**	**Substitutes (materials, products, services) leveraging emerging technologies are manufactured/provided by players traditionally not belonging to the industry value chain (e.g., in the past: MP3 and streaming services developing outside the traditional record music value chain).**
Comments for high magnitude	a.	New materials will be developed by new technological players.
Comments for low magnitude	b.	IoT technological innovation is happening now; by 2030 the pace of disruption will have slowed down.
Industry comments	c.	*Automotive* - Electric and autonomous vehicles will bring in new players challenging current industry incumbents.
	d.	*Machinery and Equipment* - As AMTs broaden possible applications, machinery producers will face new competitors.
Conclusion		*Product innovation is triggering the entrance of new players already today. Expectations for 2030 mainly refer to new materials.*
Median magnitude: ***2019: 2 → 2030: 3***	**11.**	**Companies manufacture physical products without owning any production facility (in a virtual manufacturing setting).**
Comments for high magnitude	a.	Outsourcing will increase as manufacturing capabilities will be accessed through cloud manufacturing platforms.
	b.	New technologies for data and system integration will simplify suppliers' coordination.
	c.	Outsourcing to specialized players will support mass customization and flexibility.
	d.	Most companies will outsource production due to declining marginalities.
Comments for low magnitude	e.	Outsourcing to specialists will be limited as product customization will be relevant only in specific market segments.
	f.	Automation technologies will support a cost-effective re-internalization of production.

Industry comments	g.	*Apparel and Footwear* - The industry is increasingly characterized by complete outsourcing to full-package suppliers.
	h.	*Apparel and Footwear* - In order to increase flexibility, production will be outsourced on a local basis to players implementing automation technologies (e.g., sewbots, laser grinders).
	i.	*Apparel and Footwear* - Production will be further outsourced to decrease costs.
	j.	*Apparel and Footwear* - Production will be internalized for specific product categories displaying higher marginalities.
	k.	*Apparel and Footwear* - Production will be internalized and brought back to the home country to limit the incidence of tariffs and the environmental footprint of operations.
	l.	*Automotive* - Outsourcing opportunities are increasing as big electronic contractors are entering the automotive industry.
	m.	*Automotive* - The industry is currently characterized by an increasing internalization of production due to higher product complexity and safety requirements.
	n.	*Automotive / Machinery and Equipment* - Full outsourcing will be prevented by intellectual property concerns.
Conclusion		*New technologies will simplify outsourcing and access to manufacturing capabilities through Internet-based platforms. Virtual manufacturing will however not be possible for complex products and not pursued for high-margin productions (e.g., personalized goods).*
Median magnitude: 2019: 2 → 2030: 4	**12.**	**Intermediaries adopting a platform business model match demand and supply of products, components, and services along the value chain.**
Comments for high magnitude	a.	New technologies (e.g., retail technologies, payments) will simplify online purchases.
	b.	Services and applications for smart products will be sold through Internet-based platforms.
	c.	Platforms will spread across industries; consumers will prefer them to firm-specific channels.
	d.	Business support services (e.g., accounting, legal, free-lance professionals…) will be accessed through platforms.
	e.	Production capacity related to AMTs and advanced robotics will be accessible through cloud manufacturing platforms.
Comments for low magnitude	f.	Manufacturing companies will internalize sales because of the need to control data and establish a direct customer relationship.
Industry comments	g.	*Apparel and Footwear* - Brands will pursue a direct sales strategy, platforms will be mainly concession-based.
	h.	*Apparel and Footwear* - There will be no need for cloud manufacturing platforms as supply is normally managed by vertically integrated full-package suppliers.
	i.	*Automotive* - Platforms operated by major car manufacturers will develop in relation to the mobility ecosystem.
	j.	*Automotive / Machinery and Equipment* - The spread of cloud manufacturing platforms will be limited as companies are not willing to share production data and intellectual property, especially for complex products.
Conclusion		*Digital platforms will become pervasive for consumer sales of products and services. In business to business settings, platforms will spread in business support services. Several barriers will prevent the emergence of cloud manufacturing platforms along the supply chain.*
Median magnitude: 2019: 2 → 2030: 4	**13.**	**Pure-play digital players perform intermediation activities previously offered by traditional "brick-and-mortar" companies (i.e., with physical shops or distribution networks).**
Comments for high magnitude	a.	Online purchases will become even simpler due to augmented reality, digital fitting, and payment technologies.
	b.	Digital channels will form part of an omnichannel (physical and digital) distribution strategy.
Comments for low magnitude		-
Industry comments	c.	*Apparel and Footwear* - Digital channels will increase as logistics and product delivery become more effective.
	d.	*Automotive* - The mobility ecosystem will be characterized by interactions on digital platforms.
	e.	*Automotive* - New players in the electric vehicle segment mostly sell through digital channels.
	f.	*Automotive* - The proven effectiveness of local dealer networks will prevent a full shift towards digital channels.
	g.	*Machinery and Equipment* - Specialist salespersons are needed for complex tailor-made machinery.
Conclusion		*Digital sales will increase within an overall omnichannel sales strategy. The presence of legacy sales networks might slow down the trend. Complex industrial products will need specialized salespersons.*
Median magnitude: 2019: 2 → 2030: 4	**14.**	**Customers are offered product usage, instead of product ownership, leveraging on time-based or performance-based payment schemes.**
Comments for high magnitude	a.	Smart products will enable product-as-a-service approaches.
	b.	Shorter product lifecycle (e.g., pace of innovation, number of collections) will make ownership less appealing.
Comments for low magnitude	c.	Cultural barriers in both the consumer and the business sectors will not be overcome.
Industry comments	d.	*Apparel and Footwear* - New generations have a reduced need for ownership and stronger environmental concerns.
	e.	*Apparel and Footwear* - Renting and subscription-based models are spreading (e.g., high-end/children segments).
	f.	*Apparel and Footwear* - Many apparel and footwear items are too personal to share.
	g.	*Automotive* - Car leasing is already a common practice.
	h.	*Automotive* - Product-as-a-service will be at the core of the mobility ecosystem.
	i.	*Machinery and Equipment* - Customers are demanding pay-per-use schemes and lifecycle management.
	j.	*Machinery and Equipment* - Payment schemes are difficult to calculate for customized products.
Conclusion		*Demand will evolve towards servitization in both the business and consumer sectors, more decisively for new generations. Products too personal to share will not be subject to this trend.*
Median magnitude: 2019: 1 → 2030: 3	**15.**	**Public administrations at the local/city level match demand and supply of products and services within a smart city context.**
Comments for high magnitude	a.	Metropolitan areas are developing smart city solutions very fast, especially in developing countries.

Comments for low magnitude	b.	Bureaucracy and political constraints will not be overcome.
Industry comments	c.	*Automotive* - Smart cities and public/private partnerships will play a key role in the mobility ecosystem.
Conclusion		*Smart cities and public/private partnerships will gain relevance in emerging market ecosystems (e.g., mobility solutions). Smart cities will develop faster in developing countries.*
		2B. Size
Median magnitude: 2019: 3 → 2030: 4	**16.**	**Activities related to sourcing of raw materials are concentrated with a limited number of global suppliers.**
Comments for high magnitude	a.	Raw material suppliers are experiencing a consolidation trend across many industries.
	b.	The scarcity of natural resources will trigger further consolidation of players.
Comments for low magnitude	c.	New materials and materials for AMTs will bring in new players.
	d.	Antitrust regulations will prevent further consolidation.
	e.	Online platforms will provide sales channels for small suppliers to serve specific segments.
Industry comments		-
Conclusion		*The trend towards an increasing consolidation of raw material suppliers will continue across industries, just partially mitigated by regulation and the entry of players providing new materials.*
Median magnitude: 2019: 3 → 2030: 3	**17.**	**Activities related to the manufacturing of intermediate goods are concentrated with a limited number of global suppliers.**
Comments for high magnitude	a.	There is an ongoing trend towards higher concentration in intermediate goods.
	b.	Only large suppliers can offer a high service level as needed to operate across different geographies.
	c.	Low margins in production will drive a higher concentration of players.
Comments for low magnitude	d.	Authorities will prevent the emergence of large conglomerates.
	e.	AMTs and advanced robotics have lower returns to scale and enable small players to be competitive.
Industry comments	f.	*Apparel and Footwear* - Production is increasingly outsourced to large vertically integrated full-package suppliers.
	g.	*Automotive* - Risk-sharing agreements for product innovation are causing a rationalization of the supplier base resulting in higher concentration levels.
	h.	*Machinery and Equipment* - AMTs will cut down the need for components, only large companies pursuing cost-efficiency will be able to operate in an increasingly shrinking market.
Conclusion		*The concentration levels of players in intermediate goods will be subject to industry-specific dynamics related to the applicability of AMTs and current supply chain practices.*
Median magnitude: 2019: 3 → 2030: 3	**18.**	**Activities related to the manufacturing of final products are fragmented with the participation of a large number of small and medium enterprises.**
Comments for high magnitude	a.	Large manufacturers will coordinate small suppliers for improving flexibility to the point of mass customization.
	b.	Lower returns to scale of AMTs and advanced robotics will enable small players to be competitive.
Comments for low magnitude	c.	As the demand for customized products will be limited, there will be no need for specialized suppliers.
	d.	A further decline in production margins will support even higher concentration levels to pursue cost-synergies.
	e.	Large factories will still have significant scale and quality advantages.
	f.	Control over consumer data will represent a new barrier to entry for small companies.
	g.	Late-stage customization will be internalized by large manufacturing companies to retain higher margins.
Industry comments	h.	*Apparel and Footwear* - Only full-package suppliers can guarantee the high service levels needed by global brands.
	i.	*Automotive* - Components might be produced by small and medium-size enterprises, final product assembly will remain a core competence of car manufacturers.
	j.	*Automotive* - In the future cars will be shared: there will be no demand for product customization and thus no need to involve small suppliers for customization purposes.
	k.	*Machinery and Equipment* - Capabilities related to final product manufacturing will be available only to large companies.
Conclusion		*Large, structured companies will leverage small suppliers for personalization and customization only in specific industries/segments.*
Median magnitude: 2019: 3 → 2030: 3	**19.**	**Activities related to design (product and software) are fragmented with the participation of a large number of small and medium enterprises and micro-companies.**
Comments for high magnitude	a.	Product design and software programming have limited scale advantage.
	b.	Digital coordination and platforms will simplify access to remote talent, including single professionals.
	c.	Smart products supported by open platforms will guarantee to software developers the access to the data needed to develop new digital solutions.
Comments for low magnitude		-
Industry comments	d.	*Apparel and Footwear* - Brands will increasingly involve consumers in co-creation practices.
	e.	*Apparel and Footwear* - Design activities are increasingly internalized as a core competence of large brands.
	f.	*Automotive* - Due to cybersecurity issues related to onboard technologies there will be a strong selection of suppliers.
	g.	*Automotive* - Co-design practices between car and components manufacturers will limit the space for small players.
Conclusion		*Technology will support smoother coordination with supplier, but further involvement of SMEs and micro-companies might be hindered by other factors.*

Median magnitude: *2019: 3 → 2030: 4*	**20.**	**Activities related to data management are concentrated with a limited number of global players.**
Comments for high magnitude	a.	Concentration dynamics will be driven by data-related economies of scale.
	b.	In the presence of network effects, providers of cloud computing and web services are typically large horizontally integrated conglomerates.
	c.	A strong reduction in the number of players will result from future IoT standardization.
	d.	Data management will show declining marginalities that will support higher concentration levels.
	e.	Innovation pressures in data management will be better managed by large companies.
	f.	Only large manufacturing companies, service providers and intermediaries will have the capabilities to directly manage the data related to their supply chain.
Comments for low magnitude	g.	Data will be retained at the company level as a source of competitive advantage.
	h.	Data marketplaces and digital players are under the spotlight of the Antitrust.
	i.	Data management will be characterized by specialized solutions creating opportunities also for small companies
Industry comments		-
Conclusion		*Data management services will be offered by a limited number of large companies, alongside some specialized players for market niches. Large companies will develop data management capabilities, particularly for the data that represent a source of competitive advantage.*
Median magnitude: *2019: 3 → 2030: 3*	**21.**	**Activities related to the provision of services (including services via software applications) are fragmented with the participation of a large number of small and medium enterprises and micro-companies.**
Comments for high magnitude	a.	Small companies will enter in digital services for smart products and mobile applications.
Comments for low	b.	Data for digital services will not be accessible to small players but controlled by large manufacturers and platforms.
Industry comments	c.	*Automotive* - Manufacturers and platforms will outsource maintenance and on-site services to small local players.
Conclusion		*Large manufacturing companies and digital platforms owning the data will be governing the service space. Specific digital services might be developed by smaller companies. Small players will be engaged by manufacturers/platforms for services requiring local presence.*
Median magnitude: *2019: 3 → 2030: 3*	**22.**	**Intermediation activities (e.g., sales and distribution, platforms) are concentrated with a limited number of global players.**
Comments for high magnitude	a.	As sales move online, data ownership and marketing investments will provide a competitive edge to large brands and platforms.
	b.	Digital platforms will increasingly consolidate due to network effects and customer lock-in.
Comments for low magnitude	c.	Sales will still stay local as cultural barriers in both the consumer and the business sectors will not be overcome.
	d.	New players can easily enter as digital platforms require low set-up cost/time.
Industry comments	e.	*Automotive* - Digital sales channels and services will be managed at the central level by car manufacturers.
	f.	*Automotive* - Few global platforms will dominate the mobility ecosystem.
	g.	*Automotive* - Local physical showrooms owned by independent dealers proved to be the most effective model.
	h.	*Machinery and Equipment* - Sales and distribution require significant investments in infrastructure.
Conclusion		*Online sales channels will be more concentrated as low set-up costs are offset by data-related advantage, network effects, and customer lock-in. The overall effect will be however limited due to cultural barriers.*
		2C. Barriers to entry
Median magnitude: *2019: 2 → 2030: 3*	**23.**	**New players can easily enter manufacturing activities as barriers to entry are low (e.g., due to asset-light business models, limited need for personnel, declining cost of technology...).**
Comments for high magnitude	a.	Cost and time to enter manufacturing will decrease due to lower costs/higher flexibility of production technologies, including AMTs and advanced robotics.
	b.	New production models (small-scale/localized) are needed to improve flexibility and enable customization; these new models will enable non-manufacturing players (i.e., retailers, logistics providers) to enter manufacturing industries.
Comments for low magnitude	c.	Barriers to entry will be related to the customer/supplier trusted relationships.
	d.	Barriers to entry will be related to the control of customer and supply chain data.
Industry comments	e.	*Automotive* - Product innovation (e.g., electric vehicles, autonomous vehicles) is bringing in new players.
	f.	*Automotive* - New players will enter the luxury segment due to small lots/highly customized production.
	g.	*Automotive* - As electric vehicles reach maturity, the presence of a dominant design will pose limitations to new entrants.
	h.	*Automotive / Machinery and Equipment* - Production technologies and increasingly complex products will require considerable investments/capabilities.
Conclusion		*Barriers to entry in manufacturing will only partially decrease due to AMTs and other flexible technologies. Barriers to entry will be related to data accessibility, customer relationships, product innovation, and technological capabilities.*
Median magnitude: *2019: 3 → 2030: 3*	**24.**	**New players can easily enter service provision activities as barriers to entry are low (e.g., due to asset-light business models, limited need for personnel, declining cost of technology...).**
Comments for high magnitude	a.	Digital data-driven services based on common software technologies will require low start-up cost and time.
	b.	Barriers to entry will decrease because of the declining cost of technology and the spread of smart products.
Comments for low magnitude	c.	Large companies will offer comprehensive service solutions and lock-in their customer base.
	d.	Investments in software technologies will still be significant and prevent the entrance of new players.

