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## The future of manufacturing: A Delphi-based scenario analysis on Industry 4.0



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### ABSTRACT

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 features of the emerging paradigm appear to be a contested territory among different academic disciplines. This study assumes a value chain perspective to analyze the evolutionary trajectories of manufacturing companies. 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. Researchers can derive from our study a series of hypotheses and opportunities for future research on Industry 4.0. Managers and policymakers can leverage the scenarios in long-term strategic planning.

### 1. Introduction

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, 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 macroeconomic indicators (Brynjolfsson and McAfee, 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 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; Rymaszevska 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., 2020; 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

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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 et al., 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; Sartor et al., 2015; Raikes et al., 2000).

Under this premise, the following research question is addressed:

*RQ1: 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). As a result, we provide a comprehensive overview of which configurations are to be expected under the Industry 4.0 paradigm and raise questions on some impacts that, although broadly discussed in the literature, were perceived as controversial by the expert panel. The link between contextual drivers and future configurations is made explicit in eight scenarios.

This study contributes to the current debate on Industry 4.0 by highlighting its most agreed-upon paradigmatic properties in the configuration of manufacturing companies and by explicating a context-specific typology. We also draw the attention of business leaders and policy makers towards current uncertainties and far-reaching implications of Industry 4.0.

The rest of the paper is structured as follows. Section 2 provides the literature background presenting the current knowledge about the

effects of Industry 4.0 and related technologies on manufacturing VCs. Section 3 describes the research methodology. Section 4 presents the statistics and content analysis of the Delphi study. In Section 5 we discuss the main implications deriving from the Delphi study and formulate the scenarios. We conclude in Section 6 by outlining the main contributions and limitations of the study.

## 2. 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 2.1) we elucidate the concept and provide an overview of the main research issues. The literature more closely related to the scope of this study is then summarized in Section 2.2 (impacts of Industry 4.0 on manufacturing companies) and in Section 2.3 (impacts of Industry 4.0 on other players involved in manufacturing VCs). Finally, limitations of the literature and research gaps are outlined in Section 2.4.

The papers presented in Sections 2.2 and 2.3 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”). 7115 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.

### 2.1. Industry 4.0: concept and research issues

Industry 4.0 is an overarching concept describing an ongoing industrial revolution triggered by a new wave of technological innovation (Lasi et al., 2014; Liao et al., 2017; Ghombakhloo, 2018). The idea was first expounded in the context of industrial policy when in 2011 Germany introduced the initiative “Industrie 4.0”, which was aimed at instilling new impetus to manufacturing through innovation-driven collaboration among business, academia, and politics (Kagermann et al., 2013; Reischauer, 2018). 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., 2020); 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., 2020). 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 technologies underpinning the phenomenon are various – Chiarello et al. (2018) identified more than 1,000 individual technologies referring to 30 different disciplinary fields – and the landscape is still evolving through convergence and mutual combination (Yoo et al., 2012; OECD, 2017). Some classifications of the main enabling technologies have been put forward in the literature (e.g., Ghombakhloo, 2018; Pereira and Romero, 2017; Frank et al., 2019a; Culot et al., In Press). Overall, the technologies most mentioned are the Internet of Things, cyber-physical systems, cloud computing, big data analytics, vertical and horizontal system integration, additive manufacturing, simulation, augmented reality, advanced robotics, augmented reality, and – most recently – the blockchain technology. New materials – e.g., “smart”, nano-, bio-based materials – and energy storage solutions have also been cited, although less frequently (e.g., OECD, 2017; Kusiak, 2018). Specific applications of these technologies might further automate internal production and business processes, provide support and assist the workforce, facilitate interactions with clients and customers along the supply chain, and be used for “smart products” (Frank et al., 2019a).

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., 2020); best-practice implementation processes (e.g., Mellor et al., 2014; Svan et al., 2017; Zangiacomì et al., 2020; Tortorella et al., 2020; Veile et al., 2020); 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., 2020; Castelo-Branco et al., 2019), expert studies (Lu and Weng, 2018a, 2018b) and case research (Calabrese et al., 2020). 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 Johnson, 2016); 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., 2020). 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.

## 2.2. 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 1.

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, in particular Automotive and Machinery and Equipment, while few papers have considered the evolutionary trajectories that are taking place in both manufacturing and services.

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

**Table 1**  
Relevant literature

Author(s), year	Technologies	Perspective	Methodology	Industry focus	Time horizon	Main topics
Ancarani et al., 2019	Industry 4.0	Firm	Secondary data analysis	Manufacturing	Present	Relationship between reshoring, Industry 4.0 adoption, and performance objectives.
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.
Athanasopoulou et al., 2019	IoT, energy solutions	Business model	Expert study	Automotive	Future	Technology-driven services impacting automotive business models.
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.
Barbieri et al., 2017	Industry 4.0	Firm	Conceptual	Manufacturing	Present	Review extant research on manufacturing reshoring.
Bessière et al., 2019	IoT, Big Data	Industry	Expert study	Consumer goods	Future	Challenges, opportunities, and research questions on redistributed manufacturing.
Berman, 2012	AMTs	Not specified	Conceptual	Manufacturing	Future	Characteristics and applications of AMTs in the light of mass customization.
Bertola and Teunissen, 2018	Industry 4.0	Industry	Illustrative cases	Apparel and Footwear	Present/ Future	Product characteristics and approaches to operations and supply chain.
Birtchnell and Urry, 2013	AMTs	Economy/society	Conceptual	Manufacturing	Future	Future applications and spread of AMTs.
Birtchnell et al., 2017	AMTs	Economy/society	Multiple case study	Manufacturing	Present	Involvement of tertiary institutions in AMTs.
Boehmer et al., 2020	IoT	Business model	Multiple case study	Automotive, Machinery and Equipment	Present	Pathways to servitizing the business model through IoT implementation.
Bokrantz et al., 2017	Industry 4.0	Function	Expert study	Machinery and equipment	Future	Future developments of the maintenance function.
Bogers et al., 2016	AMTs	Supply chain	Conceptual	Consumer goods	Future	Interdependent evolution of business models and supply chain geographical configuration.
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.
Cenamora 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.
Chang et al., 2019	Blockchain	Supply chain	Conceptual	Manufacturing	Future	Impact of the blockchain technology and smart contracts on supply chain process design.
Cole et al., 2019	Blockchain	Supply chain	Conceptual	Manufacturing	Present	Potential applications of blockchain technology in the context of operations and supply chain management.
Corcynen et al., 2017	Digital technologies	Business model	Multiple case study	Manufacturing	Present	Servitization pathways of manufacturing SMEs
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.
Dachs, et al., 2019	Industry 4.0	Firm	Survey	Manufacturing	Present	Relationship between reshoring, Industry 4.0 adoption, and performance objectives.
D'Aveni, 2015	AMTs	Firm/Ecosystem	Illustrative cases	Manufacturing	Future	Future applications of AMTs and strategic implications for managers.
D'Aveni, 2018	AMTs	Firm	Illustrative cases	Manufacturing	Future	Typology of AMT implementation models and competitive implications.
Durach et al., 2017	AMTs	Supply chain	Expert study	Manufacturing	Future	Emerging applications of AMTs, barriers, and timeline of adoption.
Ehret and Wirtz, 2017	IoT	Business model	Conceptual	Manufacturing	Present	Conditions for non-ownership business models and their characteristics.
Ferráz-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.
Frank et al., 2019b	Industry 4.0	Business model	Conceptual	Manufacturing	Present	Interplay between servitization, and Industry 4.0 in product firms.
Fratocchi, 2018	AMTs	Firm	Multiple case study	Manufacturing	Present	Relationship between reshoring, AMTs adoption, motivation and sourcing.
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.

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**Table 1** (continued)

Author(s), year	Technologies	Perspective	Methodology	Industry focus	Time horizon	Main topics
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.
Halassi et al., 2019	AMTs	Not specified	Survey	Manufacturing	Present	Emergence of "prosumers" designing and printing at home.
Hamalainen and Karjalainen, 2017	AMTs	Business model	Multiple case study	Manufacturing	Present	Nature of technology-driven business models based on firm-individual collaboration.
Hannibal and Knight, 2018	AMTs	Global factory	Conceptual	Manufacturing	Future	Industry and product characteristics driving the localization of production.
Holmström et al., 2016	AMTs	Supply chain	Conceptual	Manufacturing	Present/ Future	Impact of AMTs on production operations and supply chain structure.
Iansiti and Lakhani, 2014	IoT	Business model	Illustrative cases	Manufacturing, Services	Future	Impact of IoT and digital transformation on business models and competition.
Jia et al., 2016	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.
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.
Kapetanidou et al., 2018	AMTs	Firm/Industry	Secondary data analysis	Manufacturing	Present	Differences between industries and firms in the application of AMTs.
Katsikeas et al., 2020	Cloud computing, big data analytics	Firm	Conceptual	Manufacturing, Services	Future	Impact of digital technologies on foreign market selection and entry decisions.
Kiel et al., 2017	IoT	Business model	Multiple case study	Manufacturing	Present	Impact of IoT on manufacturing business models.
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.
Kotarba, 2018	Various digital technologies	Business model	Conceptual	Manufacturing, Services	Present	Changes in the morphology of business models due to increasing digitalization.
Kumar et al. 2016	IoT, Big data, AMTs	Supply chain	Conceptual	Manufacturing	Future	Role of smart cities in supply chain design.
Langley et al., 2020	IoT	Business model/ Ecosystem	Conceptual	Manufacturing, Utilities, Services	Future	Impact of IoT on business models from a networked/ecosystem perspective.
Laplume et al., 2016	AMTs	Global value chains (GVCs)	Conceptual	Manufacturing	Future	Impact of AMTs on GVCs (production) across different industries.
Leminen et al., 2020	IoT	Business model/ Ecosystem	Conceptual and illustrative cases	Automotive, Machinery & Equipment	Future	Types of IoT-enabled servitized business models.
Montes and Ollerros, 2019	AMTs, various digital technologies	Firm	Conceptual	Manufacturing	Present	Enablers and implications of the micro-factory model.
Morandlou and Tate, 2018	AMTs	Firm	Survey	Manufacturing	Present	Relationship between reshoring, AMTs adoption, and postponement.
Morkunas et al., 2019	Blockchain	Business model	Conceptual	Manufacturing, Services	Future	Effects of blockchain technologies on the business models of non-financial firms.
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.
Nascimento et al., 2019	Industry 4.0	Business model	Expert study	Manufacturing	Future	Integration of Industry 4.0 and circular economy practices.
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.
Oprešnik and Taisch, 2015	Big Data	Business model	Conceptual	Manufacturing	Future	Role of big data as enabler of servitization strategies.
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.
Petrick and Simpson, 2013	AMTs	Not specified	Conceptual	Manufacturing	Future	Future disruptions triggered by AMTs on manufacturing.
Porter and Heppelman, 2014	IoT	Industry	Illustrative cases	Manufacturing	Present/ Future	Impact of smart products on industry structure and the nature of competition.
Potstada and Zybura, 2014	AMTs	Economy/society	Expert study	Consumer electronics	Future	Science fiction prototyping for home fabrication in 2033.
Rauch et al., 2017	Industry 4.0	Manufacturing networks	Conceptual	Manufacturing	Present/ Future	State of the art and future developments of redistributed manufacturing.
Rayna and Striukova, 2016	AMTs	Firm/ecosystem	Conceptual	Manufacturing	Present	Impact of AMTs on business model configuration and innovation.