	e.	Data will not be accessible to small players but controlled by smart product manufacturers and digital platforms.
Industry comments	f.	*Machinery and Equipment* - Product maintenance requires significant technological capabilities, even more in the future due to more complex product technologies.
Conclusion		*Barriers to entry in services are not expected to decrease. Barriers to entry for digital services will be related to data accessibility, software investments, and customer relationship.*
Median magnitude: 2019: 2 → 2030: 3	**25.**	**New players can easily enter intermediation activities (e.g., sales, distribution, platforms) as barriers to entry are low (e.g., asset-light business models, limited need for personnel, declining cost of technology...).**
Comments for high magnitude	a.	Digital channels have lower start-up costs than physical ones due to limited investments in infrastructures.
Comments for low magnitude	b.	Data will represent the new barrier to entry and will be controlled by platforms and industry incumbents.
	c.	Digital platforms will shape their offering and customer experience to retain their customer base.
	d.	Omnichannel requires critical mass/investments in both physical and digital channels to be effective.
Industry comments	e.	*Apparel and Footwear* - Only large companies can guarantee the high service levels demanded in the consumer market.
	f.	*Machinery and Equipment* - As products are increasingly complex and customized, intermediaries need to have significant technological capabilities that are hardly available on the market.
Conclusion		*Barriers to entry in intermediation will partially decrease due to asset-light business models. Barriers to entry will be related to data accessibility, customer relationship, and technological capabilities.*
		2D. Location
Median magnitude: 2019: 3 → 2030: 2.5	**26.**	**Production and related operations of manufacturing companies are located in Western Europe, the United States, and Japan.**
Comments for high magnitude	a.	Lower labor intensity brought about by AMTs and advanced automation will enable reshoring.
	b.	Production will be reshored due to protectionism and political instability of emerging economies.
	c.	Production will be performed in proximity to the end markets to increase flexibility, speed, and responsiveness.
	d.	Capabilities for Industry 4.0 will be mostly available in Western countries.
Comments for low magnitude	e.	Production will be located in emerging economies as they are becoming relevant destination markets.
	f.	Mature economies have low workforce availability and high salaries.
Industry comments	g.	*Apparel and Footwear* - Production will still be very labor-intensive and located in countries with lower labor cost.
	h.	*Apparel and Footwear / Automotive* - Production will be reshored just for specific segments (customization/high-end).
Conclusion		*Production will be organized on a more local basis (not limited to developed countries) for flexibility and customization purposes. Protectionism, political stability, and workforce capabilities will play a major role in location decisions.*
Median magnitude: 2019: 2 → 2030: 3.	**27.**	**Production is performed in small-scale factories/workshops operating closer to products' point-of-sale/point-of-use.**
Comments for high magnitude	a.	AMTs and advanced robotics will enable low-scale production (e.g., in-store, logistic centers, “plants on wheels”).
	b.	Local production will be more effective in addressing increasing environmental concerns.
	c.	Increasing product customization and demand unpredictability require new forms of production.
Comments for low magnitude	d.	Logistics will become more efficient; the location of plants will not play a major role in meeting manufacturers' operational and environmental objectives.
Industry comments	e.	*Apparel and Footwear* - The vast majority of products are not suitable for automation.
	f.	*Automotive* - The industry is subject to internalization trends.
	g.	*Automotive* - New forms of production will not be feasible due to product safety requirements and technological complexity.
	h.	*Automotive / Machinery and Equipment* - Local production will be limited to customized components and spare parts, it will not be possible for complex products or heavy industrial equipment.
Conclusion		*New forms of local production will emerge in connection with new production technologies. Their spread will be limited to relatively simple products subject to customization/personalization and spare parts.*
Median magnitude: 2019: 3 → 2030: 3	**28.**	**Customer interactions (e.g., marketing and sales) are managed centrally with limited resource commitment in local affiliates.**
Comments for high magnitude	a.	Online channels, data analytics (e.g., from social networks, channels, smart products) and investments will be managed centrally.
Comments for low magnitude	b.	Local presence will still be needed to intercept market needs.
Industry comments	c.	*Automotive* - The effectiveness of local dealer networks will prevent a full shift towards online channels.
	d.	*Machinery and Equipment* - Specialist salespersons and face-to-face interactions are needed to discuss technical specifications.
Conclusion		*Customer data, investments and online channels will be managed centrally, but a local presence in marketing and sales will still be relevant.*

Cross-activity

The analysis referring to the third level of the conceptual framework – i.e., cross-activity dynamics linking together single activities along the VC – is included in Table 16.

Overall, the results concerning *Governance* (*3A*) show some clear trajectories. Considering specifically the configuration of manufacturing companies, the analysis prognosticates a growth of in-house capabilities for supply chain data management (**#34**) and a moderate internalization of end-of-life product management activities (**#31**). With respect to non-manufacturing players integrating within the manufacturing space, it seemed likely that intermediaries, logistics operators and service providers will internalize production activities (**#35**), as small-scale production models become feasible for customization and spare parts (#35a/b/g). Intermediaries and digital players are also projected to develop their product and service offerings (**#36**, **#37**) leveraging on the access to data and the spread of smart products (#36a, #37b/c). Finally, the results indicate that proprietary technologies might be increasingly relevant in the future (**#38**), although this trend should be seen against a progressive standardization and market availability of IoT and production technologies (#38c/e).

Other vertical integration decisions of manufacturing companies seem subject to contrasting dynamics. Internalization of production activities (**#29**) could be supported by the increased flexibility of production technologies and by the attractive marginalities of customized products (#29a/b/c); however, digital technologies and cloud manufacturing platforms could simplify outsourcing (#29e/f/g) and product innovation drive vertical specialization (#29l). The internalization of service provision (**#30**) emerged as potentially attractive (#30b/c) notwithstanding the lack of specific skills and capabilities (#30d.). The disintermediation of sales channels (**#32**) is similarly envisaged as an opportunity for manufacturing companies (#32a/b) against the increasing prevalence of digital platforms (#32c). By the same token, the approach to customer data management (**#33**) is also better understood within the broader context of cross-industry synergies and data-specific scale advantages (#33c/d).

In terms of *Rent distribution* (*3B*), a further increase in service margins (**#39**) seems to be confirmed despite the price transparency provided by digital platforms (#39b). The profitability of data management activities (**#40**) will most likely depend on the concentration of cloud vendors and data marketplaces (#40c); however, control over data is believed to fundamentally affect the overall performance of manufacturing companies (#40b). In production (**#41**), the answers point to even lower margins (#41b/c) except for late-stage customization requiring expertise not easily available on the market (#41a/e).

To conclude, as far as the *Geographic spread* (*3C*) is concerned, manufacturing VCs are still expected to develop at global level (**#42**) although with an increasing regionalization of supply chains (**#43**) due to protectionism and in order to pursue higher flexibility (#42a/b/c; #43a/c/e).

Table 16. Cross-activity projections - Content analysis and final conclusive narrative

		Level of analysis **- Projection -** Associated arguments
	No.	***3A. Governance***
Median magnitude: 2019: 3 → 2030: 3	**29.**	**Manufacturing companies have internalized production activities from intermediate goods to final product assembly.**
Comments for high magnitude	a.	Production will be internalized to pursue higher control needed for flexibility and customization.
	b.	Internalization will be supported by AMTs (lower minimum efficient scale, products manufactured as single piece)
	c.	Customization will generate high margins and will be internalized by manufacturing companies.
	d.	Reshoring and new forms of local manufacturing are generally coupled with a greater internalization of production.
Comments for low magnitude	e.	Cloud manufacturing platforms will simplify access to outsourced manufacturing capabilities.
	f.	Manufacturing companies are not interested in internalizing production as it is the lowest value-added activity.
	g.	Data sharing, process integration, and digital coordination technologies will simplify outsourcing.
Industry comments	h.	*Apparel and Footwear* - Production will be internalized for the product categories displaying the highest marginalities.
	i.	*Apparel and Footwear* - The industry is increasingly characterized by full-package suppliers.
	j.	*Apparel and Footwear* - Production will still be very labor-intensive and outsourced to countries with lower labor costs.
	k.	*Automotive / Machinery and Equipment* - The cost of production technologies and increasing calls for product innovation will drive vertical specialization.
	l.	*Automotive / Machinery and Equipment* - Product simplification and modularization will simplify outsourcing.
Conclusion		*The drivers of production internalization (e.g., higher margins in customized production, need for control, new production technologies) are counterbalanced by equally important drivers to outsourcing (e.g., digital coordination and cloud manufacturing platforms, declining margins in production). The configuration will be segment specific.*
Median magnitude: 2019: 3 → 2030: 3	**30.**	**Manufacturing companies have internalized service provision activities in relation to their products.**
Comments for high magnitude	a.	Manufacturing companies will internalize data-driven digital services for smart products.
	b.	Services will represent the main source of revenues in emerging market ecosystems.
	c.	Services that contribute creating a distinctive customer experience will be internalized.
Comments for low magnitude	d.	Manufacturing companies lack specific skills and capabilities to compete in the service market.
Industry comments	e.	*Apparel and Footwear* - Services are not a core competence of apparel companies.
	f.	*Machinery and Equipment* - Core services have already been internalized.
Conclusion		*Manufacturing companies will internalize only digital data-driven services for smart products and those contributing to distinctive customer experiences. Traditional services requiring specialized capabilities will not be internalized.*
Median magnitude: 2019: 2 → 2030: 3	**31.**	**Manufacturing companies have internalized end-of-life product management, including remanufacturing, refurbishment and recycling.**
Comments for high magnitude	a.	Companies will be more proactive in recycling practices for reputational reasons.
Comments for low magnitude	b.	Manufacturing companies lack end-of-life product management capabilities.
	c.	Specialist players are emerging in recycling and remanufacturing activities.
Industry comments	d.	*Apparel and Footwear* - Major brands will operate direct collection networks, recycling will be outsourced.
	e.	*Automotive* - Recycling will be a major issue in relation to batteries for electric vehicles.
	f.	*Automotive* - Manufacturers will play a role in coordinating end-of-life product management, but not internalize recycling.
	g.	*Machinery and Equipment* - Players in the AMT sector are creating new markets for obsolescence/end-of-life programs.
	h.	*Machinery and Equipment* - Manufacturers will internalize end-of-life activities to access new revenue streams.
Conclusion		*Manufacturing companies will internalize only specific end-of-life product management activities in relation to revenue/reputational opportunities.*
Median magnitude: 2019: 3 → 2030: 3	**32.**	**Manufacturing companies have internalized intermediation activities (e.g., sales, distribution, platforms) related to their products and services.**
Comments for high magnitude	a.	Intermediation activities will be internalized because of their high margins.
	b.	Direct customer relationship and access to consumer data will be a source of competitive advantage.
Comments for low magnitude	c.	Sales internalization will be limited by the increasing prevalence of one-stop-shop platforms offering a frictionless customer experience.
Industry comments	d.	*Apparel and Footwear* - Sales internalization is needed to have control of omnichannel consumer experience.

	e.	*Apparel and Footwear* - New forms of Internet platforms (concession-based) will provide digital marketplaces while enabling brands to have more control of retail data.
	f.	*Automotive* - Car manufacturers will operate platforms and "shop service centers" in relation to the mobility ecosystem.
	g.	*Automotive* - Local dealer networks proved to be effective and there is no interest in sales internalization.
	h.	*Machinery and Equipment* - Customer relationship is a core competence of manufacturers of complex products.
Conclusion		*Control of sales channels will be a source of competitive advantage in relation to data, customer relationship, and digital services. The internalization of sales channels will be prevented by the increasing prevalence of one-stop-shop Internet-based platforms and local dealer networks.*
Median magnitude: *2019: 3 → 2030: 3*	**33.**	**Manufacturing companies have internalized data management activities in relation to their products, services, and customers.**
Comments for high magnitude	a.	Data management capabilities are needed to compete in a data-intensive economy (e.g., data for targeted offerings).
	b.	The increasing spread of smart products will require manufacturing companies to manage related data.
Comments for low magnitude	c.	Skills and capabilities for data management are scarce on the market and not available for manufacturing companies.
	d.	Cross-industry synergies and data-specific scale advantages will drive the emergence of large data specialists.
Industry comments	e.	*Apparel and Footwear* - Data management will be internalized for product launches and production planning.
	f.	*Automotive / Machinery and Equipment* - Manufacturers are already building data management capabilities.
Conclusion		*Manufacturing companies able to attract the right skills and capabilities will internalize only the management of data providing a source of competitive advantage.*
Median magnitude: *2019: 2 → 2030: 4*	**34.**	**Manufacturing companies have internalized data management activities in relation to their supplier base with direct access and control over suppliers' data (e.g., real-time production capacity, machine status).**
Comments for high magnitude	a.	Supply chains will be characterized by end-to-end data and system integration to increase flexibility, responsiveness, and enable mass customization.
	b.	Supply chain coordination will become simpler as technologies for sharing and analyzing data will be broadly available on the market.
Comments for low magnitude	c.	Skills and capabilities for data management will be available only to large companies.
Industry comments	d.	*Apparel and Footwear* - As production is performed by full-package suppliers, Apparel and Footwear companies will not integrate suppliers' data.
	e.	*Apparel and Footwear* - The typical suppliers have an overall low adoption of information systems.
	f.	*Automotive* - Supply chain data integration is already a common practice.
Conclusion		*Manufacturing supply chains will be increasingly characterized by end-to-end data integration managed by focal companies. Industries characterized by low technological intensity might be slower to adapt.*
Median magnitude: *2019: 1 → 2030: 2*	**35.**	**Intermediaries (distributors, retailers, platforms), logistics operators and after-sales service providers (e.g., maintenance network) produce final products or components.**
Comments for high magnitude	a.	Small-scale/local/mobile production will be enabled by the flexibility of AMTs and advanced robotics.
	b.	Intermediaries will be engaged in late-stage customization.
Comments for low magnitude	c.	Non-manufacturing players will be involved only in case of product personalization (e.g., product accessories) and, for the most part, production will be standardized and performed in structured industrial environments.
Industry comments	e.	*Apparel and Footwear* - Production will still be very labor-intensive with limited applicability of new technologies.
	f.	*Apparel and Footwear* - Only large retailers might have the infrastructure/capabilities to manage production activities.
	g.	*Automotive / Machinery and Equipment* - Non-manufacturing players will be engaged only in spare parts.
	h.	*Automotive* - Homologation requirements and product safety will be a major barrier to new production models.
Conclusion		*New point-of-sale production models will develop with applications limited to product personalization and spare parts.*
Median magnitude: *2019: 2 → 2030: 3*	**36.**	**Intermediaries (distributors, retailers, platforms) develop their own offering of products and services.**
Comments for high magnitude	a.	Internet-based intermediaries will leverage their control over customer data to promote their product/service offering.
	b.	Intermediaries will externalize the production of physical products to manufacturing suppliers.
Comments for low magnitude	c.	Intermediaries lack manufacturing skills and capabilities.
	d.	Manufacturing industries have limited attractiveness for digital platforms that will consolidate within the service space.
Industry comments	e.	*Apparel and Footwear* - Intermediaries will develop mass-market best-sellers, not designer items.
	f.	*Apparel and Footwear* - Consumers will still value the brand name in purchasing decisions.
	g.	*Automotive* - Already today Uber is investing in product/service innovation.
	h.	*Automotive / Machinery and Equipment* - Intermediaries will not have access to relevant Intellectual Property.
Conclusion		*Access to consumer data will enable intermediaries to develop their own offering (products and services). Production will be outsourced. Intellectual property and brand equity will represent a barrier in several industries.*
Median magnitude: *2019: 2 → 2030: 4*	**37.**	**Major digital players (e.g., Google, Amazon, Apple) develop their own offering of products and services.**
Comments for high magnitude	a.	Digital players have capital to invest in cross-industry growth opportunities.
	b.	Smart products and control over data will be the entry point for digital players to disrupt manufacturing industries.
	c.	Digital players will develop data-driven services connected to retail and payment technologies.
Comments for low magnitude	d.	Manufacturing industries have a limited attractiveness for digital players that will rather consolidate within the service space.
Industry comments	e.	*Apparel and Footwear* - Amazon develops its own offering of best-selling items to capture higher margins, actual production is however outsourced to third parties.

	f.	*Automotive* - Digital players will leverage on their know-how in digital technologies for autonomous vehicles, there are relevant examples already today (e.g., Google).
	g.	*Automotive* - The competitive advantage of digital players will shrink as manufacturers will build internal datasets from connected cars.
Conclusion		*Digital players will pursue new growth opportunities with own product and service offering as a consequence of increasing prevalence of digital channels, smart products and due to digital product innovation.*
Median magnitude: ***2019: 3 → 2030: 4***	**38.**	**Large companies develop in-house proprietary technology (e.g., algorithms, robotics, blockchain...).**
Comments for high magnitude		-
Comments for low magnitude	a.	Manufacturing companies lack the skills and capabilities for developing proprietary technologies.
Industry comments	b.	*Apparel and Footwear* - Proprietary technologies for product customization and retail technologies will represent a source of competitive advantage.
	c.	*Apparel and Footwear* - Customization technologies (e.g., AMTs, sewbots) will be available on the market.
	d.	*Automotive* - Product innovation is one of the major sources of competitive advantage.
	e.	*Automotive* - Already today car manufacturers are acquiring technological companies (e.g., in artificial intelligence)
	f.	*Automotive / Machinery and Equipment* - By 2030 current innovation will be standardized/available on the market.
	g.	*Machinery and Equipment* - Companies are investing to set the standard for the Internet of Things and related technologies.
Conclusion		*The relevance of proprietary technology will depend on the industry. The investments (direct or through mergers and acquisitions) will depend on the time of technological standardization.*
		3B. Rent distribution
Median magnitude: ***2019: 3 → 2030: 4***	**39.**	**Activities related to the provision of services display the highest margins along the value chain.**
Comments for high magnitude	a.	Already today services display the highest marginalities in most manufacturing industries.
Comments for low magnitude	b.	Internet-based platforms will bring about price transparency driving down margins.
Industry comments	c.	*Automotive* - Product sales will be marginal in the future, cars will be used and revenues generated through services.
	d.	*Automotive* - Connected cars will have a series of digital services (e.g., infotainment) providing additional revenues with low set-up costs.
	e.	*Automotive* - Consumers will have a low willingness to pay for on-board services and expect them for free.
	f.	*Machinery and Equipment* - Digital data-driven services are self-sustained after initial technological investment.
	g.	*Machinery and Equipment* - Manufacturers risk not to generate sufficient returns from product-as-a-service models, as payment schemes are hard to be calculated for customized products.
	h.	*Machinery and Equipment* - Customization supported by new production technologies will drive back margins in production activities.
Conclusion		*Service marginality will further increase as new opportunities for digital services/product-as-a-service emerge. Limitations are related to price transparency, customer willingness to pay, and the calculation of payment schemes for complex products.*
Median magnitude: ***2019: 2 → 2030: 4***	**40.**	**Activities related to the management of data display the highest margins along the value chain.**
Comments for high magnitude	a.	The increasing relevance of data and limited availability of related capabilities will support margin growth.
	b.	Access to data will influence all performance dimensions (e.g., flexibility, productivity, quality) and provide additional sources of revenues due to digital services.
Comments for low magnitude	c.	Margins will be pushed down quickly as new players enter the data management/data marketplace business (e.g., cloud vendors, analytics providers, marketplaces).
Conclusion		*Control over data will affect all other operational performance dimensions in manufacturing and provide additional sources of revenues. Margins of providers of data management services (e.g., cloud vendors, data marketplaces) will depend on their concentration.*
Median magnitude: ***2019: 2 → 2030: 2***	**41.**	**Activities related to the production of physical products display margins comparable to pre-production (e.g., product development) and post-production (e.g., marketing and sales) phases.**
Comments for high magnitude	a.	Higher margins will be retained in late-stage customization supported by new production technologies.
Comments for low magnitude	b.	Increasing pressures on costs will further drive down production marginalities.
	c.	Smart products will shift the value away from production to service provision.
	d.	*Automotive* - Physical products will not be relevant in the mobility ecosystem.
	e.	*Machinery and Equipment* - Production will be commoditized as manufacturing capabilities will be accessed through cloud manufacturing platforms.
Conclusion		*Production margins will increase only for late-stage/customization whenever manufacturing capabilities are specific and not accessible through cloud manufacturing platforms.*
		3C. Geographic spread
Median magnitude: ***2019: 3 → 2030: 4***	**42.**	**The several activities along the value chain are dispersed globally across multiple locations according to differential locational advantages.**

Comments for high magnitude	a.	Economic integration and trade agreements will support the emergence of new countries as potential producers.
Comments for low magnitude	b.	Due to protectionism and tariffs production will be reorganized in shorter supply chains in proximity to the end markets.
	c.	Shorter time to market, flexibility, and customization will require production to be organized on a more local level.
	d.	Consumers' sustainability concerns will drive more responsible sourcing decisions.
Conclusion		*The trend towards a global dispersion of VC activities will continue as new countries gain relevance, only partially mitigated by protectionism, tariffs, and increasing calls for flexibility and sustainability.*
Median magnitude: *2019: 3 → 2030: 4*	**43.**	**Integrated regional supply chains (e.g., North America, Europe, Far East...) serve the needs of their respective markets.**
Comments for high magnitude	a.	The increasing regionalization of supply chains is driven by demand unpredictability and shorter time to market.
	b.	Production will be organized in regional hubs to serve new geographies of demand (e.g., China, Russia),
	c.	Supply chains will be more localized to avoid tariffs.
	d.	Regional/local production will be enabled by increasing system integration along the supply chain.
Comments for low magnitude	e.	Regional/local production will make sense only for personalized/fast-moving items that will represent a small share of the overall production volume.
Conclusion		*Production of high-end/customized products will be organized on a more local basis (not limited to developed countries) to serve relevant destination markets. Protectionism and tariffs will play a major role in location decisions.*

3.6. Outlook and scenarios

The main goal of this study was to provide an outlook on the paradigmatic characteristics of Industry 4.0 with regards to the configuration of manufacturing companies. Three key trends appear to characterize the phenomenon. First, the panel expects data to be increasingly relevant across business operations (Projections #2; # 7; #20; #34; #40) and large manufacturing firms to maintain control and invest in data-management capabilities for data that represent a source of competitive advantage, thus raising the bar for new entrants (Projections #23; #24; #25). The picture is consistent with the literature on managing data for value creation in the era of big data and artificial intelligence (e.g., Davenport, 2017; Iansiti and Lahkani, 2020; Hagiu and Wright, 2020; Spierkemann and Korunustovska, 2017).

Second, servitization appears to be on the rise. An acceleration is expected in relation to technology-push factors – e.g., smart products and data-driven services – and demand-pull dynamics such as sustainability concerns, new generations' lifestyles and cost-efficiency in business settings (Projections #5; #9; #14; #37; #39). A conceptual shift from a goods-dominant to a service-dominant logic has long been documented in the literature (Vargo and Lusch, 2004; Lightfoot *et al.*, 2013; Green *et al.*, 2017); research has also related the new wave of technological innovation to increasing servitization opportunities for manufacturing companies (e.g., Coreynen *et al.*, 2017; Langley *et al.*, 2020) and to sharing economy practices (e.g., Acquier *et al.*, 2017; Geissinger *et al.*, In Press). The "servitization paradox" highlighted by previous research (e.g., Gebauer *et al.*, 2005; Visnjic and Van Looy, 2013) is reflected in the results for Projection #39, as overall services are expected to capture more and more value, but there are concerns among the respondents in relation to complex payment schemes and consumers' willingness to pay.

Third, experts largely expect supply chains and operations footprints to be reshaped by new products and processes. Raw material suppliers will be impacted by the increasing demand for sustainable products– e.g., organic fibers and metals for electric batteries – and by the emergence of smart products: research into substitute or smart materials is expected to flourish (Projections #3; #10; #16; #38). Results (Projections #4; #31) also confirm an intimate relationship between Industry 4.0 and circular economy practices (e.g., Nascimento *et al.*, 2019; Kouhizadeh *et al.*, In press; Rosa *et al.*, 2020). Vice versa, the widespread expectations for small-scale localized production models (e.g., Srai *et al.*, 2016; Montes and Olleros, 2019) and for the reshoring phenomenon (e.g., Barbieri *et al.*, 2017; Dachs *et al.*, 2019) do not come out so clearly from the results. Even though an increasing regional organization of supply chains is expected (Projection #42), new models seem applicable mainly to volatile high-value product categories leaving the bulk of mass market production relatively unaffected (Projections #6; #8; #26; #35), while new outsourcing opportunities seem less relevant as focal companies internalize high-margin production (Projections #11; #29; #41).

Overall, the results also confirm that emerging configurations in manufacturing need to be analyzed against broader evolutionary dynamics stretching beyond traditional industry boundaries (Projection #5). Non-manufacturing companies – in particular digital players and platform-based intermediaries – are expected to compete head-to-head with industry incumbents for high-value opportunities (Projections #36; #37). The increasing prevalence of online channels and platform-based value intermediation is projected to affect customer expectations, product variety, and demand volatility (Projections #12; #13; #15). The timing and characteristics of technological standardization are basically linked to manufacturers' investments in proprietary technologies and their sources of competitive advantage (Projection #38).

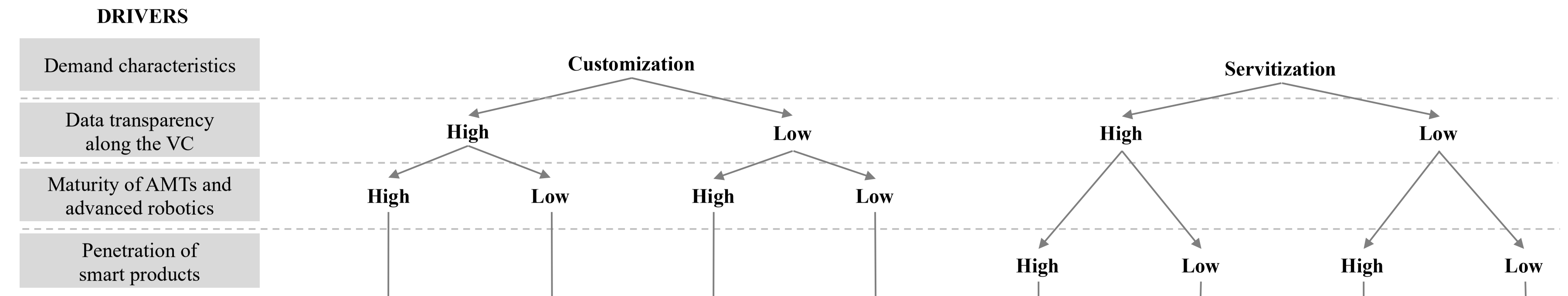
In order to better understand these cross-industry dynamics, we believe that further analyses are required as the ways in which Industry 4.0 is changing manufacturing VCs' "control points" – i.e., which activities along the VC hold the greater value or power (Rülke *et al.*, 2003; Pagani, 2013) – within increasingly complex networks of business partners and competitors. Data ownership (Projections #20; #23; #24; #25; #34; #40), control over sales channels (Projection #22; #32), standardization of IoT product-service platforms (Projections #37; #38) emerged from our study as increasingly relevant elements, and still occupy a contested territory between manufacturing incumbents and born-digital companies. The future of many manufacturing companies may depend on their ability to early identify and seize opportunities and challenges related to the rapid evolution of such control points.

The results of the Delphi study unveiled several uncertainties behind the expert judgements. Some of these uncertainties recurred very frequently in the comments related to several projections across the various levels and sub-levels of our conceptual framework (Tables 14-16). We analyzed how these uncertainties – also called "drivers" in the scenario planning literature – may unfold in time and determine different configurations of manufacturing VCs. Our analysis identified four main drivers leading to eight analytically coherent presentations of possible futures (Fig. 7), namely "scenarios" (van Notten *et al.*, 2003; Bishop *et al.*, 2007).

The first driver refers to the dominant <u>*demand characteristics*</u> by 2030. Two trends emerged as controversial. One is related to demand volatility and customization/personalization of physical products (i.e., "customization"), the other to product servitization and non-ownership models (i.e., "servitization"). These two trends should not be seen as conceptual alternatives (e.g., Sousa and Silveira, 2019), yet they emerged from the expert assessment as distinct options under the assumption that with physical products being "*shared rather than owned, there will be no need to customize*". For the purpose of scenario development, we assumed either one of these demand characteristics to be dominant in the future.

The second driver approaches the question of <u>*data transparency along the VC*</u>. We already discussed how data are expected to be increasingly relevant. Notwithstanding *"cross-industry synergies and data-specific scale advantages"*, several comments underscored that *"data will be retained at the company level as they are a source of competitive advantage"*. However, many efficiency- and innovation-related benefits are expected to come from data sharing (Kagermann *et al.,* 2013; Evans and Annunziata, 2012; Liao *et al.*, 2017). Policymakers are working on a solution for legal issues related to the access to and transfer of non-personal machine-generated data, data liability, as well as portability of non-personal data, interoperability and standards (e.g., European Commission, 2020). Intellectual property legislation is also expected to evolve to reap the benefits of new production models (e.g., Kurfess and Cass, 2014; Steenhuis and Pretorius, 2017; Chan *et al.*, 2018). In the scenarios, we assumed two extreme states of data transparency: "high", i.e., full real-time visibility on suppliers' processes and the opportunity to easily acquire customer data on the market and "low", i.e., operations and marketing data are strictly kept within organizational boundaries.

Figure 7. Drivers and scenario development framework



SCENARIOS	***1.*** *Production commoditization*	***2.*** *End-to-end VC transparency*	***3.*** *In-house production*	***4.*** *In-house technology*	***5.*** *Open smart ecosystems*	***6.*** *Platform-based renting/leasing*	***7.*** *In-house smart servitization*	***8.*** *Enhanced renting/leasing*
SHORT DESCRIPTIONS	Production capabilities are accessed through digital platforms (**#12**). Micro-factories and intermediaries produce in proximity to the customers (**#8**; **#27**; **#35**). Manufacturers have fully outsourced production (**#11; #29**). New players can easily enter production activities due to low-scale technologies and data availability (**#23**). Low margins have however triggered concentration dynamics (**#17**; **#18**; **#23**; **#41**). Simple products are 3D-printed at home (**#6**).	Manufacturing firms outsource production to broad networks of specialist suppliers (**#18**; **#29**). The management of supply chain data is internalized (**#34**). Capabilities for data management and the high specificity of production technologies represent a barrier to entry in manufacturing (**#23**). Production margins are higher than today because of players' specialization (**#41**).	Manufacturing firms have internalized production and redesigned their footprint for higher customer proximity (**#27**; **#29**). Suppliers of AMTs and related materials have gained relevance (**#1**). Barriers to entry in manufacturing are high because of the control of data and sales channels (**#23**). Large companies are favored (**#18; #20; #22**). Production margins are higher than today (**#41**).	Manufacturing firms have internalized production developing proprietary production technologies (**#29; #38**). Barriers to entry in manufacturing are high because of these technologies together with the control of data and sales channels (**#23**). Players are concentrated (**#18; #20; #22**). Production margins are higher than today (**#41**). Workforce technological capabilities are among the key drivers of location decisions (**#26**).	Several specialized companies develop digital services for smart products (**#9**; **#19**; **#21**), data availability has lowered barriers to entry (**#2**; **#7**; **#24**). Services and products are accessed through platforms (**#14**; **#12**). Cross-industry ecosystems have taken shape (**#5**). Digital services display the highest margins (**#39**; **#41**). Data-related marginalities are low; data marketplaces are concentrated (**#20**; **#40**)	Products are offered as-a-service, e.g. renting and leasing (**#14**). Transactions are intermediated by digital platforms (**#12**). Access to data simplifies the entry in intermediation / services (**#2**; **#24**; **#25**), however platforms are subject to network effects (**#22**). Margins have further shifted away from products to intermediation and services (**#39**; **#41**). Data-related marginalities are low; data marketplaces are concentrated (**#20**; **#40**)	Manufacturing firms internalize/coordinate digital service development for smart products and data management activities (**#7**; **9**; **#30**; **#33**). Digital services are sold through direct channels (**#32**). Barriers to entry and concentration levels are high in relation to data and capabilities (**#24**). Building on data access, digital players and platforms develop their offering (**#36**; **#37**). Margins are determined by the access to data (**#40**). .	Products are offered as-a-service, e.g. renting and leasing (**#14**). Firms controlling sales channels (manufacturers and intermediaries) offer additional services building on their access to customer data (**#30**, **#32**; **#33**; **#36**). Comprehensive solutions trigger customer lock-in with the result of high barriers to entry and concentration levels in services (**#21**; **#24**). Margins are determined by the access to data (**#40**).

Note: Number of most relevant projections affected by each scenario is in brackets

The third driver calls into question the *maturity of AMTs and advanced robotics*. The rapid developments and successful applications of new production technologies – especially AMTs – have often fueled huge expectations (e.g., Jiang *et al.*, 2017; Wang *et al.*, 2019b). Academic research has also underlined ongoing limitations in their applicability (e.g., LaPlume *et al.*, 2016; Durach *et al.*, 2017) and their cost-effectiveness in large-scale manufacturing operations (e.g., Atzeni *et al.*, 2010; Baumers *et al.*, 2016, 2017; Baumers and Holweg, 2018). These concerns were echoed in several experts' comments. In our analysis, the hypothesis of a "high" maturity describes a future where AMTs and advanced robotics can easily be bought on the market and applied cost-effectively on a broad range of products, vice versa "low" maturity assumes that these technologies do not apply. This driver is relevant for the production of physical products and thus has been considered only for the customization scenarios.