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Table 1 (continued)

Author(s), year	Technologies	Perspective	Methodology	Industry focus	Time horizon	Main topics
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).
Roden et al., 2017	Big Data	Firm	Multiple case study	Manufacturing	Present	Role of Big Data in transforming firms' operation models.
Rong et al., 2015	IoT	Ecosystem	Multiple case study	Automotive, Media	Present	Parallel evolution of individual firms' business models and their ecosystems.
Roscoe and Blome, 2019	AMTs	Supply chain	Multiple case study	Pharmaceuticals	Future	Reconciliation of efficiency and flexibility targets in redistributed manufacturing.
Ryan et al., 2017	AMTs	Supply chain	Conceptual	Manufacturing	Present/ Future	Existing scenarios and future opportunities for AMTs.
Rymaszewska et al., 2017	IoT	Value chain	Multiple case study	Machinery and Equipment, Energy, Electronics	Present	Value creation dynamics in IoT-driven servitization.
Sandström, 2016	AMTs	Industry	Multiple case study	Medical devices	Present	Developments of AMTs in the hearing aid industries between 1989-2008.
Sklyar et al., 2019	Various digital technologies	Ecosystem	Multiple case study	Machinery and Equipment	Present	Organizational change in service ecosystem due to digital servitization.
Srai et al., 2016	AMTs, various digital technologies	Supply chain	Expert study	Manufacturing	Future	Challenges and opportunities for redistributed manufacturing.
Stentoft and Rajkumar, 2019	Industry 4.0	Firm	Survey	Manufacturing	Present	Drivers and barriers related to Industry 4.0 in the location decision process.
Strange and Zucchella, 2017	Industry 4.0	Global value chains (GVCs)	Conceptual	Manufacturing	Future	Future impact of emerging technologies on GVCs.
Subramanian et al., 2019	IoT	Ecosystem	Conceptual	Manufacturing, Services	Future	Impact of the emergence of digital ecosystems on firms' strategy.
Sun and Zhao, 2017	AMTs	Industry	Conceptual	Apparel and Footwear	Future	Impacts and challenges of AMTs.
Suppattavech et al., 2019	IoT	Business model	Conceptual	Manufacturing	Present	Types of IoT-enabled servitized business models.
Tziantopoulos et al., 2019	AMTs	Supply chain	Conceptual	Manufacturing	Present	Decision-making process model for supply chain reconfiguration.
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.
Verboeket and Krikke, 2019	AMTs	Supply chain	Conceptual	Manufacturing	Future	Impact of AMTs on supply chain design and performance.
Wang et al., 2016	AMTs	Not specified	Survey	3D printing	Present	Characteristics of the early adopters of home-based 3D printing systems.
Wang et al., 2019a	Blockchain	Supply chain	Conceptual	Manufacturing	Future	Impact of blockchain technologies on supply chain structure and practices.
Weller et al., 2015	AMTs	Industry	Conceptual/Simulation	Manufacturing	Future	Impact of AMTs on industry, based on industry characteristics.
Yun et al., 2016	Robotics, autonomous driving	Industry	Multiple case study	Automotive, Machinery and Equipment	Future	Interdependencies among technology, business models and industry structure.
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.
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.

and logistics operators (e.g., Jia et al., 2016; 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 (2020). 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., Chekurov 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, 2018; Rayna and Striukova, 2016; Kohtamäki et al., 2019).

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; Athanasopoulou 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).

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

As shown in Table 1, 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:

- (1) 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 Lakhani, 2014; Kiel et al., 2017; Rong et al., 2015; Cenamor et al., 2017);
- (2) 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);
- (3) 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 “middleman” 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);
- (4) 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, 2016); and
- (5) 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., 2016); 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., 2016; 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 Lakhani, 2020; Hagiwara 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., 2020) and in the big data industries (e.g., Urbinati et al., 2019; Nuccio and Guerzoni, 2019).

#### 2.4. 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 Rüscher, 2017; OECD, 2017; World Economic Forum, 2019) and business model innovation (Bughin and van Zeebroeck, 2017; Weking et al., 2020). 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. Research 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 a recent literature review on the definition of Industry 4.0 and similar concepts (Culot et al., 2020), 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., 2017; 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

### Research process

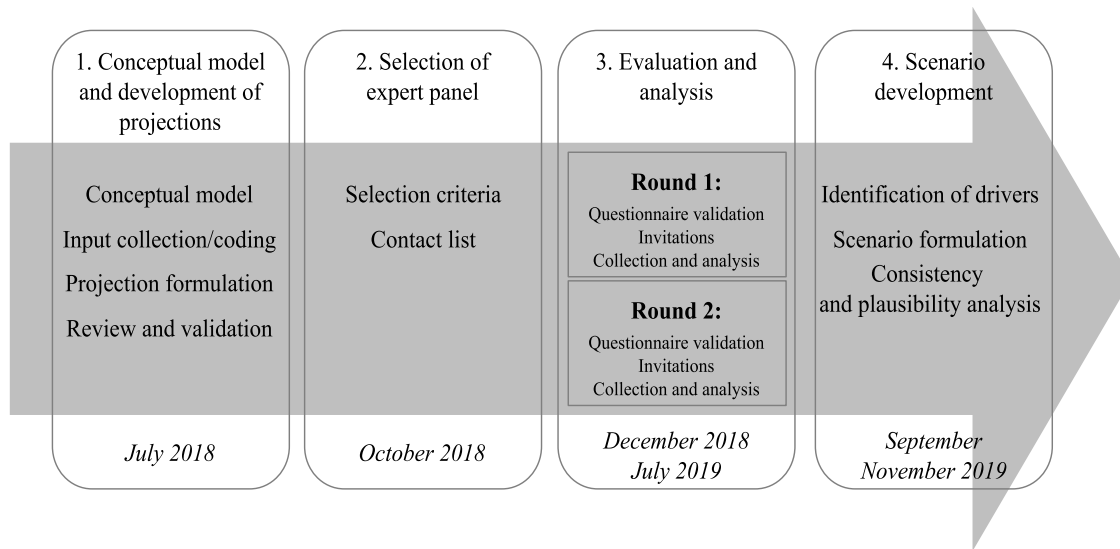


Fig. 1. Research process.

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 research process and timeline are illustrated in Fig. 1. The four main phases are described in detail in the following paragraphs. The study was conducted with the collaboration of BCG.

#### 3.1. Conceptual model and development of projections

Our first step was to develop a conceptual model of the VC (Fig. 2) 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.

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

### Conceptual model

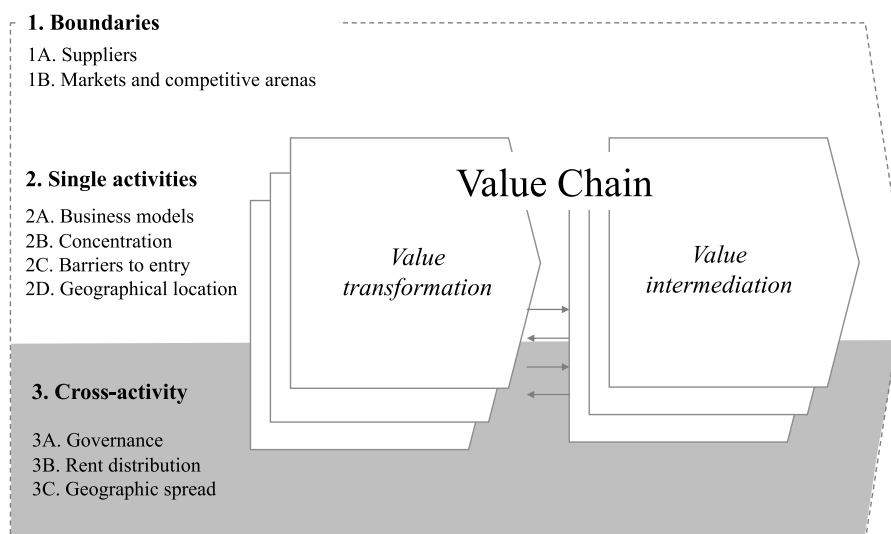


Fig. 2. Conceptual model.

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., 2005), 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 1) 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. 2), 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. 2. 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, 2011; 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 2. The projections are clustered according to the level of analysis and the main topics of the conceptual model in Fig. 1. The final questionnaire is based on the same structure.

### 3.2. 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 to 20 participants (e.g., McCarthy 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

**Table 2**  
Final list of projections.

No	Projection
<b>1. BOUNDARIES</b>	
<b>1A. Suppliers and partners</b>	
1.	Players in the <b>additive manufacturing</b> value chain provide machines and materials for manufacturing activities.
2.	Digital players <b>provide individual-level customer-, product- or process- data</b> needed for activities (e.g., production, service provision, intermediation) within the value chain.
3.	<b>Rare natural resources</b> are needed in manufacturing activities and in the product itself (e.g., rare metals for batteries).
4.	Players in the <b>waste management value chain</b> provide inputs for manufacturing activities (e.g., disassembly and routing of components/materials back into production).
<b>1B. Markets and competitive arenas</b>	
5.	End-markets are characterized by broad <b>cross-industry ecosystems</b> where companies from traditionally different industries compete for similar customer needs (e.g., from "automotive" to "mobility solutions").
6.	Consumers are <b>producing directly at home</b> products and components thanks to additive manufacturing technologies.
7.	Individual-level customer- process- and product- <b>data generated within the industry value chain are sold</b> to players in the data management value chain.
<b>2. SINGLE ACTIVITIES</b>	
<b>2A. Business models and new entrants</b>	
<i>Value transformation (manufacturing / services)</i>	
8.	<b>Small scale workshops</b> (e.g., fab labs, small factories) produce physical products (final or intermediate goods) for a variety of customers.
9.	<b>Digital players offer (e.g., via software applications) services</b> meeting demand previously addressed by traditional manufacturing and service companies.
10.	<b>Substitutes</b> (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 <b>virtual manufacturing</b> setting).
<i>Value intermediation (sales and distribution)</i>	
12.	Intermediaries adopting a <b>platform business model</b> match demand and supply of products, components, and services along the value chain.
13.	<b>Pure-play digital players</b> perform intermediation activities previously offered by traditional "brick-and-mortar" companies (i.e., with physical shops or distribution network).
14.	Customers are offered <b>product usage instead of product ownership</b> , 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 <b>smart city</b> context.
<b>2B. Concentration</b>	
<i>Value transformation (manufacturing / services)</i>	
16.	Activities related to sourcing of <b>raw materials are concentrated</b> with a limited number of global suppliers.
17.	Activities related to the <b>manufacturing of intermediate goods are concentrated</b> with a limited number of global suppliers.
18.	Activities related to the <b>manufacturing of final products are fragmented</b> with the participation of a large number of small and medium enterprises.
19.	Activities related to <b>design (product and software) are fragmented</b> with the participation of a large number of small and medium enterprises and micro-companies.
20.	Activities related to <b>data management are concentrated</b> with a limited number of global players.
21.	Activities related to the <b>provision of services</b> (including services via software applications) <b>are fragmented</b> with the participation of a large number of small and medium enterprises and micro-companies.
<i>Value intermediation (sales and distribution)</i>	
22.	<b>Intermediation</b> activities (e.g., sales and distribution, platforms) are <b>concentrated</b> with a limited number of global players.
<b>2C. Barriers to entry</b>	
<i>Value transformation (manufacturing / services)</i>	
23.	New players can <b>easily enter manufacturing</b> 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 <b>easily enter service provision</b> activities as barriers to entry are low (e.g., due to asset-light business models, limited need for personnel, declining cost of technology...).
<i>Value intermediation (sales and distribution)</i>	
25.	New players can <b>easily enter intermediation activities</b> (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...).
<b>2D. Geographical location</b>	
<i>Value transformation (manufacturing / services)</i>	
26.	<b>Production</b> and related operations of manufacturing companies are located in <b>Western Europe, the United States and Japan</b> .
27.	Production is performed in small-scale factories/workshops operating <b>closer to products' point-of-sale/point-of-use</b> .
<i>Value intermediation (sales and distribution)</i>	
28.	<b>Customer interactions (e.g., marketing and sales) are managed centrally</b> with limited resource commitment in local affiliates.
<b>3. CROSS-ACTIVITY</b>	
<b>3A. Governance</b>	
29.	<b>Manufacturing</b> companies have <b>internalized production activities</b> from intermediate goods to final product assembly.
30.	<b>Manufacturing</b> companies have <b>internalized service provision</b> activities in relation to their products.
31.	<b>Manufacturing</b> companies have <b>internalized end-of-life product management</b> , including remanufacturing, refurbishment and recycling.
32.	<b>Manufacturing</b> companies have <b>internalized intermediation activities</b> (e.g., sales, distribution, platforms) related to their products and services.
33.	<b>Manufacturing</b> companies have <b>internalized data management</b> activities in relation to their <b>products, services, and customers</b> .
34.	<b>Manufacturing</b> companies have <b>internalized data management</b> activities in relation to their supplier base with direct access and control over suppliers' data (e.g., real-time production capacity, machine status).
35.	<b>Intermediaries</b> (distributors, retailers, platforms), <b>logistics operators and after-sales service</b> providers (e.g., maintenance network) <b>produce final products or components</b> .
36.	<b>Intermediaries</b> (distributors, retailers, platforms) develop their <b>own offering</b> of products and services.
37.	<b>Major digital players</b> (e.g., Google, Amazon, Apple) <b>develop their own offering</b> of products and services.
38.	<b>Large companies</b> develop <b>in-house proprietary technology</b> (e.g., algorithms, robotics, blockchain...).
<b>3B. Rent distribution</b>	
39.	Activities related to the <b>provision of services</b> display the <b>highest margins</b> along the value chain.
40.	Activities related to the <b>management of data</b> display the <b>highest margins</b> along the value chain.
41.	Activities related to the <b>production of physical products</b> display margins comparable to pre-production (e.g., product development) and post-production (e.g., marketing and sales) activities.
<b>3C. Geographic spread</b>	
42.	The several activities along the value chain are <b>dispersed globally</b> across multiple locations according to differential locational advantages.
43.	<b>Integrated regional supply chains</b> (e.g., North America, Europe, Far East...) serve the needs of their respective markets.

**Table 3**  
Composition of the subpanels.

	Apparel and Footwear <i>n</i> = 21	Automotive <i>n</i> = 24	Machinery and Equipment <i>n</i> = 31	Total
<b>Respondent category</b>				
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
<b>Years of experience</b>				
5–10	8	5	5	18
11–20	10	11	16	37
>20	3	8	10	21
<b>Self-rated familiarity</b> (5 = high; 1 = low)				
<b>Median (Interquartile range)</b>				
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)	
<b>Gender</b>				
Male	11	19	29	59
Female	10	5	2	17
<b>Geography (location of home institution/company)</b>				
<b>Europe</b>				
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
<b>Total Europe</b>	<b>11</b>	<b>17</b>	<b>22</b>	<b>50</b>
<b>Americas</b>				
Trinidad and Tobago	1	–	–	1
US	5	7	7	19
<b>Total Americas</b>	<b>6</b>	<b>7</b>	<b>7</b>	<b>20</b>
<b>Asia</b>				
China	1	–	1	2
Japan	1	–	–	1
Singapore	–	–	1	1
Saudi Arabia	1	–	–	1
Thailand	1	–	–	1
<b>Total Asia</b>	<b>4</b>	<b>–</b>	<b>2</b>	<b>6</b>
<b>Home institution/company</b>				
<b>Industry executives</b>	<i>Adidas, Bottega Veneta, Calzedonia, Ermenegildo Zegna, Esprit, Geox, Guess, Hanky Panky, Kering, LVMH, Mango, Nike</i>	<i>Audi, Aptiv, Automotive Lighting (x2), BMW (x2), CNH Industrial, FCA, Intercable, Magneti Marelli, McLaren, Schaeffer Technologies, Volkswagen</i>	<i>ABB (x2), Atomat, Bonfiglioli, Bosch (x2), Danieli, EOS, Fincantieri, Flex, General Electric (x2), Johnson&amp;Johnson, Leonardo (x2), Nystar, Solari, Thermokey, Veolia, Wärtsila</i>	
<b>Academics</b>	<i>Chiang Mai University (TH), Kansai University (JP), Polytechnic University of Milan (IT), Prince Sultan University (SA), University of the West Indies (TT)</i>	<i>Aalborg University (DK), Corvinus University (HU), Free University of Bolzano-Bozen (IT), Hawai'i Pacific University (US), Jade Hochschule (DE), Michigan State University (US)</i>	<i>ETH Zurich (CH), Lund University (SE), University of Stuttgart (DE), University of Catania (IT)</i>	
<b>Digital executives</b>	<i>Amazon, Google</i>	<i>Cisco, Google, Microsoft</i>	<i>IBM, Microsoft</i>	
<b>Management consultants, digital consultants, entrepreneurs</b>	<i>Others (2)</i>	<i>BCG (1), Others (1)</i>	<i>BCG (1), Others (4)</i>	

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 3. We firmly believe that the profiles of the experts are outstanding, both from a scientific point of view and regarding the variety of backgrounds