The last driver is related to the *penetration of smart products*. Academic research and practical whitepapers exhibit optimism towards the current technological issues related to smart products, e.g., cybersecurity, networking, and standardization of communication protocols (Atzori *et al.*, 2010; 2017). However, their spread might be limited in non-durable consumer goods (e.g., Bertola and Teunissen, 2018), as the results indicate for the Apparel and Footwear subpanel. Even in more mature industries, the penetration of smart products could be unevenly spread across geographies due to the need for support infrastructure, as in the case of autonomous vehicles (e.g., Cavazza *et al.*, 2019). This driver applies to the servitization scenarios only. We considered as "high" the full applicability and spread of smart products and as "low" no applicability at all.

The scenarios resulting from the combination of these four drivers are illustrated in Fig. 3 and their core mechanisms briefly outlined below.

The common denominator of the four "customization" scenarios is a new approach to production in order to meet a highly fragmented demand. The abundant literature on mass customization in operations and supply chain management provides the starting point (e.g., Fogliatto *et al.*, 2012; Suzić *et al.*, 2018). In the first two scenarios – *(1) Production commoditization* and *(2) End-to-end VC transparency* – high levels of data transparency enable efficient outsourcing due to a decrease in transaction costs (Coarse, 1937; Williamson 1987). In scenario *(1)* a low AMTs' asset specificity makes suppliers virtually interchangeable (McGuiness, 1994; Lonsdale, 2001). This, in turn, leads to price pressures, commoditization of production, and efficiency-seeking efforts. As a result, a process of market consolidation takes place; new manufacturing giants operate a broad network of localized production facilities. In scenario *(2) End-to-End VC transparency* focal companies orchestrate articulated supply chains of specialized manufacturers of intermediate goods. The core dynamics of this scenario are explained through the resource dependency theory (Donaldson, 2001): because of specialized capabilities, suppliers have at their disposal high bargaining power against the focal company, maintain high barriers to entry, and retain some of the extra profit related to customization. The remaining two "customization" scenarios are based on the opposing logic for outsourcing. Data-related transaction costs make it inconvenient for focal companies to coordinate suppliers within very short time intervals, which is needed required for customization. The higher margins related to customized products drive production internalization in scenario *(3) In-house production*. In case AMTs and advanced robotics will not be available – as in scenario *(4) In-house technology* – focal companies are incentivized to invest in proprietary technology in order to reduce the labor-intensity of production processes.

The four "servitization" scenarios elaborate on manufacturing companies disintermediating sales and service networks as opposed to digital players and platforms developing their own offering. Central to our line of reasoning is the literature on manufacturing servitization (e.g., Baines and Lightfoot, 2014; Berret *et al.*, 2015; Story *et al.*, 2017) as well as the ever-growing research on platforms, both from an "economic" and an "engineering design" perspective (e.g., Gawer, 2014; McIntyre and Srinivasan, 2017). The "engineering design" perspective – i.e., platforms as technological architectures to orchestrate a set of system complementors (e.g., Elorata and Turunen, 2016; Ondrus *et al.*, 2016; Wei *et al.*, 2019; Broekhuizen *et al.*, In press) – is at the basis of scenario *(5) Open smart ecosystems*. In this scenario highly specialized players participate in broad business ecosystems thanks to IoT platforms based on an open architecture. Data transparency offers relatively equal opportunities for value capture to the various firms involved. The "economic perspective" of platform research – i.e., platforms as multi-sided markets (e.g., Eisenmann *et al.*, 2011; Cennamo and Santalo, 2013; Ghazawneh and Henfridsson, 2015) – is the most relevant for scenario *(6) Platform-based renting/leasing*. This scenario describes a situation where platforms become the dominant models in value intermediation. In a regime of high data transparency, low barriers to entry prevent "winner takes all" dynamics. In both scenarios *(5)* and *(6)* high data transparency coupled with cross-industry market ecosystems triggers the commoditization of data management activities. Scenario *(7) In-house smart servitization* describes a head-to-head competition among industry incumbents, digital players and intermediaries. Manufacturers orchestrate their own IoT platform-based architectures and build up a competitive advantage through the ownership of product in-use data and the internalization of sales channels together with core services. Digital players and intermediaries capitalize on their access to customer data and invest in their own IoT product-service architectures so as to grow across different industries. In the last scenario – *(8) Enhanced renting/leasing* – traditional products are offered as a service. In a regime of low data transparency manufacturers and intermediaries internalize services that guarantee extra profit.

Although these eight scenarios are based on extreme future states of their underlying drivers, there already exist actual examples that fit at least in part into similar narratives. An in-depth analysis of such examples is outside the scope of this paper.

CHAPTER 4. Sharing information along digital supply chains

4.1. Purpose

Information sharing has a long-lived history in supply chain management (SCM) research. Despite the promise of tangible benefits, previous studies have raised doubts about its real practice. Over the last few years, digital technologies – including the Internet of Things, cloud computing, and artificial intelligence – have increased dramatically the opportunities for data generation, storage, access and analysis. Few studies have investigated whether these opportunities relate to a new stance on information sharing in emerging digital supply chains. This paper develops a single embedded case study analysis on inter-organizational information flows within the extended automotive supply chain. Results show that – alongside already theorized dynamics – new trends can be seen at the horizon requiring scholars to rethink some assumptions underpinning existing frameworks. An earlier version of this chapter was presented at the 51st DSI Annual conference[7].

4.2. Positioning of the research

New digital technologies in manufacturing come with the promise of substantial efficiency gains and revenue growth due to increasing data-driven decision making (Frank et al., 2019; Kusiak, 2018; Yin *et al.*, 2018). Production can be rooted to the most appropriate facilities in terms of geographical proximity, capabilities, and cost (Calatayud *et al.*, 2019; Srai *et al.*, 2016; Yadekar *et al.*, 2016). Machine downtimes can be minimized thanks to predictive maintenance and remote services and optimization algorithms operating on large data lakes can support process improvements (Bokrantz *et al.*, 2017; Ehret and Wirtz, 2017). Smart products deliver to the customer digital services in the form of captive or third-party applications, physical services can be activated according to product or user communicated status (Rong *et al.*, 2015; Porter and Heppelmann, 2015).

At the basis of all this, there are staggering amounts of data generated by connected products, machines and processes, together with increased and more convenient analytical capabilities brought about by technologies such as artificial intelligence, machine learning and cloud computing (Culot *et al.*, 2020a; Mariani and Borghi, 2019). As value generation often involves multiple parties along dispersed supply chains and broad cross-industry ecosystems,

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[7] Culot G., Nassimbeni G., Sartor M., Orzes G. (2020). Data sharing in inter-organizational settings: emerging patterns in the context of Industry 4.0, In: *Decision Sciences in the age of connectivity. Proceedings of the 51st Decision Sciences Conference*.

it is clear that these opportunities require companies to pursue higher levels of information integration and to share data across organizational boundaries (Elia *et al.*, 2020; Kache and Seuring, 2017). Technology shows significant potential in this direction (Fatorachian and Kazemi, 2020; Wu et al., 2016) and a number of regulatory initiatives together with industry consortia are working towards related legislative frameworks and standards (European Commission, 2020; Open Manufacturing Platform, 2020; Industrial Internet Consortium and Plattform Industrie 4.0, 2017). Against the widespread optimism about such digital connections across companies, machines and products, recent reports and academic studies highlight however ongoing managerial concerns about letting data outside the boundaries of the organization and lower-than expected penetration of sharing practices (WEF, 2020; Culot et al., 2020b; Müller *et al.*, 2018).

This apparent contradiction is the focus of this study. We address the issue both theoretically and empirically by examining how novel digital technologies change what is already known about information sharing in supply chains. The topic has been broadly investigated over decades of research as a key pillar in SCM research (Colicchia *et al.*, 2019; Kembro and Näslund, 2014; Fawcett *et al.*, 2009). Today, however, digitalization is bringing about profound changes in the context in which information is (or is not) shared, requiring further exploration.

Our starting point is represented by current theorizations of the phenomenon in the literature (Halldórsson *et al.*, 2015; Kembro *et al.*, 2014) with reference to: *(i.)* the understanding of information as a resource explained through the resource-based view (RBV); *(ii.)* the characteristics of dyadic buyer-supplier practices seen through the lenses of the resource dependence theory (RDT); and *(iii.)* the overall sharing dynamics within the extended supply chain understood as a complex adaptive system (CAS). The development of a single embedded case study involving (so far) 13 companies and 27 key informants within the extended automotive supply chain provides empirical evidence as for the handling of information at inter-organizational boundaries in the digital context. Our analysis shows that emerging practices and the below-potential information sharing in supply chains are mostly explained through a combination of the abovementioned theoretical perspectives, confirming once again that supply chain relationships are hardly illustrated through mono-theoretic approaches (Halldórsson *et al.*, 2015; Chicksand *et al.*, 2012; Power and Singh, 2007). Some idiosyncrasies of the digital context, however, seem to fall out existing frameworks, urging us to engage in further theoretical elaboration.

The main contribution of the study is to offer empirically grounded middle-range insights (Merton, 1957; Mintzberg, 1977) on digital supply chains – a phenomenon that has been approached mainly from a conceptual point of view so far – by focusing on the issue of inter-organizational information sharing. In doing so, we trust that our elaboration can provide academics and managers some foundational elements to analyze and explain the phenomenon in its context-specific variations.

4.2. Literature background

Before delving into the theoretical aspects of our endeavor (subsection 4.2.3.), it is worth to summarize how research has approached information sharing in supply chains over the years (subsection 4.2.1.) and the current understanding on the role of digital technologies in SCM (subsection 4.2.2.).

4.2.1. Information sharing in supply chains

Information sharing in supply chains is broadly defined as the «inter-organizational sharing of data, information and/or knowledge in supply chains» (Kembro and Näslund, 2014, p. 181). It can occur at different levels: operational, tactical and strategic (Rai *et al.*, 2006; Mentzer *et al.*, 2001). At the operational level, information is related to specific processes and material flows, such as demand and sales data, order information, and stock levels (Wiengarten *et al.*, 2010; Klein and Rai, 2009). Moving on to the tactical level, companies share information to facilitate resource planning and alignment among supply chain partners (Bowersox et al., 2000; Patnayakuni *et al.*, 2006). Finally, at the strategic level, the focus is on creating a shared vision and sustain long-term growth of partners involved (Premus and Sanders, 2008; Mohr and Spekman, 1994).

Research interest on the issue has been raising since the late 1950s, with an initial focus on the potential effects of sharing demand and capacity-related information to smooth out material flows along the chain in order to limit the so-called bullwhip effect (Forrester, 1958). Over time, this initial understanding evolved within the idea of supply chain integration (Lockström *et al.*, 2010; Frolich, 2002; Frohlich and Westbrook, 2001) and the debate further intensified with the spread of information and communication technologies (ICTs) as Electronic Data Interchange (EDI) and eBusiness tools (e.g., Prajogo and Olhager, 2012; Narayanan et al., 2009; Harland et al., 2007).

The research on information sharing in supply chains has mainly elaborated on the following topics: why (not) to share, what information to share with whom, how to share information, and organizational contingencies (Kembro and Näslund, 2014). Although there has been a strong focus over the years on information related to tracking, tracing, and demand and supply planning (Jonsson and Mattsson, 2013), the matter is equally for innovation and new product development (NPD) considering that firms are increasingly counting on supply chain partners for this (Lawson *et al.*, 2015; Choi and Krause, 2006). More recent studies have also drawn the attention to how shared information is actually utilized by supply chain partners and their organizational capabilities (Sener *et al.,* 2019; Srinivasan and Swink, 2018; Jonsson and Myrelid, 2016).

Although the bulk of the literature has taken a positive look at information sharing in supply chains, other studies have instead casted doubts on its real practice and outed some concerns in terms of related costs and risks (Vanpoucke et al., 2009; Roh et al., 2008; Uzzi and Lancaster, 2003). Some scholars have also underlined a potential detrimental role of technologies for weaker supply chain partners and the presence of power-related dynamics (Zhao *et al.,* 2008*;* Hart and Saunders, 1997; Webster, 1995).

Finally, it should be noted that most empirical studies have examined information sharing within buyer-supplier dyads (Kembro and Näslund, 2014). This is only partially related to the methodological complexities of empirical investigations on extended supply chains, and mostly refer to a still low implementation of information sharing projects involving multi-tier partners due to technological, relational, behavioral, and structural issues in networks of multiple companies (Kembro *et al.*, 2017; Kembro and Selviaridis, 2015; Fawcett *et al.*, 2007).

4.2.2. Supply chain digitalization

The second stream of literature relevant to this study refers to supply chain digitalization. Overall, it has been posited that – as a set of digital and process technologies comes of age – deep paradigm shift will affect the social and economic environment, including consumption patterns, value generation dynamics, and process organization (Culot *et al.*, 2020a; 2020b; Frank *et al.*, 2019; Mariani and Borghi, 2019). Supply chains are not exempt from these transformative trends, although the figures still show a limited uptake of large-scale applications in this context (WEF, 2020).

Given the relative novelty of the phenomenon, most of the efforts so far have been devoted to the analysis of potential applications and effects in order to derive avenues for future research. Some studies have examined opportunities and early examples related to single technologies, including the blockchain (Cole *et al.*, 2020; Queiroz *et al.*, 2019b; Wang *et al.,* 2019a, 2019b), the Internet of Things (Ben-Daya *et al.*, 2019), additive manufacturing (Chan *et al.*, 2018), and big data analytics (Chehbi-Gamoura *et al.*, 2020; Roßmann *et al.*, 2018; Waller and Fawcett, 2016). In light of the significant interdependence between key enabling technologies (Culot *et al.,* 2020a*;* Yoo *et al.*, 2012), a number of papers has developed holistic approaches to the issue and conceptualized future “digital”, “smart” and “self-thinking” supply chains (Büyüközkan and Göçer, 2018; Calatayud et al., 2019; Wu *et al.*, 2016). In a nutshell, the idea is that the connectivity of components, products, machines and vehicles coupled with enhanced analytical capabilities and decentralized databases will make supply chains more responsive, flexible and efficient, while reducing the need for human intervention. So far, research has developed empirical evidence on selected topics, performance implications of big data analytics being certainly the most investigated area (e.g., Mikalef et al., 2019; Gunasekaran *et al.*, 2017; Fosso Wamba *et al.*, 2015).

What is clear is that altogether digital technologies create a “new data frontier” (Feldman *et al*., 2015) calling for deep reconsiderations of supply chain management practices. Although several challenges appear to be currently unaddressed in academic literature (Schniederjans *et al.*, 2020), it is striking that most contributions assume that data will smoothly flow between organizations and do not build on the warnings of previous research on information sharing in terms of low willingness to share, limited spread of practices beyond dyadic relationships, non-technological barriers, and potential risks. By the same token, the literature on digital ecosystems and technology-enabled servitization has also mostly overlooked the issue of data availability and sharing, although assuming a more structured governance of participating players (Kiel *et al.*, 2017; Rong *et al.*, 2015). Overall – besides few but notable exceptions (Kache and Seuring, 2017) – most of the contributions take data/information sharing for granted, not focusing on this issue despite its centrality in the SCM literature.

4.2.3. Relevant theories

As common in SCM studies (Halldórsson *et al.*, 2007, 2015; Chicksand *et al.*, 2012; Choi and Wacker, 2011), relevant theories for explaining information sharing are germane to other fields of research and – due to the broad and integrative features of supply chains as a theoretical construct – can be seen as complementary. In their review, Kembro *et al.* (2014) identify a series of perspectives that have been applied in the study of the phenomenon; a thorough analysis of their relevance and applicability in the digital context would be beyond the scope of the study. In this paper, we set to elaborate on three different levels that reflect multiple accounts into the complexity of the issue.