**Table 4.**  
Delphi study descriptive statistics.

	Round 1				Round 2							
	Apparel & Footwear n = 21		Automotive n = 24		Machinery Equipment n = 31		Apparel & Footwear n = 18		Automotive n = 21		Machinery Equipment n = 29	
	2019	2030	2019	2030	2019	2030	2019	2030	2019	2030	2019	2030
<b>1. Boundaries</b>												
<b>1A. Suppliers and partners</b>												
1. AMTs suppliers	3	4	1.5	3	2	4	2	4	1	3	1	4
2. Data bought	3	5	2	4	2	5	3	5	2	4	2	5
3. Rare resources suppliers	3	(3)	2	4	3	(4)	(3)	3	2	4	3	3
4. Waste management suppliers	2	4	(2)	(3)	(2)	(4)	2	4	2	3	2	4
<b>1B. Markets and competitive arenas</b>												
5. Cross-industry ecosystems	2	(4)	(2)	(4)	2	4	2	4	(2)	(4)	2	4
6. 3D printing at home	1	(2)	1	2	1	(2)	1	(2)	1	2	1	2
7. Data sold	3	4	2	(4)	2	(4)	3	4	2	3	2	3
<b>2. Single activities</b>												
<b>2A. Business models and new entrants</b>												
8. Micro-factories	2	(3)	2	(3)	(2)	(3)	2.5	3	1	3	2	(3)
9. Digital services	2	(4)	2	(4)	(2)	(4)	2	(4)	2	4	2	(4)
10. Technology substitutes	(2)	3	2	3.5	2	4	2.5	3	2	4	2	4
11. Virtual manufacturing	(3)	(4)	1	(2)	2	4	3	(4)	1	2	2	4
12. Digital platforms	2	(4)	(2)	(4)	(2)	(4)	2	(4)	2	4	2	4
13. Pure-play online	3	5	2	(3)	2	(4)	3	5	2	3	2	4
14. Products "as a service"	1	(4)	2	4	2	(4)	1	(3)	2	4	2	4
15. Smart cities	1	(2)	1	(3)	1	(3)	1	2	1	3	1	3
<b>2B. Size</b>												
16. Raw concentration	3	(4)	(3)	(4)	(3)	(4)	3	3.5	3	4	3	(4)
17. Intermediate concentration	3	4	2	3	3	3	3	4	2	3	3	3
18. Final fragmentation	(3)	(3)	(2.5)	(2.5)	3	(4)	3	(3)	(2)	2	3	4
19. Software/design fragment.	2	(3)	(2.5)	(3)	(3)	3	2	3.5	3	3	3	4
20. Data concentration	3	(4)	2.5	(3)	(3)	(4)	(3)	4	2	(3)	3	4
21. Service fragmentation	3	(3)	2	(3)	3	3	3	(2.5)	2	3	3	3
22. Intermediaries concentration	3	4	(2.5)	(3)	3	(3)	3	4	2	(3)	3	3
<b>2C. Barriers to entry</b>												
23. Low barriers manufacturing	2	(3)	(2)	(2)	2	(3)	2.5	(3)	(2)	2	2	3
24. Low barriers services	3	4	2.5	3	3	(4)	(3)	3.5	3	3	3	4
25. Low barriers intermediation	(2)	(3)	2	(3)	(2)	3	2	3	2	3	2	3
<b>2D. Location</b>												
26. Production in HCCs	(2)	(2)	(3)	2	(3)	(3)	(2)	(2)	(3)	2	3	(3)
27. Redistributed manuf.	2	(3)	1.5	(2)	2	(3)	2	3	1	2	2	3
28. No local marketing/sales	(3)	3	(2)	(3)	3	3	3	(3)	(2)	3	3	3
<b>3. Cross-activity dynamics</b>												
<b>3A. Governance</b>												
29. Upstream internalization	2	(3)	3	(3)	3	(3)	2	(3)	3	3	3	(3)
30. Service internalization	3	(3)	2	(3)	3	(3)	3	(3.5)	2	3	3	3
31. End-of-life internalization	2	(2)	(2)	(3)	2	(3)	2	2.5	2	(3)	2	(3)
32. Disintermediation	3	(4)	(2.5)	(3)	3	(3)	3	(3)	(3)	(3)	3	3
33. Customer data internalization	(3)	(3)	(3)	(3)	(3)	(3)	3	(3)	3	(3)	3	3

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Table 4. (continued)

	Magnitude (Median)				Stability (Spearman's $\rho$ )					
	Round 1		Round 2		Round 2 vs. Round 1		Round 2 vs. Round 1			
	Apparel & Footwear n=21	Automotive n=24	Machinery Equipment n=31	Apparel & Footwear n=18	Automotive n=21	Apparel & Footwear n=18	Automotive n=21	Machinery Equipment n=29		
34. Supplier data internalization	2	(2)	(4)	(2)	4	(4)	2	4	2	4
35. Intermediaries production offering	1	(2)	(2)	(2)	3	(2)	1	2	2	2
36. Intermediaries own offering	(2)	1.5	(3)	(2)	(3)	(3)	2	3	2	(3)
37. Digital own offering	2	(2)	(3)	(2)	(4)	(3)	2	3	2	(4)
38. Captive technology	2	(3)	(4)	(3)	(3)	(4)	2	4	(3)	3
39. Service marginality	3	2	(4)	3	(4)	(4)	2	(4)	3	4
40. Data marginality	(3)	(2)	3	(3)	4	(3)	(2)	3	2	4
41. Production marginality	3	3	(2)	2	(3)	(2.5)	2	(2)	2	(3)
3C. Geographic spread										
42. Global value chains	4	(5)	(4)	(3)	(3)	(4.5)	4	4	3	3
43. Regional supply chains	(3)	(3)	(4)	(3)	3	3.5	(3)	4	3	3
<b>Magnitude (Median)</b>										
<b>Round 2</b>										
<b>Total n = 68</b>										
<b>Level of agreement (IQR)</b>										
<b>Round 2</b>										
<b>Apparel &amp; Footwear n=18</b>										
<b>Automotive n=21</b>										
<b>Machinery Equipment n=29</b>										
2019	2030	2019	2030	2019	2030	2019	2030	2019	2030	2030
<b>1. Boundaries</b>										
<b>1A. Suppliers and partners</b>										
1. AMT's suppliers	2	4	1	1	1	1	1	1	1	1.000
2. Data bought	2	5	1	0.75	1	1	1	1	1	1.000
3. Rare resources suppliers	3	3	1.75	1	1	1	1	1	1	0.869
4. Waste management suppliers	2	4	0	1	1	1	1	1	1	0.826
<b>1B. Markets and competitive arenas</b>										
5. Cross-industry ecosystems	2	4	0	1	2	2	1	1	1	0.946
6. 3D printing at home	1	2	0	2	0	1	1	1	1	0.896
7. Data sold	2	4	1	1	1	1	1	1	1	1.000
<b>2. Single activities</b>										
<b>2A. Business models and new entrants</b>										
8. Micro-factories	2	3	1	1	1	1	1	1	2	0.876
9. Digital services	2	4	1	1.75	0	0	0	0	2	0.823
10. Technology substitutes	2	4	1	1	1	1	1	1	1	0.949
11. Virtual manufacturing	2	3	0	2	1	1	1	1	1	0.856
12. Digital platforms	2	4	0.75	2	1	1	1	1	1	0.881
13. Pure-play online	2	4	1	1	0	0	0	0	1	0.911
14. Products "as a service"	2	4	1	2	0	0	0	0	1	0.940
15. Smart cities	1	3	0	0.75	1	1	1	1	1	0.815
<b>2B. Size</b>										
16. Raw concentration	3	4	0.75	1	1	1	1	1	2	0.863
17. Intermediate concentration	3	3	0.75	1	1	1	1	1	1	0.983
18. Final fragmentation	3	3	1	1.75	2	2	1	1	1	0.976
19. Software/design fragment.	3	3	1	1	1	1	1	1	1	0.965

(continued on next page)

Table 4. (continued)

	Magnitude (Median) Round 2 Total n = 68	Level of agreement (IQR)		Automotive n = 21	Machinery Equipment n = 29	Stability (Spearman's ρ)		Automotive n = 21	Machinery Equipment n = 29		
		Round 2 Apparel & Footwear n = 18	Round 1 Apparel & Footwear n = 18			Round 2 vs. Round 1 Apparel & Footwear n = 18	Round 2 vs. Round 1 Apparel & Footwear n = 18				
20. Data concentration	3	4	1.75	1	1	0.963	0.857	1.000	0.968	0.839	0.836
21. Service fragmentation	3	3	1	1	1	0.923	0.887	1.000	0.924	0.988	0.894
22. Intermediaries concentration	3	3	1	1	1	1.000	0.961	0.828	0.725	0.999	0.907
<b>2C. Barriers to entry</b>											
23. Low barriers manufacturing	2	3	1	2	1	0.908	0.924	0.927	0.756	0.952	0.809
24. Low barriers services	3	3	1.5	1	1	1.000	1.000	1.000	1.000	1.000	0.853
25. Low barriers intermediation	2	3	1	1	0	0.947	0.910	1.000	0.787	0.704	0.976
<b>2D. Location</b>											
26. Production in HCCs	3	2.5	1.75	2	1	0.858	0.911	0.945	0.971	0.848	0.862
27. Redistributed manuf.	2	3	1	1	0	0.509	0.912	0.790	0.824	0.890	0.874
28. No local marketing/sales	3	3	1	1.75	2	0.949	1.000	0.962	1.000	0.983	0.926
<b>3. Cross-activity dynamics</b>											
<b>3A. Governance</b>											
29. Upstream internalization	3	3	0.75	2	1	0.753	0.922	0.894	0.835	0.948	0.762
30. Service internalization	3	3	1	1.75	1	0.821	0.898	0.945	0.665	0.896	0.789
31. End-of-life internalization	2	3	1	1	2	0.952	0.786	0.882	0.902	0.953	0.897
32. Disintermediation	3	3	0	1.75	2	1.000	0.907	0.641	0.796	0.979	1.000
33. Customer data internalization	3	3	0.75	1.75	1	0.914	0.849	0.929	0.903	0.914	0.894
34. Supplier data internalization	2	4	1.75	1.75	1	1.000	0.907	0.914	0.694	0.914	0.803
35. Intermediaries production	1	2	1	1.75	1	0.984	0.918	0.895	0.782	0.791	0.913
36. Intermediaries own offering	2	3	1	2	1	0.935	0.935	0.895	0.945	0.827	0.911
37. Digital own offering	2	4	0	1	1	0.737	0.921	0.982	0.927	0.913	0.935
38. Captive technology	3	4	0	1	0	0.937	1.000	0.734	0.613	0.871	0.897
<b>3B. Margin distribution</b>											
39. Service marginality	3	4	0	1	2	1.000	1.000	1.000	0.912	0.970	0.954
40. Data marginality	2	4	1.75	1	1	0.892	1.000	0.802	0.962	0.979	1.000
41. Production marginality	2	2	1	1.75	1	0.946	0.941	1.000	0.966	0.991	0.901
<b>3C. Geographic spread</b>											
42. Global value chains	3	4	0.75	1.75	1	0.719	0.964	0.989	0.922	0.927	0.926
43. Regional supply chains	3	4	1.5	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).

and professional experiences. 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.

### 3.3. Evaluation and analysis

The questionnaire was developed starting from the list of 43 projections (Table 2) previously formulated (Section 3.1). 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; 1218 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 et al., 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 ( $\rho$ ) (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. 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.

## 4. Results

This section presents the results of the Delphi study. First, we outline the descriptive statistics for the two rounds (Section 4.1), thereafter we illustrate the content analysis of the experts’ comments and present a conclusive narrative for each projection in 2030 (Section 4.2).

### 4.1. Delphi statistics

The analysis of the Likert items is presented in Table 4. 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 ( $IQR \leq 1$ ). 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  $\rho$ ) 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 (Section 3.1). 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  $\rho$  highlights relatively more stability in the Machinery and Equipment subpanel.

### 4.2. Content analysis and conclusive narratives

The following sections present the results of the content analysis of the experts’ comments collected over the two rounds. 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 4, 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. 2).

#### 4.2.1. Boundaries

The projections related to the first level of analysis – the redefinition of the boundaries of manufacturing VCs – are presented in Table 5.

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),

**Table 5.**  
Boundaries projections – content analysis and final conclusive narrative.

	No.	Level of analysis – Projection – Associated arguments 1A. Suppliers and partners
<i>Median magnitude: 2019: 2 → 2030: 4</i>	1.	<b>Players in the additive manufacturing value chain provide machines and materials for manufacturing activities.</b>
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.
Comments for low magnitude	c.	AMTs will be integrated into current manufacturing processes or as Centers of Excellence alongside traditional plants.
	d.	AMTs will not apply to many production processes.
Industry comments	e.	Traditional production technologies will still be more effective for high volumes, customization will be limited.
Conclusion	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.
	h.	<i>Automotive</i> - Product complexity as well as safety and homologation requirements might hinder broad applications. <i>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.</i>
<i>Median magnitude: 2019: 2 → 2030: 5</i>	2.	<b>Digital players provide individual-level customer-, product- or process- data needed for activities (e.g., production, service provision, intermediation) within the value chain.</b>
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.
Comments for low magnitude	c.	Internet-based players (e.g., marketplaces, social networks) will sell their data as part of their revenue model.
Industry comments	d.	Data sale/purchase will be subject to specific regulations that will clarify data-related opportunities.
Conclusion	e.	Privacy-related regulation will limit sales and purchase of individual-level consumer data.
	f.	<i>Machinery and Equipment</i> - Players in the industrial sector will be slower to realize the relevance of data. <i>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.</i>
<i>Median magnitude: 2019: 3 → 2030: 3</i>	3.	<b>Rare natural resources are needed in manufacturing activities and in the product itself (e.g., rare metals for batteries).</b>
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.
Industry comments	c.	Recycling and circular economy practices will reintroduce rare natural resources into the process.
Conclusion	d.	<i>Apparel and Footwear</i> - Organic fibers will become a "rare resource" as a consequence of increasing demand due to rising consumer environmental concerns.
	e.	<i>Automotive</i> - Rare metals will be increasingly needed for batteries in electric vehicles. <i>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.</i>
<i>Median magnitude: 2019: 2 → 2030: 4</i>	4.	<b>Players in the waste management value chain provide inputs for manufacturing activities (e.g., disassembly and routing of components/materials back into production).</b>
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.
Comments for low magnitude	c.	The increasing scarcity of natural resources will result in more recycling of raw materials.
Industry comments	d.	Sustainability will still not be a major concern in many areas of the world.
	e.	Environmental regulations will evolve very slowly.
Conclusion	f.	It will be difficult to ensure end-to-end supply chain collaboration as needed in circular economy practices.
	g.	<i>Automotive / Machinery and Equipment</i> - Tracing and tracking technologies will support the routing of components back into production.
	h.	<i>Automotive / Machinery and Equipment</i> - AMTs will support product repair and repurposing. <i>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.</i>
		<b>1B. Markets and customers</b>
<i>Median magnitude: 2019: 2 → 2030: 4</i>	5.	<b>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").</b>
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.

(continued on next page)



Table 5. (continued)

	No.	Level of analysis – Projection – Associated arguments
		<b>1A. Suppliers and partners</b>
<b>Industry comments</b>	d.	<i>Apparel and Footwear</i> - 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.	<i>Apparel and Footwear</i> - Ecosystems will emerge only in relation to smart products in the sportswear segment.
	f.	<i>Automotive</i> - 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.	<i>Automotive</i> - Incumbents in the automotive industry will fight back to maintain the status quo.
<b>Conclusion</b>		<i>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.</i>
<b>Median magnitude: 2019: 1 → 2030: 2</b>	6.	<b>Consumers are producing directly at home products and components thanks to additive manufacturing technologies.</b>
<b>Comments for high magnitude</b>	a.	Desktop applications of AMTs will be broadly available on the market.
	b.	Individual consumers will use AMTs to produce customized and personalized products.
<b>Comments for low magnitude</b>	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.
<b>Industry comments</b>		-
<b>Conclusion</b>		<i>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.</i>
<b>Median magnitude: 2019: 2 → 2030: 4</b>	7.	<b>Individual-level customer-, process- and product-data generated within the industry value chain are sold to players in the data management value chain.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	d.	Intellectual property and data-related regulations will evolve to support data monetization.
	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.
<b>Industry comments</b>	g.	<i>Machinery and Equipment</i> –Players in the industrial sector will be slower in realizing the relevance of data.
<b>Conclusion</b>		<i>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.</i>

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).

#### 4.2.2. Single activities

Table 6 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 (#12b/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

**Table 6.**  
Single activities projections – content analysis and final conclusive narrative

		<i>Level of analysis - Projection –Associated arguments</i>
		<b>No. 2A. Business models and new entrants</b>
<b>Median magnitude: 2019: 2 → 2030: 3</b>	<b>8.</b>	<b>Small-scale workshops (e.g., fab labs, small factories) produce physical products (final or intermediate goods) for a variety of customers.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	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.
<b>Industry comments</b>	k.	<i>Apparel and Footwear</i> - Demand will become even more unpredictable due to online sales and new forms of small-scale local production will be needed.
	l.	<i>Apparel and Footwear</i> - The industry is increasingly characterized by large full-package suppliers, only market niches will be available to small players.
	m.	<i>Automotive</i> – Small specialized suppliers will not be needed: with cars being shared rather than owned, there will be no need to customize physical products.
	n.	<i>Automotive</i> – The increasing complexity of electric vehicles will represent a high barrier to entry for small suppliers.
	o.	<i>Automotive / Machinery and Equipment</i> – Products and processes will become simpler due to modularization and platform thinking.
<b>Conclusion</b>		<i>Small-scale suppliers supported by new production technologies will be increasingly involved for customization purposes, whenever production internalization will not be possible/convenient.</i>
<b>Median magnitude: 2019: 2 → 2030: 4</b>	<b>9.</b>	<b>Digital players offer (e.g., via software applications) services meeting demand previously addressed by traditional manufacturing and service companies.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>		-
<b>Industry comments</b>	e.	<i>Apparel and Footwear</i> – Smart products and digital services will have a limited application, e.g., in sportswear.
	f.	<i>Automotive</i> – Digital services and software applications will be the main source of profit in the new mobility ecosystem.
	g.	<i>Automotive</i> – Mobility services will be appealing only to new generations.
	h.	<i>Automotive/Machinery and Equipment</i> – Digital services will augment physical services (e.g., preventive maintenance).
<b>Conclusion</b>		<i>Digital services will be developed for smart products and product-as-a-service business models. Business services will go digital.</i>
<b>Median magnitude: 2019: 2 → 2030: 4</b>	<b>10.</b>	<b>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).</b>
<b>Comments for high magnitude</b>	a.	New materials will be developed by new technological players.
<b>Comments for low magnitude</b>	b.	IoT technological innovation is happening now; by 2030 the pace of disruption will have slowed down.
<b>Industry comments</b>	c.	<i>Automotive</i> – Electric and autonomous vehicles will bring in new players challenging current industry incumbents.
	d.	<i>Machinery and Equipment</i> – As AMTs broaden possible applications, machinery producers will face new competitors.
<b>Conclusion</b>		<i>Product innovation is triggering the entrance of new players already today. Expectations for 2030 mainly refer to new materials.</i>
<b>Median magnitude: 2019: 2 → 2030: 3</b>	<b>11.</b>	<b>Companies manufacture physical products without owning any production facility (in a virtual manufacturing setting).</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	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.
<b>Industry comments</b>	g.	<i>Apparel and Footwear</i> – The industry is increasingly characterized by complete outsourcing to full-package suppliers.
	h.	<i>Apparel and Footwear</i> – In order to increase flexibility, production will be outsourced on a local basis to players implementing automation technologies (e.g., sewbots, laser grinders).
	i.	<i>Apparel and Footwear</i> – Production will be further outsourced to decrease costs.
	j.	<i>Apparel and Footwear</i> – Production will be internalized for specific product categories displaying higher marginalities.
	k.	<i>Apparel and Footwear</i> – Production will be internalized and brought back to the home country to limit the incidence of tariffs and the environmental footprint of operations.
	l.	<i>Automotive</i> – Outsourcing opportunities are increasing as big electronic contractors are entering the automotive industry.
	m.	<i>Automotive</i> – The industry is currently characterized by an increasing internalization of production due to higher product complexity and safety requirements.
	n.	<i>Automotive/Machinery and Equipment</i> – Full outsourcing will be prevented by intellectual property concerns.