First, we rely on the Resource-based view (RBV) to investigate information and data as a resource. The RBV focuses on the firms' internal resources as the primary unit of analysis and suggests that organizations that possess resources that are valuable, rare, inimitable and/or non-substitutable develop and sustain an edge over competitors (Wernerfelt, 1984; Barney, 1991). As a consequence, firms should protect and keep internally resources with these characteristics (Peteraf, 1993); this may apply to information that supports rent generation and leads to competitive advantage. However, the RBV is vague with respect to the origins of these resources (Priem and Butler, 2001), which might extend beyond the firm's boundaries (Lavie, 2006; Dyer and Singh, 1996) and involve inter-firm routines, processes and knowledge, thus building a strong argument for information sharing (Patnayakuni et al., 2006; Hernández-Espallardo et al., 2010).

Second, we analyze information sharing based on the characteristics of dyadic buyer-supplier relationships. The resource dependence theory (RDT) proposes that organizations engage in exchanges with their environment to obtain resources (Pfeffer and Salancik 1978). The underlying assumptions are that very few organizations are internally self-sufficient with respect to strategic and critical resources, and firms seek to reduce uncertainty and manage dependence by purposefully structuring their exchange relationships, establishing formal and semiformal links with other firms (Paulraj and Chen, 2017; Ulrich and Barney 1984). This perspective has been broadly used in SCM studies also in relation to information sharing (Vijayasarathy, 2010; Crook and Combs, 2007).

Third, Complex Adaptive Systems (CAS) enables the appreciation of different information sharing dynamics within the different portions of the extended supply chain and the presence of adaptive mechanisms (Holweg and Pil, 2008). CAS – according to the conceptualization of Choi *et al.* (2011) and Carter *et al.* (2015) – are seen as dynamic networks of autonomous agents (or firms) which interact with one another and in their environment to produce evolving systems. The study of CAS is characterized by three analytical dimensions: the internal mechanisms governing the relations among the agents, the adaptability of the network to changes in the external environment and the presence of co-evolutionary dynamics spreading through specific portions of the network.

4.3. Methodology

The issue of information sharing in supply chains has been broadly investigated by previous research; however, the spread of digital technologies and related business practices is deeply redefining the context in which information sharing has been practiced and studied so far (Kache and Seuring, 2017; Schniederjans et al., 2020; Culot et al., 2020b). Supply chain digitalization is, however, still a rather new phenomenon (Nasiri et al., 2020; WEF, 2019), therefore it ought to be first explored in its complexity before testable hypotheses could be formulated.

Case research was thus selected because it gave us the opportunity to investigate information sharing within the new digital context with the necessary depth, latitude and serendipity. Our approach was based on abductive reasoning (Ketokivi and Choi, 2014; Voss et al., 2002; Meredith, 1998), which – differently than the most common inductive approaches aimed at theory generation– could better support the elaboration of previous knowledge on the matter.

Due to the potential scope of digitalization highlighted by recent literature (Schniederjans *et al.*, 2020; Wu *et al.*, 2016), the setting of our research was defined as the extended supply chain, meaning multi-tier linkages involving both physical and support activities (Carter *et al.*, 2015). We developed a single embedded case study analysis (Yin, 2018) of inter-organizational information flows involving individual companies along one extended supply chain. Overall, we were aware of the potential drawbacks of our choice in terms of generalizability; however, we trusted that this focus could improve our control of extraneous variables which –especially in the study of networks such as extended supply chains – make it difficult to run comparative analyses due to the different structural characteristics of the cases (Halinen and Törnoos, 2005). The development of single embedded case studies proved in fact to be particularly suited for abductive reasoning, as the shared context constitutes a common frame around the subcases which enables a sharper analysis of the variations between them (Dubois and Gadde, 2002; Ketokivi, 2006).

4.3.1. Case selection

The embedded unit of analysis of our study were inter-organizational information flows within an extended supply chain. After five preliminary interviews at different manufacturing companies, we decided to focus on automotive. The selection was made because of two reasons. First, previous research on information sharing had broadly investigated automotive supply chains (e.g., Lockstöm et al., 2010; Iskadar et al., 2001), so that the practices and the context of information sharing prior to digitalization was known for the large part. Second, the fact that automotive was deeply impacted by emerging digital technologies at both process- and product-level made this context particularly interesting (Culot *et al.*, 2020b; Llopis-Albert et al., 2021; Fahrani *et al.*, 2017).

We started off from the conceptualization of Carter *et al.* (2015) of the supply chains as networks of companies (i.e., "agents") relative to a particular product or focal firm. These networks include both agents through which products physically flow, defined as the "physical chain", and many additional companies that play a vital but indirect role in the movement, storage, and transformation of products across organizations, understood as the "support chain". With respect to the focal company, all these agents may fall within or outside their visible horizon.

This conceptualization demanded us to take two main decisions. The first one was related to the understanding of a supply chain as relative to a particular focal firm. The automotive industry is not characterized by a one-to-one relationship between original equipment manufacturers (OEMs) and first-tier suppliers, who instead provide major systems to many clients (Mohamad and Songthaveephol, 2020; Huang *et al.*, 2020). This supply chain structure made it meaningless – if not impossible – to isolate one OEM-specific extended supply chain. We set to overcome this limitation by including a geographic scope in our analysis, assuming that – as automotive supply chains are characterized by a strong and ever-increasing regionalization (Sturgeon *et al.*, 2008) – this would support the identification of companies with a business relation one another. We focused on European automotive manufacturers, given the comparatively higher rate of industrial technology implementation in the region as opposed to the United States and China together with the role played by the German automotive industry in leading the digital transformation (Bosche *et al.*, 2018; Li, 2018; Sung, 2018).

The second decision concerned the delimitation of the boundaries of our analysis, considering the many actors potentially involved along the extended supply chain but aiming at «[...] a reasonable balance between realism and pragmatism» (Carter *et al.*, 2015, p. 89). In our case, this was even more complex as innovation and technology are expected to lead to profound changes in the size, shape, configuration and governance of supply chains, so that the previous understanding of automotive supply chains might no longer hold true (MacCarthy *et al.*, 2016; Choi *et al.*, 2001). Following Halinen and Törnoos (2005) methodological recommendations, we defined the boundaries through the informants used in the empirical study and on the basis of our embedded unit of analysis – i.e., inter-organizational information flows. As a first step, we focused OEMs and leading first-tier suppliers through a stratified sampling approach (Patton, 2002). This initial selection led us through a sequential approach to the identification of upstream/downstream information sharing links in the physical or in the support chain.

Figure 8. Extended automotive supply chain

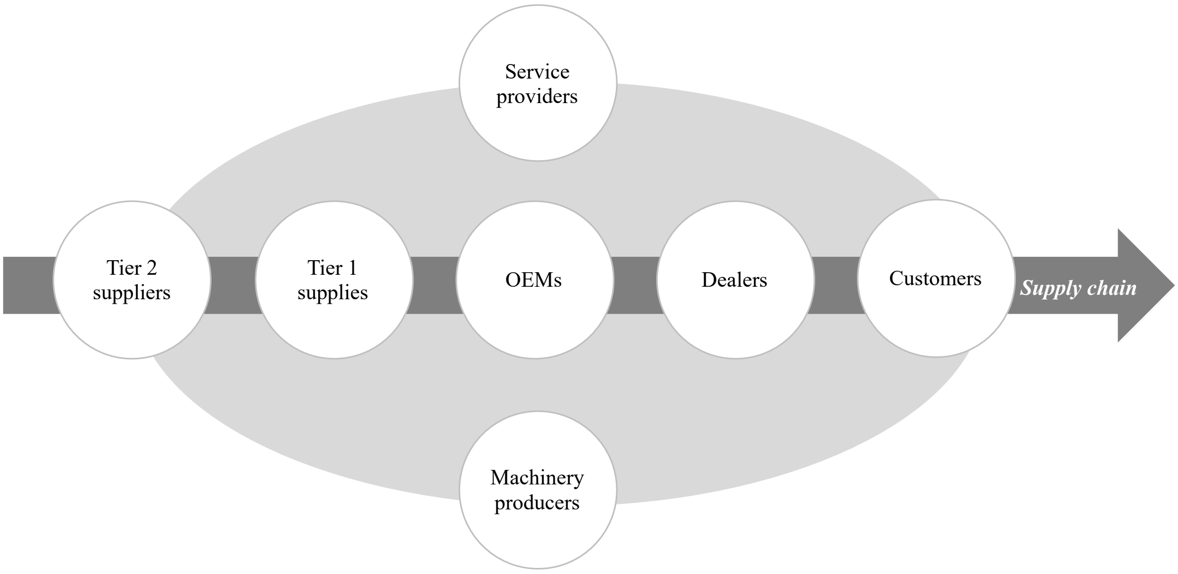


Figure 8 graphically illustrate the automotive extended supply chains, as for the links and nodes relevant for the study of inter-organizational information sharing. Data collection is still ongoing, and we plan to and plan to conclude the study once the theoretical saturation point is reached (Yin, 2018). Table 17 provides an overview of the companies. Given the sensitivity of the matter, an agreement was put in place stating that no organization or informant could be identified – placing some limitations on what we are able to report. Individual companies, i.e., subcases – are referred to by generic monikers instead of their real names

Table 17. Subcase companies

Category	**Company**	**Description**
OEMs	Commercial OEM	- Design, production and sale of commercial vehicles (buses, trucks and special vehicles). - Other business units dedicated to industrial equipment. - Revenue: $25-50 bn.
	Premium OEM 1	- Design, production and sale of premium motor vehicles (only in the consumer segment). - Revenue: $50-75 bn.
	Premium OEM 2	- Design, production and sale of premium motor vehicles (both consumer and commercial segments) - Revenue: $150-175bn.
	Mass market OEM	- Design, production and sale of mass market motor vehicles (mostly in the consumer segment) - Revenue: $100-125bn.

	Luxury sports OEM	- Design, production and sale of luxury sports cars - Revenue: $1-2bn.
Tier 1 suppliers	Diversified supplier	- Design, production and sale of powertrain, climate and lighting and car interiors systems and components - Revenue: $10-15bn.
	Hardware and software supplier	- Design, production and sale of powertrain, steering, breaking and battery systems and components - Production of various sensors for connected vehicles and provision of related digitals services - Revenue: $75-100bn.
	Powertrain supplier	- Design, production and sale of powertrain and chassis systems and components - Other business units dedicated to industrial equipment. - Revenue: $10-15bn.
Dealers	Importer	- Import of vehicles from other European country. - Relationship with network of dealers, including training.
	Dealer 1	- Multi-brand large regional dealer.
	Dealer 2	- Multi-brand large regional dealer.
Industrial Equipment Manufacturers	Metal equipment	- Design, production and sale of equipment and plants for the metal industry. - Business unit dedicated to automation and digitalization. - Revenue: $2-3bn.
	Plastic equipment	- Design, production and sale of equipment for injection molding of plastic materials. - Revenue: $0.5 bn.
Digital solution providers	Supply chain platform	- Provision of AI-based services for inventory/flow optimization. - Start-up.
	System integrator	- Digital system integrator specializes in manufacturing. - Small company.

4.3.2. Data collection

A through case study protocol including semi-structured interview questions was developed and refined through a pilot interview (the final checklist is included in Appendix). Data collection started in Summer 2020 and continued until Spring 2021. Because of the restrictions to in-person meetings due to the pandemic situation, all interviews were conducted as online videocalls. This approach facilitated the recording of data and ensured a consistent interview process across the firms involved in the study. Interviews were conducted by the principal investigator of this study together with at least one other researcher having extensive experience in case-based research. For each company, we interviewed executives with at least manager-level responsibility, aiming at involving different functions given the breadth of inter-organizational information flows. Depending on the position of the company within the extended supply chain, we set to interview executives with expertise in: *(i.)* supply chain or purchasing; *(ii.)* production or logistics; *(iii.)* digital transformation or information systems; *(iv.)* research and development (R&D), innovation, or connected vehicle development; *(v.)* project management or customer facing roles. Table 18 includes the list of key informants per company. Again, as we granted anonymity to our interviewees, roles have been made generic in their wording, so that no individual respondent could be identified.

Table 18. Key informants

			Expertise				
Category	**Company**	**Informants**	*Supply chain or Purchasing*	*Production or Logistics*	*Digital transf. or information systems*	*R&D, innovation or connected vehicle*	*Project management or customer facing*
OEMs	Commercial OEM	Head of Digital Transformation			x		
		Head of I4.0 Supply Chain	x		x		
		Head of Connected Vehicles				x	
	Premium OEM 1	Head of Supply Chain – plant	x				
		Head of Production – plant		x			
		Project Manager					x
		Director of Connected Vehicles				x	
	Premium OEM 2	Head of Innovation				x	
		Head of Industry 4.0	x	x	x		
	Mass market OEM	Production manager – plant		x			
	Luxury sports OEM	Head of Connected Vehicles				x	
Tier 1 suppliers	Diversified supplier	Supply Chain Manager	x				
		ICT Director			x		
		Head of R&D – business unit				x	
		Head of Logistics – plant		x			
		Head of Purchasing – plant	x				
	Hardware and software supplier	Managing Director – plant	x		x		x
		Head of Production – plant		x			
		ICT Director – plant			x		
		Head of R&D – business unit				x	
	Powertrain supplier	Head of Purchasing	x		x		
Dealers	Importer	Marketing Manager					x
	Dealer 1	Marketing Manager			x		x
	Dealer 2	Marketing Manager					x
		Chief Information Officer			x		
Industrial Equipment Manufacturers	Metal equipment	Director – business unit			x		x
		Head of Project Management – business unit					x
		Chief Information Officer			x		
	Plastic equipment	Chief Information Officer			x		
Digital solution providers	Supply chain platform	Founder and Chief Executive Officer			x		x
	System integrator	Founder and Chief Executive Officer			x		x

Each interview lasted between 50' and 150', on some occasion respondents shared their screen to show us specific dashboard and interfaces of their information systems. All interviews were fully transcribed and stored in a cloud-based case study database, where we filed also relevant information and supplemental material including internal memos and presentations shared by the informants, information from the companies' websites, annual reports and press releases; the abundance and variety of material allowed for data triangulation (Yin, 2018; Patton, 2015). Overall, we are confident about how the data collection phase was developed to meet reliability – i.e., use of a case study protocol and development of a case study database – and construct validity – i.e., use of multiple sources of evidence – criteria (Yin, 2018; Ellram, 1996).

4.3.3. Data analysis

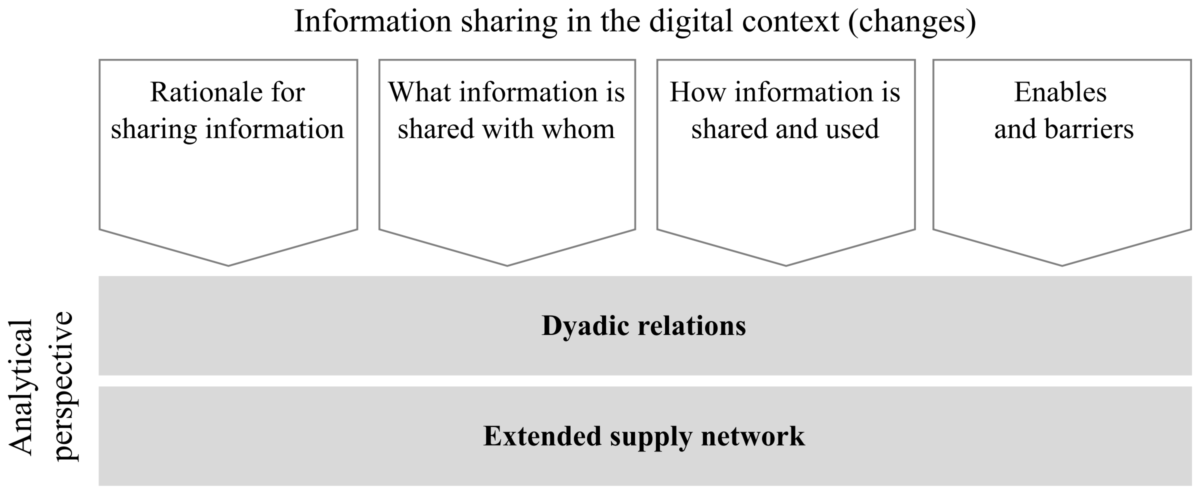
Data analysis was shaped in line with the abductive approach underpinning our study (Ketokivi and Choi, 2014; Voss et al., 2002; Meredith, 1998). As illustrated in Figure 9, we set off with a provisional analytical framework drawing from previous literature reviews on information sharing in supply chains (Kembro and Näslund, 2014; Kembro et al., 2014) complemented by more recent scientific developments on the matter (Johnson and Mirelind, 2016; Kache and Seuring, 2017; Wu *et al.*, 2016). In order to avoid the framework «[...] blind[ing] the researcher to important features in the case» (Miles and Huberman, 1994, p. 16), we used this as a guideline when entering the empirical word and let it evolve in line with our empirical observations.

The data collected for each case was also analyzed through open coding, examining transcript and support material line-by-line to identify key terms and concepts (Miles and Huberman, 1994; Strauss and Corbin, 1990). An iterative process was then put in place to identify key categories, these have then been analyzed to create links between them and their underlying dimensions. The themes that were following outside the initial analytical framework were highlighted, and the framework further elaborated (Dubois and Gadde, 2002),

The material was coded by the main interviewer, who then developed a report for each company – i.e., subcase – involved in the study. Both coding and reports were examined and compared – with direct access to the case database – by at least two other researchers involved in the project. In case of different views, the material was analyzed and coded again through group discussion to ensure consistency. We trust that this approach improved the objectivity of the analysis by increasing inter-rater reliability (Pagell and Krause, 2005).

Starting from here, we analyzed inter-organizational information flows and their changes in the new digital context within the extended automotive supply chain as a whole. The presence of multiple subcases for each category of players enabled us to leverage a pattern-matching logic. The results were compared with prior knowledge on information sharing in supply chains. In the following section, we present the findings of our analysis.

Figure 9. Analytical framework



4.4. Empirical observations

The empirical evidence gathered was analyzed according to the framework illustrated in Fig. 9. This section presents our findings in terms of emerging changes in the digital context of information sharing in supply chains. Each of the following subsections is focused on one overarching rationale for sharing information – which has been worked out from the data through iterative coding – and illustrate: what information is shared with whom, how information is shared and used (with focus on digital technologies), and the presence of drivers and barriers in the implementation process.

4.4.1. Information is shared to align efforts along the supply chain

Our interviews revealed several opportunities for sharing information in order to align efforts and improve efficiency along the supply chain.

Alignment of demand with supply – This is the most classical situation for sharing information along the supply chain. As for the sharing demand data to upstream partners, we do not report any major change in the context of digitalization: long term forecasts and weekly/biweekly updates are shared through EDI, supplier portals or other communication channels, depending on the means available to the supplier. As in the words of one of our interviewees, «[...] *it is not about getting more client data, they might be overoptimistic. We need to leverage other data to have a more accurate estimate and timely communicate with our suppliers what capacity they need to keep for us*» [Diversified supplier, Supply Chain Manager]. In terms of downstream sharing of information related to capacity utilization and work in progress, we found some application of technology for real-time communication exclusively between Tier 1 and Tier 2 suppliers, especially with more closely related subcontractors and whenever there is deep process know-how on the side of the client. The relationship between OEMs and Tier 1 suppliers appeared to be still disciplined through contractual levers. It was reported that they «[...] *don't have visibility on suppliers, everything is managed through contracts and penalties. I am not sure that having more visibility will bring more value to us: in case of issues, we get a phone call and reschedule*» [Mass market OEM, Production manager].

We also encountered a pilot of supply chain platform: having direct access to the information systems of the players along the supply chain, a trusted third party calculated the optimal planning for each player thanks to the application of artificial intelligence algorithms (with no need to give to each player visibility on production data of the other players). The main barrier for this model to work are information security – «*we have a very strict information security policy, our data need to stay on our servers or proprietary cloud*» [Hardware and software supplier, Head of Production] – and possible dependency issues – «[...] *prospects are concerned about losing control of their planning process*» [Supply chain platform, Founder and Chief Executive Officer]. At any rate, personal relationships are reported to be still relevant in the digital age to work things round in case of issues «[...] *the system may say that something is not possible, but yet you can find a solution with a phone call*» [Premium OEM 1, Head of Production].

Synchronization of material flows – Our interviews revealed the more significant and widespread application of digital technologies in logistics, including real-time communication and geo-localization. This is true at all tiers of the supply chain, provided that plant lay-outs and internal processes are up to the challenge. Logistics digitalization, in fact, starts with the optimization of internal processes: «*We complemented our internal product tracing system enabled by digital connectivity with information from our suppliers. The only thing we could ask however was to enrich their systems and tags.* » [Diversified supplier, Head of Logistics]. OEMs seem particularly active on this front, cooperating with both sequencing provides and logistics companies, as explained by one of our informants, «*gates, sensors and connectivity* *improved significantly the pearl-chain model of assembly lines. In case of unexpected events on the line, we provide real-time visibility directly into the systems of our sequencing partners. Geo-fencing helps us to better foresee the expected time of arrival and allow short-term rescheduling*» [Premium OEM 1, Head of Supply chain].

4.4.2. Information is shared for joint product/process improvements

Our interviews showed that data can be pulled together for increasing process efficiency and improving quality with mutual benefits.

Joint process improvements – Again, we found more interest in this in the relationship between Tier 1 and Tier 2 suppliers. One possible reason for this is margin distributions along the supply chain, as «[...] *OEMs have more margins per products that Tier 1 suppliers. This means that they need to cut off all the possible inefficiency to stay profitable. Once they are done optimizing inside the plant, they need to work with their extended value system*» [Premium OEM 1, Head of Supply chain].

In any case, to embark on a data sharing project «[...] *we need to have a shared vision with our suppliers and trust* » [Powertrain supplier, Head of Purchasing]. This is easier whenever the supplier does not serve direct competitors of the customers, as illustrated by a Tier 1 supplier launching «[...] *a "smart foundry" project following the request of a supplier. We merge our data on final product quality with their process data with the objective to reduce scraps and extend the lifespan of molds. The foundry does not work with our competitors*» [Hardware and software supplier, Managing Director]. Several barriers persist as «[...] *we can't reach end-to-end system integration until each company standardizes its internal processes and technologies*» [Diversified supplier, ICT Director]. Moreover, Tier 2 suppliers are often characterized by low digital maturity, as «[...] *many of suppliers are small firms, they do not even collect or use the data, they do not understand what data can be relevant neither the value of sharing*» [Hardware and software supplier, Managing Director], so that supplier development programs focused on digitalization are put in place.

Joint product improvements – Our informants at R&D departments of Tier 1 suppliers suggested that component data from connected vehicles could be shared to improve NPD and reduce product failures. However, «*OEMs are rather "jealous" of these data. We would need access to avoid the risk of overdesigning in R&D. In most of the cases we get data only when there are issues, for us to pay penalties rather than proactively fix the problem*» [Diversified supplier, Head of R&D]. The evidence points also to technical issues in this respect, as «*OEMs* *don't want us to see data that show issues on competitors' components or on the engine, but disaggregating data meaningful for each supplier is either not possible or too costly*» [Hardware and software supplier, Head of R&D].

4.4.3. Information shared for supplier monitoring and control

In this case, the customer demands visibility in order to monitor or control what is done beyond its factory walls for quality or traceability reasons. The object of monitoring can be either process data or product/component history. Overall, we found that digital technologies enable more data to be gathered essentially due to sensors and connectivity; this information is mostly not made available upfront to the customer but shared in case of issues.

Process monitoring – In terms of process, suppliers do normally not share raw data, but align on the insights of the analysis: «*technically speaking, there will be the opportunity to provide our clients the visibility on our workstations, but they do not require this. Whenever there is an issue, they ask us to work on solving the problem, we align on the analysis not on data. Only* [name of client OEM] *requires us direct visibility on a particular screwing process, that for them is crucial in terms of product quality*» [Hardware and software supplier, Head of Production]. On the one hand, there are technical issues related to process standardization, as «*in-detail process data are not shared even within the company between different plants, the standardization process in underway*» [Hardware and software supplier, ICT Director]; on the other hand, the analysis and interpretation of process data requires a know-how that is specific of the supplier. In this sense, we could appreciate a deeper application of technologies – e.g., virtual desktop infrastructure, digital cameras, connected machines – with subcontractors, namely whenever the client has knowhow on the specific process and a more favorable balance of power due to relative size and share of revenue generated. In most cases, information sharing projects for monitoring and control are initiated by the customer, provided that there are organizational incentives in this direction. As one interviewee recalled about an initiative that was not implemented: «*For vendor tooling relationships, I wanted to connect accelerators to the machines, so that we could had visibility on the number of pieces produced and control for the sales of spare parts on the black market. Technology was there, the suppliers could not refuse, but it didn't fly in the end. I guess the point was that the purchasing department who is in charge of these relationships is incentivized only on cost reduction*» [Commercial OEM, Head of I4.0 Supply Chain]

Product traceability – Suppliers seemed overall less reluctant to share product/component history, rather than internal process data. One of our informants at a Tier 1 supplier – commenting on a blockchain pilot project with one client – stated that: «*we had many discussions with* [name of client OEM] *as for what information to share. At the end, the data they required were very limited. If they had asked second-level process tracing, we would have seen more risks*» [Diversified supplier, ICT Director]. These initiatives appeared to be often promoted by OEMs, with the precondition of a proper internal organization as «*the implementation of traceability technologies such as the blockchain required us to have higher levels of sophistications in our internal systems and warehouses. We are not ready*» [Commercial OEM, Head of I4.0 Supply Chain].

The role of the customer is explained through the performance implications of these initiatives. Again, on the same blockchain pilot, «*honestly, we did not experience any improvement in our internal processes after the implementation; the main reasons for us to take part in the initiative was reputational, we wanted to further increase the level of trust the customer places in us* » [Diversified supplier, ICT Director]. On the contrary, collaborative projects are initiated whenever there are shared benefits, as for solving together quality issues: «*we realized that quality issues were related to the ambient conditions in the shipping from China. We worked with our supplier to place sensors that could detect and analyze the status of the containers*» [Powertrain supplier, Head of Purchasing].

4.4.4. Information is shared to automate/augment interactions

In several cases, digital technologies were applied to automate information sharing that would have happened in other ways, such as emails or phone calls and just upon request. The point here is not to share more or different data, but to use different technological interfaces to share, store and access the same information.

Purchases and supplier relationship – Overall, our interviews pointed to an ever-increasing spread and functionalities of supplier portals. «*Suppliers portals are not an absolute novelty, but over the last few years they have increased their functionalities and reach, different information can be stored there, handled and easily accesses*» [Powertrain supplier, Head of Purchasing]. The main driver seems the increasing complexity of vehicles and their systems. An interviewee at a Tier 1 supplier commented: «*Only recently we did set up a supplier portal. As our product is becoming more complex and with increasing electronical content, we needed to standardize how we relate to our suppliers. This was essentially to speed up the purchasing process and enable the handling of vast amounts of information related to each component,* *which is useful in case we need to rapidly address a quality issue*» [Diversified supplier, Head of Purchasing].

From the point of view of a supplier, however, this is not always beneficial as they need to operate with as many portals as the clients they work with. «*With portals everything is more complicated that 10 years ago, when OEM clients were happy with EDI alone. Our personnel have now more workload in relation to monitoring and information uploading on these portals*» [Diversified supplier, Head of Logistics]. This might even lead to a tug-of-war between partners about what portal to use, as documented in the example of a logistics portal implemented by a Tier 1 supplier: «*Most of the logistics provider we work with did not have any issue in using our portal to share shipment information, but one of the largest providers had its own portal and was rather reluctant to use ours*» [Powertrain supplier, Head of Purchasing].

Against this, a possible trajectory seems to be to move from firm-specific portals to platforms. In our interviews we found the example of the spin-off seeking to set up a platform initiative in the automotive plastic components and machinery supply chain. This, however, seems possible only when there is no clear governance or dominant player: «*From Tier 2 suppliers on, the plastic supply chain is very fragmented and without a clear governance, we thought that a platform could provide valuable solutions for suppliers to showcase products and capabilities, and for customers to scout for supplies and allocate orders*» [Plastic equipment, Chief Information Officer].

NPD process – Another example in which technology is applied to share information more conveniently emerged in relation to R&D, and in particular the transmission of technical specifications. «*In the past clients would communicate with us their technical specification through a normal document. The product is becoming increasingly complex, we would need to read thousands of pages every time we offer a product. The usage of a requirement management tool is the most reasonable approach today*» [Diversified supplier, Head of R&D]. However, similar tools appeared to be used only by OEMs and Tier 1 suppliers «*because our Tier 2 suppliers are still not able to leverage these tools, and anyway we don't want to share all the information included, which is part of our know-how*» [Diversified supplier, Head of R&D].

4.4.5. Information is shared to enable service provision

This motivation for information sharing is essentially related to the opportunity – novel in the digital context – to generate value out of data related to connected products and machinery by offering additional services. The comments from several interviews suggest that this area is still a contested territory between supply chain participants.

Connected car – In the case of connected vehicles, Tier 1 suppliers seemed to hardly be able to access relevant data about their systems and components, notwithstanding various discussions with OEMs. «*Our sensors on the vehicle need to interface with the central control unit to transmit data. The conversation of who is owning the data has been going on for a while, and it created frictions between us and OEMs. On the one hand, OEMs want to keep the data for themselves, in order to provide or orchestrate relevant services. On the other hand, system suppliers also see servitization opportunities*» [Hardware and software supplier, ICT Director]. Some Tier 1 suppliers tried to directly connect their sensor, but with limited success. «[Name of Tier 1 supplier] *launched a project to have the sensors directly communicating with them, but very few clients actually installed them; they need to give up that OEMs hold the governance of the connected car service ecosystem*» [Luxury sports OEM, Head of Connected Vehicles]. In other words, thanks to connected products, OEMs can spot opportunities for value added services and involve the proper partners. Partnerships can be put in place also with players outside the automotive environment, such as insurance companies.

The interviewee also reported that dealers and maintenance workshops are partially losing their autonomy, as «*contracts in terms of product data are stipulated between the client and the OEM headquarters, bypassing importers and dealers*» [Importer, Marketing manager]. Dealers could install devices to collect data, but there was not much interest as «*connecting vehicles would mean for us to offer services that we do not have the capabilities for*» [Dealer 2, Chief Information Officer].

Fleet management – In the commercial segment the focus of the service is not only the single vehicle but more often the entire fleet. Fleet management services are not a novelty, and there are several specialized players on the market. Commercial OEMs have also been moving in this direction, and – considering the fact that fleets are often multi-brand – there is ample data sharing, either locally thanks to standardization of communication buses, or thanks to cloud-based data platforms. This seems not to be perceived as risky, as stated by one informant: «*Actually I thought that sharing data between competitors would have been harder. In reality we compete on something else: the quality of the vehicle, the quality of our services, and the overall digital/physical user experience*» [Commercial OEM, Head of Digital Transformation].

Autonomous driving – Data can be used not only to activate traditional services such as maintenance and repair, but also in relation to fully digital services connected to autonomous driving. Relevant technology in this space is developed by OEMs also in cooperation with digital companies and Tier 1 suppliers. Our interviews indicated that such alliances are needed to accelerate the time to market: «*we go both ways: internal capability development and collaborations with Tier 1 suppliers, digital companies like Alphabet and technology specialists like Ndivia. What is true today is that you need to be fast***:** *slowly but surely with own resources doesn't work anymore*» [Premium OEM 2, Head of Innovation]. Tier 1 suppliers had to change attitude towards data to compete in the digital space. It was explained that they «[...] *started off like 'I have the technology and the data are mine'. This is not going to work with large OEMs, and we needed to change course and set up different agreements. Only small clients that couldn't manage complex IT infrastructures accept their data to be managed by us. We work with clients' data as Amazon or Google would do, namely as technology providers. OEMs share the data with us for specific projects but maintain the ownership*» [Hardware and software supplier, Managing Director].

Machine and equipment-related services – As our case includes also machinery and equipment companies serving automotive OEMs and suppliers, we could also investigate how data are shared in this respect. Overall, we found that machine data are mostly kept and analyzed at plant level. This was explained by our informants in various ways. Automotive OEMs and suppliers stated that: «*many machinery producers are small and do not offer smart services*» [Hardware and software supplier, Managing Director]. Even in the case of more proactive machinery providers there is skepticism: «*we run some pilots, but in multi-plant corporations you can't have as many solutions as the brands of machinery you have installed. Therefore, we centralized IoT analytics and dashboards on our cloud*» [Hardware and software supplier, ICT Director]. Some interviews also showed different data sharing attitudes depending on the type of data – «*we have some collaboration for predictive maintenance: process data are our own business; machine failures are theirs. Whenever you buy a machine and then find a way to make it perform 'at limits' you are not willing to share this advantage with others*» [Diversified supplier, ICT Director] – and on the complexity of the production equipment – «*we can manage maintenance internally for simpler machinery*» [Mass market OEM, Production manager]. These issues were reflected also in the comments of executives at machinery producers: «*We offer AI-based services for process improvement, but there are few clients asking this: it is not taking off with large groups, old machines, plant-wide projects; it* *flies whenever the client has not internal capabilities and more in general for mid-sized clients*» [Metal equipment, Director].