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Table 6. (continued)

<b>Conclusion</b>	<i>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).</i>
<b>Median magnitude: 2019: 2 → 2030: 4</b>	<b>12. Intermediaries adopting a platform business model match demand and supply of products, components, and services along the value chain.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	f. Manufacturing companies will internalize sales because of the need to control data and establish a direct customer relationship.
<b>Industry comments</b>	g. <i>Apparel and Footwear</i> – Brands will pursue a direct sales strategy, platforms will be mainly concession-based. h. <i>Apparel and Footwear</i> – There will be no need for cloud manufacturing platforms as supply is normally managed by vertically integrated full-package suppliers. i. <i>Automotive</i> – Platforms operated by major car manufacturers will develop in relation to the mobility ecosystem. j. <i>Automotive / Machinery and Equipment</i> – 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.
<b>Conclusion</b>	<i>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.</i>
<b>Median magnitude: 2019: 2 → 2030: 4</b>	<b>13. Pure-play digital players perform intermediation activities previously offered by traditional "brick-and-mortar" companies (i.e., with physical shops or distribution networks).</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	–
<b>Industry comments</b>	c. <i>Apparel and Footwear</i> – Digital channels will increase as logistics and product delivery become more effective. d. <i>Automotive</i> – The mobility ecosystem will be characterized by interactions on digital platforms. e. <i>Automotive</i> – New players in the electric vehicle segment mostly sell through digital channels. f. <i>Automotive</i> – The proven effectiveness of local dealer networks will prevent a full shift towards digital channels. g. <i>Machinery and Equipment</i> – Specialist salespersons are needed for complex tailor-made machinery.
<b>Conclusion</b>	<i>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.</i>
<b>Median magnitude: 2019: 2 → 2030: 4</b>	<b>14. Customers are offered product usage, instead of product ownership, leveraging on time-based or performance-based payment schemes.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	c. Cultural barriers in both the consumer and the business sectors will not be overcome.
<b>Industry comments</b>	d. <i>Apparel and Footwear</i> – New generations have a reduced need for ownership and stronger environmental concerns. e. <i>Apparel and Footwear</i> – Renting and subscription-based models are spreading (e.g., high-end/children segments). f. <i>Apparel and Footwear</i> – Many apparel and footwear items are too personal to share. g. <i>Automotive</i> – Car leasing is already a common practice. h. <i>Automotive</i> – Product-as-a-service will be at the core of the mobility ecosystem. i. <i>Machinery and Equipment</i> – Customers are demanding pay-per-use schemes and lifecycle management. j. <i>Machinery and Equipment</i> – Payment schemes are difficult to calculate for customized products.
<b>Conclusion</b>	<i>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.</i>
<b>Median magnitude: 2019: 1 → 2030: 3</b>	<b>15. Public administrations at the local/city level match demand and supply of products and services within a smart city context.</b>
<b>Comments for high magnitude</b>	a. Metropolitan areas are developing smart city solutions very fast, especially in developing countries.
<b>Comments for low magnitude</b>	b. Bureaucracy and political constraints will not be overcome.
<b>Industry comments</b>	c. <i>Automotive</i> – Smart cities and public/private partnerships will play a key role in the mobility ecosystem.
<b>Conclusion</b>	<i>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.</i> <b>2B. Size</b>
<b>Median magnitude: 2019: 3 → 2030: 4</b>	<b>16. Activities related to sourcing of raw materials are concentrated with a limited number of global suppliers.</b>
<b>Comments for high magnitude</b>	a. Raw material suppliers are experiencing a consolidation trend across many industries. b. The scarcity of natural resources will trigger further consolidation of players.
<b>Comments for low magnitude</b>	c. New materials and materials for AMTs will bring in new players. d. Antitrust regulations will prevent further consolidation.
<b>Industry comments</b>	e. Online platforms will provide sales channels for small suppliers to serve specific segments. –

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Table 6. (continued)

<b>Conclusion</b>	<i>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.</i>	
<b>Median magnitude: 2019: 3 → 2030: 3</b>	<b>17.</b>	<b>Activities related to the manufacturing of intermediate goods are concentrated with a limited number of global suppliers.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	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.
<b>Industry comments</b>	f.	<i>Apparel and Footwear</i> – Production is increasingly outsourced to large vertically integrated full-package suppliers.
	g.	<i>Automotive</i> – Risk-sharing agreements for product innovation are causing a rationalization of the supplier base resulting in higher concentration levels.
	h.	<i>Machinery and Equipment</i> – AMTs will cut down the need for components, only large companies pursuing cost-efficiency will be able to operate in an increasingly shrinking market.
<b>Conclusion</b>	<i>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.</i>	
<b>Median magnitude: 2019: 3 → 2030: 3</b>	<b>18.</b>	<b>Activities related to the manufacturing of final products are fragmented with the participation of a large number of small and medium enterprises.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	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.
<b>Industry comments</b>	g.	Late-stage customization will be internalized by large manufacturing companies to retain higher margins.
	h.	<i>Apparel and Footwear</i> – Only full-package suppliers can guarantee the high service levels needed by global brands.
	i.	<i>Automotive</i> – Components might be produced by small and medium-size enterprises, final product assembly will remain a core competence of car manufacturers.
	j.	<i>Automotive</i> – 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.	<i>Machinery and Equipment</i> – Capabilities related to final product manufacturing will be available only to large companies.
<b>Conclusion</b>	<i>Large structured companies will leverage small suppliers for personalization and customization only in specific industries/segments.</i>	
<b>Median magnitude: 2019: 3 → 2030: 3</b>	<b>19.</b>	<b>Activities related to design (product and software) are fragmented with the participation of a large number of small and medium enterprises and micro-companies.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	-	-
<b>Industry comments</b>	d.	<i>Apparel and Footwear</i> – Brands will increasingly involve consumers in co-creation practices.
	e.	<i>Apparel and Footwear</i> – Design activities are increasingly internalized as a core competence of large brands.
	f.	<i>Automotive</i> – Due to cybersecurity issues related to onboard technologies there will be a strong selection of suppliers.
	g.	<i>Automotive</i> – Co-design practices between car and components manufacturers will limit the space for small players.
<b>Conclusion</b>	<i>Technology will support smoother coordination with supplier, but further involvement of SMEs and micro-companies might be hindered by other factors.</i>	
<b>Median magnitude: 2019: 3 → 2030: 4</b>	<b>20.</b>	<b>Activities related to data management are concentrated with a limited number of global players.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	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.
<b>Industry comments</b>	i.	Data management will be characterized by specialized solutions creating opportunities also for small companies
<b>Conclusion</b>	– <i>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.</i>	
<b>Median magnitude: 2019: 3 → 2030: 3</b>	<b>21.</b>	<b>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.</b>
<b>Comments for high magnitude</b>	a.	Small companies will enter in digital services for smart products and mobile applications.
<b>Comments for low magnitude</b>	b.	Data for digital services will not be accessible to small players but controlled by large manufacturers and platforms.

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Table 6. (continued)

Industry comments Conclusion	c. <i>Automotive</i> - Manufacturers and platforms will outsource maintenance and on-site services to small local players. <i>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.</i>
<b>Median magnitude: 2019: 3 → 2030: 3</b>	<b>22. Intermediation activities (e.g., sales and distribution, platforms) are concentrated with a limited number of global players.</b>
Comments for high magnitude Comments for low magnitude Industry comments Conclusion	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. 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. e. <i>Automotive</i> - Digital sales channels and services will be managed at the central level by car manufacturers. f. <i>Automotive</i> - Few global platforms will dominate the mobility ecosystem. g. <i>Automotive</i> - Local physical showrooms owned by independent dealers proved to be the most effective model. h. <i>Machinery and Equipment</i> - Sales and distribution require significant investments in infrastructure. <i>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.</i> <b>2C. Barriers to entry</b>
<b>Median magnitude: 2019: 2 → 2030: 3</b>	<b>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...).</b>
Comments for high magnitude Comments for low magnitude Industry comments Conclusion	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. 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. e. <i>Automotive</i> - Product innovation (e.g., electric vehicles, autonomous vehicles) is bringing in new players. f. <i>Automotive</i> - New players will enter the luxury segment due to small lots/highly customized production. g. <i>Automotive</i> - As electric vehicles reach maturity, the presence of a dominant design will pose limitations to new entrants. h. <i>Automotive/Machinery and Equipment</i> - Production technologies and increasingly complex products will require considerable investments/capabilities. <i>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.</i>
<b>Median magnitude: 2019: 3 → 2030: 3</b>	<b>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...).</b>
Comments for high magnitude Comments for low magnitude Industry comments Conclusion	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. 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. f. <i>Machinery and Equipment</i> - Product maintenance requires significant technological capabilities, even more in the future due to more complex product technologies. <i>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.</i>
<b>Median magnitude: 2019: 2 → 2030: 3</b>	<b>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...).</b>
Comments for high magnitude Comments for low magnitude Industry comments Conclusion	a. Digital channels have lower start-up costs than physical ones due to limited investments in infrastructures. 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. e. <i>Apparel and Footwear</i> - Only large companies can guarantee the high service levels demanded in the consumer market. f. <i>Machinery and Equipment</i> - As products are increasingly complex and customized, intermediaries need to have significant technological capabilities that are hardly available on the market. <i>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.</i> <b>2D. Location</b>
<b>Median magnitude: 2019: 3 → 2030: 2.5</b>	<b>26. Production and related operations of manufacturing companies are located in Western Europe, the United States, and Japan.</b>
Comments for high magnitude Comments for low magnitude Industry comments Conclusion	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. 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. g. <i>Apparel and Footwear</i> - Production will still be very labor-intensive and located in countries with lower labor cost. h. <i>Apparel and Footwear/Automotive</i> - Production will be reshored just for specific segments (customization/high-end). <i>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.</i>

(continued on next page)



Table 6. (continued)

<b>Median magnitude: 2019: 2 → 2030: 3.</b>		<b>27. Production is performed in small-scale factories/workshops operating closer to products' point-of-sale/point-of-use.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	d.	Logistics will become more efficient; the location of plants will not play a major role in meeting manufacturers' operational and environmental objectives.
<b>Industry comments</b>	e.	<i>Apparel and Footwear</i> – The vast majority of products are not suitable for automation.
	f.	<i>Automotive</i> – The industry is subject to internalization trends.
	g.	<i>Automotive</i> – New forms of production will not be feasible due to product safety requirements and technological complexity.
	h.	<i>Automotive/Machinery and Equipment</i> – Local production will be limited to customized components and spare parts, it will not be possible for complex products or heavy industrial equipment.
<b>Conclusion</b>		<i>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.</i>
<b>Median magnitude: 2019: 3 → 2030: 3</b>		<b>28. Customer interactions (e.g., marketing and sales) are managed centrally with limited resource commitment in local affiliates.</b>
<b>Comments for high magnitude</b>	a.	Online channels, data analytics (e.g., from social networks, channels, smart products) and investments will be managed centrally.
<b>Comments for low magnitude</b>	b.	Local presence will still be needed to intercept market needs.
<b>Industry comments</b>	c.	<i>Automotive</i> – The effectiveness of local dealer networks will prevent a full shift towards online channels.
	d.	<i>Machinery and Equipment</i> – Specialist salespersons and face-to-face interactions are needed to discuss technical specifications.
<b>Conclusion</b>		<i>Customer data, investments and online channels will be managed centrally, but a local presence in marketing and sales will still be relevant.</i>

Table 7.

Cross-activity projections – content analysis and final conclusive narrative

	No.	Level of analysis – Projection –Associated arguments 3A. Governance
<b>Median magnitude: 2019: 3 → 2030: 3</b>		<b>29. Manufacturing companies have internalized production activities from intermediate goods to final product assembly.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	d.	Reshoring and new forms of local manufacturing are generally coupled with a greater internalization of production.
	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.
<b>Industry comments</b>	h.	<i>Apparel and Footwear</i> – Production will be internalized for the product categories displaying the highest marginalities.
	i.	<i>Apparel and Footwear</i> – The industry is increasingly characterized by full-package suppliers.
	j.	<i>Apparel and Footwear</i> – Production will still be very labor-intensive and outsourced to countries with lower labor costs.
	k.	<i>Automotive/Machinery and Equipment</i> – The cost of production technologies and increasing calls for product innovation will drive vertical specialization.
<b>Conclusion</b>	l.	<i>Automotive/Machinery and Equipment</i> – Product simplification and modularization will simplify outsourcing. <i>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.</i>
<b>Median magnitude: 2019: 3 → 2030: 3</b>		<b>30. Manufacturing companies have internalized service provision activities in relation to their products.</b>
<b>Comments for high magnitude</b>	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.
<b>Comments for low magnitude</b>	d.	Manufacturing companies lack specific skills and capabilities to compete in the service market.
<b>Industry comments</b>	e.	<i>Apparel and Footwear</i> – Services are not a core competence of apparel companies.
	f.	<i>Machinery and Equipment</i> – Core services have already been internalized.
<b>Conclusion</b>		<i>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.</i>
<b>Median magnitude: 2019: 2 → 2030: 3</b>		<b>31. Manufacturing companies have internalized end-of-life product management, including remanufacturing, refurbishment and recycling.</b>
<b>Comments for high magnitude</b>	a.	Companies will be more proactive in recycling practices for reputational reasons.
<b>Comments for low magnitude</b>	b.	Manufacturing companies lack end-of-life product management capabilities.
	c.	Specialist players are emerging in recycling and remanufacturing activities.
<b>Industry comments</b>	d.	<i>Apparel and Footwear</i> – Major brands will operate direct collection networks, recycling will be outsourced.
	e.	<i>Automotive</i> – Recycling will be a major issue in relation to batteries for electric vehicles.
	f.	<i>Automotive</i> – Manufacturers will play a role in coordinating end-of-life product management, but not internalize recycling.
	g.	<i>Machinery and Equipment</i> – Players in the AMT sector are creating new markets for obsolescence/end-of-life programs.

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Table 7. (continued)

	No.	Level of analysis – Projection –Associated arguments 3A. Governance
Conclusion	h.	<i>Machinery and Equipment</i> – Manufacturers will internalize end-of-life activities to access new revenue streams. <i>Manufacturing companies will internalize only specific end-of-life product management activities in relation to revenue/reputational opportunities.</i>
<b>Median magnitude: 2019: 3 → 2030: 3</b>	<b>32.</b>	<b>Manufacturing companies have internalized intermediation activities (e.g., sales, distribution, platforms) related to their products and services.</b>
Comments for high magnitude	a.	Intermediation activities will be internalized because of their high margins.
Comments for low magnitude	b.	Direct customer relationship and access to consumer data will be a source of competitive advantage.
Industry comments	c.	Sales internalization will be limited by the increasing prevalence of one-stop-shop platforms offering a frictionless customer experience.
Conclusion	d.	<i>Apparel and Footwear</i> – Sales internalization is needed to have control of omnichannel consumer experience.
	e.	<i>Apparel and Footwear</i> – New forms of Internet platforms (concession-based) will provide digital marketplaces while enabling brands to have more control of retail data.
	f.	<i>Automotive</i> – Car manufacturers will operate platforms and “shop service centers” in relation to the mobility ecosystem.
	g.	<i>Automotive</i> – Local dealer networks proved to be effective and there is no interest in sales internalization.
	h.	<i>Machinery and Equipment</i> – Customer relationship is a core competence of manufacturers of complex products. <i>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.</i>
<b>Median magnitude: 2019: 3 → 2030: 3</b>	<b>33.</b>	<b>Manufacturing companies have internalized data management activities in relation to their products, services, and customers.</b>
Comments for high magnitude	a.	Data management capabilities are needed to compete in a data-intensive economy (e.g., data for targeted offerings).
Comments for low magnitude	b.	The increasing spread of smart products will require manufacturing companies to manage related data.
Industry comments	c.	Skills and capabilities for data management are scarce on the market and not available for manufacturing companies.
Conclusion	d.	Cross-industry synergies and data-specific scale advantages will drive the emergence of large data specialists.
	e.	<i>Apparel and Footwear</i> – Data management will be internalized for product launches and production planning.
	f.	<i>Automotive/Machinery and Equipment</i> – Manufacturers are already building data management capabilities. <i>Manufacturing companies able to attract the right skills and capabilities will internalize only the management of data providing a source of competitive advantage.</i>
<b>Median magnitude: 2019: 2 → 2030: 4</b>	<b>34.</b>	<b>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).</b>
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.
Comments for low magnitude	b.	Supply chain coordination will become simpler as technologies for sharing and analyzing data will be broadly available on the market.
Industry comments	c.	Skills and capabilities for data management will be available only to large companies.
Conclusion	d.	<i>Apparel and Footwear</i> – As production is performed by full-package suppliers, Apparel and Footwear companies will not integrate suppliers' data.
	e.	<i>Apparel and Footwear</i> – The typical suppliers have an overall low adoption of information systems.
	f.	<i>Automotive</i> – Supply chain data integration is already a common practice. <i>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.</i>
<b>Median magnitude: 2019: 1 → 2030: 2</b>	<b>35.</b>	<b>Intermediaries (distributors, retailers, platforms), logistics operators and after-sales service providers (e.g., maintenance network) produce final products or components.</b>
Comments for high magnitude	a.	Small-scale/local/mobile production will be enabled by the flexibility of AMTs and advanced robotics.
Comments for low magnitude	b.	Intermediaries will be engaged in late-stage customization.
Industry comments	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.
Conclusion	e.	<i>Apparel and Footwear</i> – Production will still be very labor-intensive with limited applicability of new technologies.
	f.	<i>Apparel and Footwear</i> – Only large retailers might have the infrastructure/capabilities to manage production activities.
	g.	<i>Automotive/Machinery and Equipment</i> – Non-manufacturing players will be engaged only in spare parts.
	h.	<i>Automotive</i> – Homologation requirements and product safety will be a major barrier to new production models. <i>New point-of-sale production models will develop with applications limited to product personalization and spare parts.</i>
<b>Median magnitude: 2019: 2 → 2030: 3</b>	<b>36.</b>	<b>Intermediaries (distributors, retailers, platforms) develop their own offering of products and services.</b>
Comments for high magnitude	a.	Internet-based intermediaries will leverage their control over customer data to promote their product/service offering.
Comments for low magnitude	b.	Intermediaries will externalize the production of physical products to manufacturing suppliers.
Industry comments	c.	Intermediaries lack manufacturing skills and capabilities.
	d.	Manufacturing industries have limited attractiveness for digital platforms that will consolidate within the service space.
	e.	<i>Apparel and Footwear</i> – Intermediaries will develop mass-market best-sellers, not designer items.
	f.	<i>Apparel and Footwear</i> – Consumers will still value the brand name in purchasing decisions.
	g.	<i>Automotive</i> – Already today Uber is investing in product/service innovation.
	h.	<i>Automotive/Machinery and Equipment</i> – Intermediaries will not have access to relevant Intellectual Property. <i>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.</i>
<b>Median magnitude: 2019: 2 → 2030: 4</b>	<b>37.</b>	<b>Major digital players (e.g., Google, Amazon, Apple) develop their own offering of products and services.</b>

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Table 7. (continued)