4.5. Discussion

The aim of this paper was to explore how new technological opportunities in the digital context bring about new information sharing situations along the extended supply chain, and whether these situations reflect already theorized dynamics or require new frameworks or assumptions. We focused on one industry – automotive – that was already characterized by high levels of information sharing due to the application of previous technologies (e.g., EDI) and collaborative relations between OEMs and their suppliers.

Section 4.4. presents the results of our case study analysis. Starting from the motivations for companies to share data in inter-organizational settings (i.e., "rationale for information sharing"), we highlighted the changes that tool place over the last five to ten years. On balance, we saw that companies are still not taking full advantage of emerging technological opportunities for sharing information. In some areas, however, there is a higher integration, such as logistics – where the just-in-time and just-in-sequence models take great benefits from real-time data – and connected vehicle services. In other areas we could find some pilots, e.g., application of the blockchain technology, emergence of supply chain platforms. The early stages of the phenomenon do not enable us to make any inference about the future penetration of these practices, and yet the descriptions of their rationale, barriers and drivers seem to resonate with previous literature and theoretical perspectives applied to the information sharing phenomenon.

Among the various theories that have been used over the years to explain information sharing in supply chains (Kembro *et al.*, 2014), we set to elaborate on three different levels in order to analyze the phenomenon from different angles. In the following paragraphs, we will illustrate how these theories fit our evidence and elaborate specific comments on their relevance for information sharing in the digital context.

First, applying the RBV, we could posit that information that represent a source of competitive advantage are kept internally (e.g., connected vehicle data are not shared with Tier 1 suppliers), whereas data that support joint processes with the suppliers are shared (Patnayakuni et al., 2006; Hernández-Espallardo et al., 2010). Reading through our results, we believe that two aspects need a better articulation under this perspective. On the one hand, several interviews underscored a *difference between sharing data and sharing data ownership*. In many cases, data resources that represent a competitive advantage are shared with external partners, as long as the governance of flows and the ownership of data is kept internally. This is the case, for example, of connected vehicles data and operational data shared on supply chain platforms. On the other hand, many interviews underscored a *visibility misconception*, in that – despite the technological opportunities and the common SCM narrative – companies seemed not willing to invest to improve their visibility on the supply chain. This is mostly because of lack of other levers to intervene on suppliers and room for improvements in the internal organization. RBV could be further elaborated to explain how visibility needs to bundle with other practices/levers in order to bring real benefits to the organization.

Second, RDT explains several dynamics we saw emerging from our data, in particular power dynamics (customer dependance driving higher willingness to share data) and supplier development actions towards digitalization (Paulraj and Chen, 2017; Ulrich and Barney 1984). Further elaboration is instead needed as for the *integration misconception*, meaning that we found higher information sharing whenever the suppliers did not serve other companies in the same sector. In the pendulum between market and integration, the balance seems to shift towards higher customer-specificity of suppliers. Trust issues in fact demand closer collaborations, despite other benefits related to more market-based approaches.

Finally, CAS (Holweg and Pil, 2008) seems apt to illustrate some other emerging dynamics. In particular, we believe that the adaptive nature of the network should explain the presence of new players (e.g., supply chain platforms, digital companies) as well as different information sharing attitudes in different parts of the network (e.g., stronger roles of Tier 1 suppliers, information sharing initiatives at the Tier 2 level). Overall, we believe that information sharing should be read against the opportunity of a *focal firm misconception*, as the governance of information flows might be independent from the final buyers. A further elaboration of CAS refers to the role of the technology, as we saw local optimization (e.g., application of portals) clashing with system-level efficiency.

To conclude, the new digital context confirms many dynamics that make information sharing in supply chain an ongoing question mark. Some new trends seem however to be taking place, which are still possible to read through established theoretical lenses. However, in order for theory to be relevant in the digital scenario, further elaboration is needed.

CHAPTER 5. Concluding remarks

5.1. Synopsis

In view of the fact that Industry 4.0 is becoming increasingly topical, this doctoral dissertation presents a journey whereby key issues come progressively into focus. The dissertation is structured in three main chapters – each corresponding to a distinct study – which share the common goal of reaching a better understanding of the socio-technical features of the phenomenon and their apparent disruptive impact on current academic and managerial frameworks.

Chapter 2 raises methodological issues around the scope and the definitional dimensions of the phenomenon. These issues had mostly been overlooked by previous literature on Industry 4.0 with potential detrimental effects for related theoretical development. As is normal for complex, multi-faceted phenomena, Industry 4.0 research is expected to be characterized by phases of intense explorative investigations followed by moments of alignment and consolidation. In the light of the relative novelty of the topic, the study aims at initiating a debate with implications relevant for scholars across managerial disciplines. By means of a systematic literature review complemented with a selection of non-academic publications, the chapter illustrates a categorization of the defining elements of Industry 4.0 on six coding categories. Based on this categorization, commonalities and differences among the definitions were discussed, suggesting three research directions for the academic community to converge around the operationalization of the concept and a series of concrete implications for all researchers investigating Industry 4.0 across managerial disciplines.

Chapter 3 addresses the impact of Industry 4.0 on manufacturing value chains with a holistic perspective and a broad technological focus. Despite the ever-growing research interest in Industry 4.0 and related technologies, the overall picture was incomplete and not entirely coherent due to a fragmentation of research interest and technological focus. Moreover, impacts have been investigated mostly from the perspective of the focal company and its first-tier relations, whereas evolutionary phenomena are characterized by the embeddedness of individual decisions and outcomes in larger networks of business relations. Based on an extensive analysis of the literature, a series of workshops, and a Delphi study involving 76 experts (academics and practitioners), the chapter identifies the key dimensions of change and presents an assessment of their relevance by 2030. Starting from these analyses, the chapter concludes by putting forward an analytical perspective presented in the form of drivers and scenarios.

Finally, **Chapter 4** focuses on the impact of Industry 4.0 technologies for information sharing in supply chains. Information sharing has a long-lived history in supply chain management research and – alongside the many positive performance implications – several studies have highlighted risks, costs and ongoing reluctance. Today, as many researchers and observers posit the emergence of digital supply chains, few studies have investigated if and how companies move forward a higher level of information integration. The chapter presents a single embedded case study analysis of inter-organizational information flows within the extended automotive supply chain. As technology-driven changes and ongoing dynamics are read against established knowledge on information sharing in supply chains. The analysis highlights a series of new information sharing situations, together with drivers and barriers that only partially refer to already theorized dynamics.

5.2. Contributions

The doctoral dissertation fits in the growing debate on Industry 4.0 across managerial disciplines. Overall, the research presented contributes to a sharper understanding of the scope and breadth of changes brought about by emerging technologies, including the Internet of Things, additive manufacturing, cloud computing and artificial intelligence. The potential presence of paradigmatic properties is investigated with specific focus on manufacturing.

5.2.1. Contribution to theory

The first major contribution to theory refers to the conceptualization of the phenomenon. **Chapter 2** provides an analytical perspective for researchers to orient in the current definitional ambiguity by comparing Industry 4.0 with other concepts (e.g., Smart manufacturing, Cloud manufacturing, Fourth industrial revolution). The systematic literature review identifies a series of definitional dimensions and sub-dimensions characterizing Industry 4.0 in its technological and non-technological aspects. Some opportunities for future research to set the theoretical foundations of Industry 4.0 are also highlighted.

The second major contribution is to identify potential evolutionary trajectories and ongoing uncertainties as for the future of manufacturing value chains. In particular, **Chapter 3** promotes a cross-disciplinary debate drawing from different streams of research that have investigated the issue separately so far. The study links literature in operations and supply chain management with strategy and business model research, including broad-range considerations on topics such as manufacturing servitization, mass customization, technological platforms and multi-sided markets, reshoring, and redistributed manufacturing. The results describe the emerging paradigmatic characteristics of Industry 4.0, building on the assessment of expert academics and practitioners. This description confirms some dynamics highlighted in the literature, while putting into perspective other evolutionary trajectories, such as new production models, reshoring and individual prosumers. The formulation of eight scenarios presents a range of possible futures, making explicit how Industry 4.0 is prone to different context-specific variations that can be traced back to four key drivers, namely demand characteristics, transparency of data among value chain participants, maturity of additive manufacturing and advanced robotics, and penetration of smart products.

The third contribution refers to the empirical analysis of the impact of Industry 4.0 technologies on information sharing in supply chains presented in **Chapter 4**. Against the mainstream narrative of digital supply chains, the study highlights the presence of more complex dynamics as for the opportunity and willingness of manufacturing companies to share information and in particular product- and machine-generated data across organizational boundaries. The chapter shows how these dynamics can be seen against the established body of knowledge in the field of information sharing in supply chains. Moreover, as the issue is investigated in the context of an extended supply chain, we add to a debate that has mostly investigated situations in dyadic buyer-supplier relationships.

5.2.2. Contributions to practice

As far as the contribution to the practice is concerned, the dissertation stresses the complexity and multidisciplinary nature of the phenomenon against the typical management fashion parabola. In particular, **Chapter 2** shows how Industry 4.0 is not about “plug-and-play” technologies – as often depicted in the popular press – but requires a series of complementary innovations in organizational practices in line with contextual factors.

Part of the study was carried out with the support of the Boston Consulting Group (BCG), which was involved in the identification of the research question (Chapter 3 and Chapter 4) as well as in various brainstorming and validation sessions. This steady dialogue with consultants involved in Industry 4.0 implementation was useful to ensure the relevance of the research also for a practical audience.

The conceptual model and the list of projections presented in **Chapter 3** can be used in strategic planning exercises as an assessment tool by companies, business associations, consulting firms, or regions/countries to identify future scenarios specific for a particular company, sector and/or geographical area. The four drivers identified as determinants of the different future scenarios (i.e., demand characteristics, transparency of data among value chain participants, maturity of additive manufacturing and advanced robotics, and penetration of smart products) might also be considered separately to delve into the most compelling uncertainties behind strategy formulation. The projections – or more likely a sub-set of them – might be analyzed by the aforementioned subject either through workshops and focus groups or through Delphi studies (as applied in this paper). Managers and consultants of companies operating in Apparel and Footwear, Automotive, and Machinery and Equipment may leverage our specific results as direct input. Similarly, some specific findings might be used as a guideline for policy interventions (e.g., highlighting aspects, practices or sectors requiring more specific legislation).

The issue of information (data) sharing in the context of Industry 4.0 is likewise relevant for both managers and policymakers, as shown by the number of initiatives aimed at breaking down technical and regulatory barriers to a smoother integration of information systems and data accessibility. The results of the case study developed in **Chapter 4** show emerging dynamics in the automotive extended supply chain, explicating both opportunities and antecedents to information integration. In particular, the study dispels the myth of digital supply chains as it highlights ongoing reluctances and doubts as for the distribution of value generated through data sharing. Although the empirical setting is in automotive, executives from other industries can find in the analysis a useful analytical perspective to read opportunities, drivers and barriers applicable also to other contexts.

5.3. Limitations and future research

The research presented in this doctoral dissertation is not exempt from limitations. The most crucial ones refer to the fact that Industry 4.0 is a phenomenon “still in the making” and characterized by rapid and transformative developments. The adoption rate of new technologies is on the rise; however, many companies – especially the smaller ones – are lagging behind. As researchers, we can now only posit some evolutionary trajectories from early examples and long-term trends. Only time and further empirical investigations will show how these initial hypotheses will serve to explain future reality.

Under this premise, the systematic literature review (**Chapter 2**) presents the academic understanding on the phenomenon as for almost two years ago (research includes contributions published until February 2019). Since then, research has made significant progress sharpening the understanding of the phenomenon and its features; other articles have been published that work on conceptualizations of the phenomenon. Notwithstanding this, I still trust that the approach of the study – i.e., an open-ended conceptualization whereby key definitional categories are identified – is still a valid methodological approach to the conceptualization and operationalization of the phenomenon.

As for the Delphi-based scenario analysis of **Chapter 3**, the study presents the common downsides of forecasting with respect to unexpected events having significant (disruptive) impacts. As I was wrapping up the study, the pandemic related to the coronavirus COVID-19 was seriously affecting a large and growing number of countries around the world. Other general limitations refer to possible biases in participants' judgment formulation, as broadly discussed in Plous (2007) and Derbyshire and Wright (2014), while peculiar to the study are possible effects on the results determined by the selection of the industries to be included in the assessment and by the panel composition, which was skewed towards experts from European countries and from the US and included mostly executives from incumbent companies.

The fact the adoption of digital technologies – especially those related to supply chain applications – is still related to few companies and mostly at the pilot stage is possibly the main limitation of the case study analysis presented in **Chapter 4**, together with the industry focus. The study enabled the identification of new practices and trends; however, as digitalization proceeds very rapidly across industries and sectors, further follow-ups might be required to get an updated and accurate picture.

Several opportunities for future research arise from the dissertation. The logical next step would be for the scenarios to be substantiated with empirical studies to understand their relevance and boundary conditions, as well as with theory-based research focused on explaining their mechanisms. Our effort might also be replicated in the service sector, to better understand emerging trajectories across current industry boundaries. The most relevant research opportunities refer to how VC "control points" will evolve in the light of emerging cross-industry ecosystems. Other research topics are more specific, and refer to the implementation of small-scale production modes, the interplay between Industry 4.0 and circular economy practices, the technological determinants of reshoring, and IoT standardization effects on competition.

The issue of data at inter-organizational boundaries pinpoints this debate, managerial research is essential to understand barriers, benefits and drawbacks of data sharing with business partners and emerging data governance modes. Policy research should work to suggest a portfolio of long-term action points addressing the potential dark sides of data-sharing in manufacturing.

To conclude, as Industry 4.0 is still in the making, there are tremendous opportunities for future research. Since the scientific community is witnessing an "announced" revolution, there is room for taking an active role in providing pivotal information and supporting the translation of this vision into reality. In this peculiar historical moment as the word struggles with an unprecedented health crisis, structural measures will probably be required to inject new impetus into the economy. In manufacturing a powerful response might be to boost innovation within the Industry 4.0 trajectory. Making the right decisions requires, however, that the options and their implications are well understood- In many respects the current understanding of the nature of Industry 4.0 is still blurred: different scenarios seem equally possible today depending on some crucial issues in relation to data, technologies, and demand characteristics. The effects of how these issues are approached will be profound not only for the future of individual companies but also for the competitiveness of manufacturing economies across the globe.