	No.	Level of analysis – Projection –Associated arguments 3A. Governance
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.	<i>Apparel and Footwear</i> – Amazon develops its own offering of best-selling items to capture higher margins, actual production is however outsourced to third parties.
	f.	<i>Automotive</i> – Digital players will leverage on their know-how in digital technologies for autonomous vehicles, there are relevant examples already today (e.g., Google).
	g.	<i>Automotive</i> – The competitive advantage of digital players will shrink as manufacturers will build internal datasets from connected cars.
Conclusion		<i>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.</i>
<b>Median magnitude: 2019: 3 → 2030: 4</b>	<b>38.</b>	<b>Large companies develop in-house proprietary technology (e.g., algorithms, robotics, blockchain...).</b>
Comments for high magnitude	-	-
Comments for low magnitude	a.	Manufacturing companies lack the skills and capabilities for developing proprietary technologies.
Industry comments	b.	<i>Apparel and Footwear</i> – Proprietary technologies for product customization and retail technologies will represent a source of competitive advantage.
	c.	<i>Apparel and Footwear</i> – Customization technologies (e.g., AMTs, sewbots) will be available on the market.
	d.	<i>Automotive</i> – Product innovation is one of the major sources of competitive advantage.
	e.	<i>Automotive</i> – Already today car manufacturers are acquiring technological companies (e.g., in artificial intelligence)
	f.	<i>Automotive/Machinery and Equipment</i> – By 2030 current innovation will be standardized/available on the market.
	g.	<i>Machinery and Equipment</i> – Companies are investing to set the standard for the Internet of Things and related technologies.
Conclusion		<i>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.</i>
<b>Median magnitude: 2019: 3 → 2030: 4</b>	<b>39.</b>	<b>Activities related to the provision of services display the highest margins along the value chain.</b>
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.	<i>Automotive</i> – Product sales will be marginal in the future, cars will be used and revenues generated through services.
	d.	<i>Automotive</i> – Connected cars will have a series of digital services (e.g., infotainment) providing additional revenues with low set-up costs.
	e.	<i>Automotive</i> – Consumers will have a low willingness to pay for on-board services and expect them for free.
	f.	<i>Machinery and Equipment</i> – Digital data-driven services are self-sustained after initial technological investment.
	g.	<i>Machinery and Equipment</i> – 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.	<i>Machinery and Equipment</i> – Customization supported by new production technologies will drive back margins in production activities.
Conclusion		<i>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.</i>
<b>Median magnitude: 2019: 2 → 2030: 4</b>	<b>40.</b>	<b>Activities related to the management of data display the highest margins along the value chain.</b>
Comments for high magnitude	a.	The increasing relevance of data and limited availability of related capabilities will support margin growth.
Comments for low magnitude	b.	Access to data will influence all performance dimensions (e.g., flexibility, productivity, quality) and provide additional sources of revenues due to digital services.
Industry comments	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		<i>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.</i>
<b>Median magnitude: 2019: 2 → 2030: 2</b>	<b>41.</b>	<b>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.</b>
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.	<i>Automotive</i> – Physical products will not be relevant in the mobility ecosystem.
	e.	<i>Machinery and Equipment</i> – Production will be commoditized as manufacturing capabilities will be accessed through cloud manufacturing platforms.
Conclusion		<i>Production margins will increase only for late-stage/customization whenever manufacturing capabilities are specific and not accessible through cloud manufacturing platforms.</i>
<b>Median magnitude: 2019: 3 → 2030: 4</b>	<b>42.</b>	<b>The several activities along the value chain are dispersed globally across multiple locations according to differential locational advantages.</b>
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.

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Table 7. (continued)

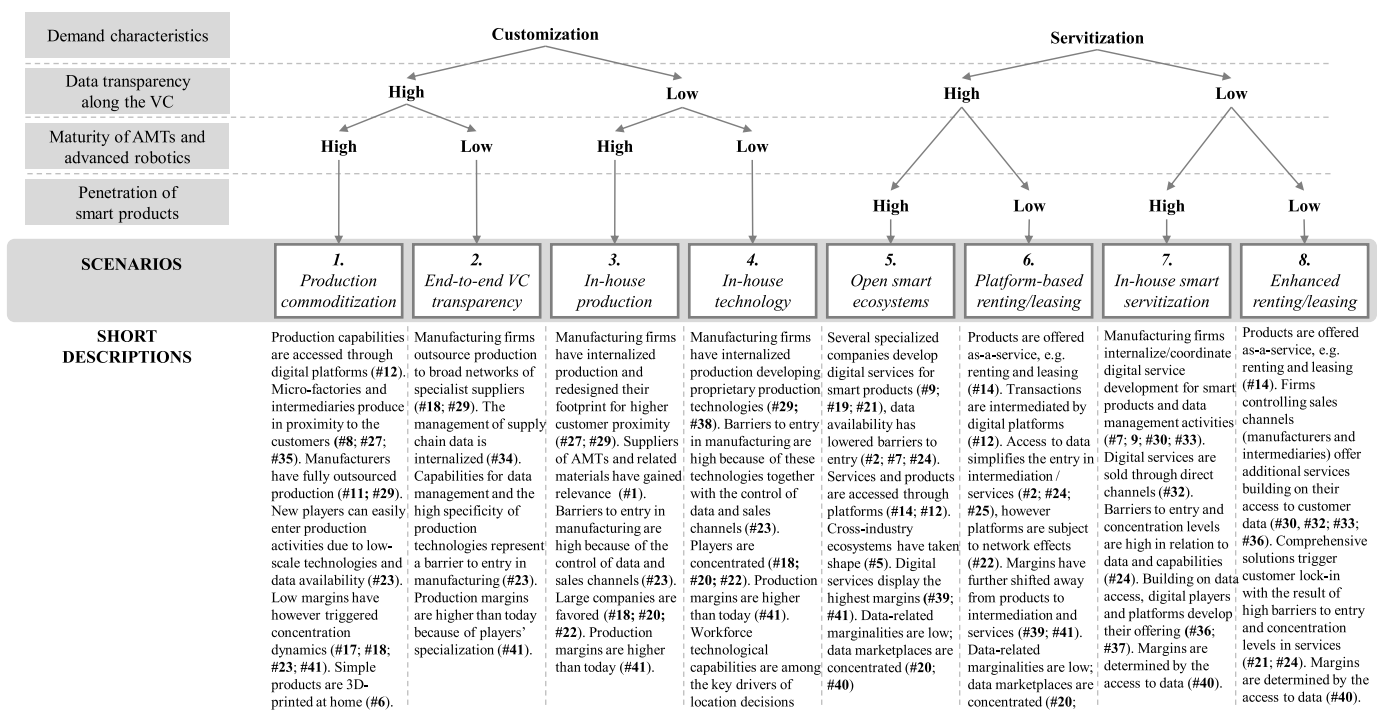
	No.	Level of analysis – Projection –Associated arguments 3A. Governance
Conclusion		The trend towards a global dispersion of VC activities will continue as new countries gain relevance, only partially mitigated by protectionism, tariffs, and increasing calls for flexibility and sustainability.
Median 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.
Comments for low magnitude	d.	Regional/local production will be enabled by increasing system integration along the supply chain.
	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.

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.



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

Fig. 3. Drivers and scenario development framework.

#### 4.2.3. 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 7.

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).

## 5. Discussion

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 Lakhani, 2020; Hagi 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 et al., 2015; 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., 2020). 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., 2020; Rosa et al., 2020). Vice versa, the widespread expectations for small-scale localized production models (e.g., Srari et al., 2016; Montes and Ollerros, 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.

### 5.1. Eight scenarios for manufacturing in 2030

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 5–7). 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. 3), namely “scenarios” (van Notten et al., 2003; Bishop et al., 2007).

The first driver refers to the dominant demand characteristics 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 data transparency along the VC. 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 reap the benefits of new production models (e.g., Kurfess and Cass, 2014; Steenhuis and Pretorius, 2017; Chan et al., 2018). The evolution of the regulatory environment, new technical solutions for interoperability and integration together with some early success examples might increase data sharing practices in the future. 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.

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, 2019). 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 (McGuinness, 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., 2015; Wei et al., 2019; Broekhuizen et al., 2020) – is at the basis of scenario (5) open smart ecosystems. Industry 4.0 solutions demand high interdependencies of competences and technological complementarity, thus often give rise to innovation ecosystems (e.g. Benitez et al., 2020). In this scenario highly specialized players are involved through 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.

## 6. Conclusions

In this study we addressed the impact of Industry 4.0 on manufacturing VCs with a holistic perspective and a broad technological focus. Based on an extensive analysis of the literature, a series of workshops, and a Delphi study involving 76 experts (academics and practitioners), we identified the key dimensions of change (Section 2 and 3) and assessed their relevance by 2030 (Section 4). Starting from these analyses, we put forward an analytical perspective presented in the form of drivers and scenarios (Section 5).

Our paper contributes to the growing literature on Industry 4.0 in at least three significant ways. First, it 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. Second, our 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. Third, the formulation of eight scenarios (see Fig. 3) 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 paper has also implications for managers, consultants and policy makers. As we explained in the methodology section, the study was carried out in collaboration with the Boston Consulting Group (BCG), which was involved in the identification of the research question as well as in various brainstorming and validation sessions. Starting from here, the conceptual model (Fig. 2) and the list of projections (Table 2) 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 (Tables 5–7) 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 study is not exempt from limitations. The most crucial ones refer to the common downsides of forecasting with respect to unexpected events having significant (disruptive) impacts. As we write,

the pandemic related to the coronavirus COVID-19 is seriously affecting a large and growing number of countries around the world. The current state of emergency impedes further considerations on how this may affect the results of our study. 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 our 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.

Several opportunities for future research arise from our study. The logical next step would be for the scenarios (Section 5.1) 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" (Section 5) will evolve in the light of emerging cross-industry ecosystems. The issue of data 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. 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.

To conclude, in this peculiar historical moment, it remains impossible to predict how long this health crisis will last and its impact on the economy at the global level. At present, targeted responses must ensure that economic systems and individual organizations survive the shock in the short-term. In the long run, structural measures will be required to inject new impetus into the economy in the face of gloomy prospects of recession and unemployment. Among these structural measures, we expect investments in innovation – more likely backed by public incentives – to turn again the spotlight on the Industry 4.0 trajectory. Making the right decisions requires, however, that the options and their implications are well understood; it can only be hoped that – once the sanitary emergency is over – the preparations of our business leaders and policymakers will not be found wanting. 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.

## Author contribution

All authors contributed equally to this manuscript and it is very difficult to distinguish specific contributions. Provided that the paper is the result of a collective effort by the research team, the following responsibilities are highlighted: Giovanna Culot: Conceptualization, Methodology, Formal analysis, Writing – Original Draft; Guido Orzes: Conceptualization, Writing – Review & Editing; Marco Sartor: Conceptualization, Writing – Review & Editing; Guido Nassimbeni: Conceptualization, Writing – Review & Editing, Supervision.

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