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APPENDIX

Table 19. Thematic findings - full coding tables - Scope and Key enabling technologies (ref. Chapter 2)

	2. Scope			3. Key enabling technologies													
Source	**Manufacturing**	**Consumer / society**	**In other sectors**	**Internet-of-Things**	**Cyber-physical systems**	**Visualization technologies**	**Cloud computing**	**Interoperability and cybersecurity solutions**	**Blockchain technology**	**Simulation and modelling**	**Machine learning and artificial**	**Big data analytics**	**3d printing**	**Advanced robotics**	**New materials**	**Energy management solutions**	**Technological generics**
Anderl, 2015	x		x	x	x		x	x		x	x						
Barreto *et al.*, 2017	x		x	x	x		x	x			x	x					x
Chiarello *et al.*, 2018	x			x		x	x		x			x	x	x			
Cimini *et al.*, 2019	x			x	x			x				x	x	x			x
Cristians and Methven, 2017	x	x			x	x	x	x		x		x	x	x			
Dobos *et al.*, 2018	x			x	x							x					
Drath and Horch, 2014	x				x		x	x		x		x					
Fatorachian and Kazemi, 2018	x			x	x		x	x				x					x
Frank *et al.*, 2019	x			x	x	x	x	x		x	x	x	x	x		x	
Ghobakhloo, 2018	x	x		x	x	x	x	x	x	x		x	x	x			
Havle *et al.*, 2018	x			x	x	x	x	x		x	x	x	x	x			x
Hermann *et al.*, 2016	x			x	x	x											x
Hofmann and Rüsch, 2017	x			x	x	x	x		x	x	x	x					x
Hozdić, 2015	x			x	x					x	x						x
Kagermann, 2015	x			x	x		x	x				x					
Kamble *et al.*, 2018	x	x		x	x	x	x	x		x		x	x	x			
Khan and Turowski, 2014	x			x	x		x	x			x						
Kirazli and Hormann, 2015	x			x	x		x				x	x		x			
Lasi *et al.*, 2014	x		x		x	x					x		x				x
Lu, 2017	x	x	x	x	x	x	x	x		x	x	x					
Muhuri *et al.,* 2019	x			x	x	x	x	x	x	x	x	x	x	x		x	x
Neugebauer *et al.*, 2016	x		x	x	x	x	x	x			x		x	x			
Ojra, 2019	x			x													x
Oztemel and Gursev, In press	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Piccarozzi *et al.*, 2018	x			x													
Pires *et al.,* 2018	x			x	x	x	x			x	x	x	x				
Pereira and Romero, 2017	x	x		x	x	x	x				x	x		x			x
Preuveneers and Ilie-Zudor, 2017	x			x	x	x	x	x		x	x	x					
Qin *et al.*, 2016	x			x	x					x	x	x					
Raja Sreedharan and Unnikrishnan, 2017	x			x	x		x										x

Roblek *et al.*, 2016	x	x	x	x	x		x	x			x						x
Rojko, 2017	x			x	x	x	x			x	x	x	x	x			x
Saldivar *et al.*, 2015	x			x	x		x	x		x	x	x					x
Santos *et al.*, 2017	x			x	x		x				x		x	x			
Schmidt *et al,* 2015	x			x	x		x				x	x					
Schuh *et al.*, 2014	x			x	x			x		x							
Suacedo-Martìnez *et al*, 2018	x					x	x	x		x		x	x	x			x
Vaidya *et al.,* 2018	x			x	x	x	x	x		x		x	x	x			x
Wan *et al.*, 2015	x	x	x	x	x	x	x	x			x	x	x	x			x
Wang *et al.*, 2017	x			x	x		x				x	x	x				
Xu *et al.*, 2018	x			x	x		x	x	x								x
Zhou *et al.*, 2015	x	x		x	x		x	x		x	x	x	x				
Adamson *et al.*, 2017	x	x		x			x	x		x	x						
Fisher *et al.*, 2018	x			x			x	x		x	x	x	x				x
Kassim *et al.*, 2017	x	x		x		x	x			x							
Kubler *et al.*, 2016	x			x			x						x				
Lu *et al.*, 2013	x			x	x		x	x		x	x						
Ning *et al.*, 2011	x			x			x	x		x							
Ren *et al.*, 2015	x			x			x	x		x	x	x					
Ren *et al.*, 2017	x			x			x	x		x	x	x					
Tao *et al.*, 2011	x	x		x			x	x		x	x						
Wu *et al.*, 2015	x	x		x	x	x	x			x		x					
Yadekar *et al.*, 2016	x	x		x			x	x		x							
Zhang *et al.*, 2014	x	x		x			x	x		x	x						
Kang *et al.*, 2016	x			x	x	x	x	x		x	x	x	x				x
Kumar, 2018	x			x				x					x	x	x		
Kusiak, 2018	x		x	x	x	x	x	x		x	x	x	x	x	x	x	
Mittal *et al.*, 2016	x			x	x	x	x	x		x	x	x	x		x		x
Radziwon *et al.*, 2014	x																
Tao and Qi, In Press	x			x	x	x	x	x		x	x	x					
Zheng *et al.,* 2018	x			x	x	x	x			x	x	x	x	x			x
Lom *et al.*, 2016	x	x	x	x	x		x			x	x						
Kumar *et al.,* 2016	x	x								x		x	x				x
Postranecky and Svitek, 2017	x	x	x	x	x	x	x	x		x	x						
Xiong *et al.*, 2018	x	x		x		x	x			x	x	x	x				
Yao and Lin, 2015	x	x		x	x		x	x			x		x				x
Yao *et al.*, 2017	x	x		x	x		x			x	x	x					
Lee *et al.*, 2016	x			x	x		x	x		x	x	x					
Song and Moon, 2017	x	x		x	x	x	x			x	x	x	x				
Maynard, 2015	x		x	x			x				x		x	x	x		
Tien, 2012	x		x				x	x		x	x	x	x	x	x	x	x
Dumitrache and Caramihai, 2014	x				x					x	x						
Zhong *et al.,* 2017	x			x	x	x	x			x	x	x	x	x			
Li *et al.*, 2017	x		x	x	x	x	x	x		x	x	x	x				
Boyes *et al.*, 2018	x		x	x			x										x
Sissini *et al.*, 2018	x			x	x												x

Ebert and Duarte, 2018	x	x	x	x		x	x	x	x	x	x		x	x			
Rödder *et al.*, 2016	x		x				x		x								x
Chu *et al.*, 2016	x						x						x				x
Thames and Schaefer, 2016	x												x				x
Thoben *et al.*, 2017	x		x	x	x		x	x			x	x		x			x
Kagermann *et al.*, 2013	x			x	x		x	x		x		x					x
Fiesp, 2017a/b	x	x		x		x				x	x		x	x	x		x
Ministrero dello Sviluppo Economico, 2016	x					x	x	x		x		x	x	x			x
State National Council, 2015	x		x	x		x	x	x		x		x	x	x	x		x
Usine du Futur, 2016	x			x	x	x	x	x		x	x	x	x	x	x	x	
Prime Minister of Japan and His Cabinet, 2017	x		x	x		x	x	x	x	x	x	x		x	x	x	
MOTIE, 2014	x	x	x	x	x	x	x	x		x		x	x		x	x	x
HM Government, 2017	x		x	x		x		x	x		x	x	x	x	x	x	x
Executive Office of the President, 2012	x				x	x				x			x	x	x	x	
UNIDO, 2017	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
European Commission, 2013	x	x		x		x	x	x		x	x	x	x	x	x	x	x
OECD, 2017	x	x	x	x		x	x	x		x	x	x	x	x	x	x	
Schwab, 2016	x	x	x	x			x	x	x		x	x	x	x	x	x	
Rußmann *et al.*, 2015	x			x		x	x	x		x	x	x	x	x			
McKinesy Digital, 2015	x			x	x	x	x	x		x	x	x	x	x		x	
IEC, 2015	x	x		x	x	x	x	x		x	x	x	x	x		x	x
Bradley *et al.*, 2013	x		x				x	x			x	x					x
Evans and Annunziata, 2012	x		x				x	x			x	x					x

Table 20. Thematic findings - full coding tables – Other enablers, distinctive characteristics, expected outcomes (ref. Chapter 2)

	4. Other enablers		**5. Distinctive characteristics**								**6. Expected outcomes**								
Source	**Organisational enablers**	**New business models**	**Real-time information transparency**	**Virtual representation of the real world**	**Predictability**	**Modularity and reconfigurability**	**Autonomy**	**Process intergration**	**Servitization of manufacturing capabilities**	**Product servitisation**	**Productivity**	**Flexibility**	**Mass customisation / personalisation**	**Time and cost to market**	**Environmental sustainability**	**Quality**	**Lead time**	**Economic growth**	**Employment**
Anderl, 2015			x	x				x			x	x		x					
Barreto *et al.*, 2017		x	x				x	x			x	x	x	x					
Chiarello *et al.*, 2018																			
Cimini *et al.*, 2019			x	x		x	x	x	x	x	x	x	x	x	x	x	x		x
Cristians and Methven, 2017			x	x			x	x			x								
Dobos *et al.*, 2018					x														
Drath and Horch, 2014			x	x			x						x						
Fatorachian and Kazemi, 2018			x	x	x	x	x	x		x	x	x	x	x	x	x	x		
Frank *et al.*, 2019	x		x	x	x	x	x	x		x	x	x	x	x	x	x	x		
Ghobakhloo, 2018	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x		
Havle *et al.*, 2018	x						x				x	x	x			x	x		
Hermann *et al.*, 2016	x		x	x		x	x					x	x						
Hofmann and Rüsch, 2017	x	x	x	x	x		x	x		x	x	x	x				x		
Hozdić, 2015		x	x	x	x	x	x	x		x	x	x	x	x		x	x		
Kagermann, 2015	x	x	x	x			x	x		x	x	x	x	x	x			x	x
Kamble *et al.*, 2018	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Khan and Turowski, 2014	x		x	x	x		x	x	x	x	x	x	x	x		x			
Kirazli and Hormann, 2015			x	x			x	x				x	x	x	x		x		
Lasi *et al.*, 2014	x		x	x		x	x	x		x	x	x	x	x	x				
Lu, 2017	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		
Muhuri *et al.,* 2019																			
Neugebauer *et al.*, 2016	x		x	x	x	x	x	x	x		x	x	x		x			x	
Ojra, 2019									x		x								
Oztemel and Gursev, In press	x		x	x	x	x	x	x	x		x	x	x	x	x	x			
Piccarozzi *et al.*, 2018	x	x						x				x							
Pires *et al.,* 2018			x	x		x		x	x	x									
Pereira and Romero, 2017	x	x	x	x		x	x	x		x	x	x	x	x		x		x	

Preuveneers and Ilie-Zudor, 2017			x	x	x	x	x	x			x	x	x			x			
Qin *et al.*, 2016			x		x	x	x	x		x									
Raja Sreedharan and Unnikrishnan, 2017								x											
Roblek *et al.*, 2016	x	x	x	x	x		x	x		x	x	x	x	x	x				
Rojko, 2017			x	x	x	x	x	x			x	x	x	x	x				
Saldivar *et al.*, 2015		x	x	x		x	x		x		x	x	x	x					
Santos *et al.*, 2017	x	x	x	x		x	x	x	x		x	x		x			x		
Schmidt *et al,* 2015	x	x		x	x			x		x			x	x			x		
Schuh *et al.*, 2014	x		x	x			x	x			x		x						
Suacedo-Martìnez *et al*, 2018																			
Vaidya *et al.*, 2018			x	x		x	x	x				x	x	x		x	x		
Wan *et al.*, 2015	x		x	x	x		x	x		x	x	x	x	x	x				x
Wang *et al.*, 2017				x			x	x					x						
Xu *et al.*, 2018	x		x	x				x	x	x									
Zhou *et al.*, 2015	x		x	x				x		x	x	x	x						
Adamson *et al.*, 2017	x	x	x	x				x	x	x	x	x	x	x	x				
Fisher *et al.*, 2018		x	x	x	x	x	x	x	x		x	x	x		x	x			
Kassim *et al.*, 2017		x		x				x	x	x	x	x	x				x		
Kubler *et al.*, 2016				x			x	x	x		x	x	x	x	x				
Lu *et al.*, 2013		x		x				x	x		x	x	x	x	x	x	x		
Ning *et al.*, 2011		x	x	x				x	x		x	x				x	x		
Ren *et al.*, 2015		x	x	x				x	x		x	x	x	x					
Ren *et al.*, 2017		x	x	x	x		x	x	x		x	x	x	x					
Tao *et al.*, 2011		x		x				x	x		x	x		x	x		x		
Wu *et al.*, 2015		x	x	x				x	x		x	x	x	x			x		
Yadekar *et al.*, 2016		x	x	x				x	x										
Zhang *et al.*, 2014	x	x		x				x	x		x			x					
Kang *et al.*, 2016			x		x		x	x	x		x	x	x		x	x	x	x	
Kumar, 2018																			
Kusiak, 2018			x	x	x		x	x	x				x		x	x			
Mittal *et al.*, 2016			x	x	x	x	x	x			x	x	x		x				
Radziwon *et al.*, 2014							x	x			x	x				x	x		
Tao and Qi, In Press			x	x	x		x	x	x		x	x	x	x	x	x			
Zheng *et al.*, 2018			x	x	x		x		x		x	x	x	x	x	x	x		
Lom *et al.*, 2016			x	x	x	x	x	x	x		x	x	x		x				
Kumar *et al.,* 2016	x	x				x	x				x	x	x	x			x		
Postranecky and Svitek, 2017			x	x		x	x	x	x	x		x			x				
Xiong *et al.*, 2018		x										x	x						
Yao and Lin, 2015	x		x					x			x	x	x	x					
Yao *et al.*, 2017			x		x		x	x	x	x	x	x	x		x				
Lee *et al.*, 2016	x			x	x		x	x			x	x		x			x		
Song and Moon, 2017			x		x		x		x		x				x	x	x		
Maynard, 2015				x											x			x	
Tien, 2012			x			x		x		x	x	x	x					x	x
Dumitrache and Caramihai, 2014			x	x			x	x			x	x	x		x	x			

Zhong *et al.*, 2017	x		x	x			x	x	x		x	x	x			x			
Li *et al.*, 2017			x	x	x		x	x	x	x	x	x	x	x	x				
Boyes *et al.*, 2018			x				x				x				x		x		
Sissini *et al.*, 2018			x	x		x		x		x					x				
Ebert and Duarte, 2018	x	x																x	
Rödder *et al.*, 2016	x	x	x		x					x			x						
Chu *et al.*, 2016						x		x			x	x	x		x	x	x		
Thames and Schaefer, 2016				x								x							
Thoben *et al.*, 2017	x	x	x	x	x		x	x	x	x	x	x	x		x	x			
Kagermann *et al.*, 2013	x	x	x	x	x	x	x	x		x	x	x	x		x			x	x
Fiesp, 2017a/b	x		x	x	x	x	x	x		x	x	x		x	x	x	x		
Ministrero dello Sviluppo Economico, 2016										x	x	x		x		x			
State National Council, 2015	x	x	x				x	x	x	x	x		x	x	x	x		x	
Usine du Futur, 2016	x	x	x		x	x	x	x		x	x	x	x	x	x	x	x	x	x
Prime Minister of Japan and His Cabinet, 2017	x		x					x		x	x	x	x	x	x			x	
MOTIE, 2014	x	x	x					x	x	x	x		x	x	x	x	x	x	
HM Government, 2017	x	x													x			x	x
Executive Office of the President, 2012								x			x		x					x	x
UNIDO, 2017	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
European Commission, 2013	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x
OECD, 2017	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
Schwab, 2016	x	x								x	x	x		x	x	x	x	x	
Rußmann *et al.*, 2015	x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x	x
McKinesy Digital, 2015	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
IEC, 2015	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Bradley *et al.*, 2013	x	x	x								x	x	x	x	x	x			
Evans and Annunziata, 2012	x		x		x		x	x			x				x			x	x

Table 21. Case study protocol – Checklist (ref. Chapter 4)

Section	**Protocol questions**
1. Background	a. Please, describe the company in terms of: - Turnover, employees, product/service offering and business lines, main clients, geographies served. - Strategy (cost leadership vs. differentiation) and main competitors by business line. - Network of relations (main suppliers, main customers, technology providers, consortia or alliances, platforms) - In- vs. outsourcing of key activities - Digital transformation strategy, implementation of key enabling technologies, concurrent changes in the business model b. Please, describe your role and your involvement in the implementation of digital projects
2. Current information sharing practices and technology-driven changes	a. Please, describe the type of information/direction of the data flow, type of business partner involved, underpinning technology, rationale for sharing. Consider: - Suppliers and upstream partners and intermediaries - Customers and downstream partners and intermediaries - Technology providers (including machinery and equipment manufacturers, digital companies) - Others (e.g., public administration, competitors, industry consortia, alliances) b. What of the information flows you just described were impacted by emerging technologies in the last 5/10 years? How? c. Is there any plan to implement other inter-organizational information sharing project in the next few years?
3. Antecedents and implementation process	a. Were there any missed opportunities for higher information sharing? Why they were not implemented? - Promoted by the company towards external players - The company was invited but did not take part b. Please, reflect upon: - The main drivers of the recent (5/10 years) changes in inter-organizational information sharing practices - The main barriers of the recent (5/10 years) missed opportunities in inter-organizational information sharing practices

	c. What were the main challenges the company needed to overcome during the implementation process of the recent (5/10 years) changes in inter-organizational information sharing practices.
4. Impact	a. Did some reconfiguration of the network of business relations happen in relation to changes in inter-organizational information sharing practices? (e.g., in- vs. out-sourcing, new suppliers/clients) If yes, why? b. Changes in performance - Did company experience some (positive/negative) changes in performance as a consequence of higher information sharing? How? - Were these in line with expectations? If not, why?