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Circular business models in the European manufacturing industry: A multiple case study analysis

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ABSTRACT

Circular economy has recently emerged as an alternative industrial paradigm to the traditional "take, make, dispose" economic model, with the aim to promote more sustainable resource consumption patterns and production processes. However, more empirical research is needed to address the topic of how circular economy is adopted in practice by companies. In this study, we mainly adopt the lenses of circular business models and analyze three European case studies operating in the manufacturing industry that embraced circular economy principles in their business. In particular, the paper investigates and presents peculiar managerial practices to create and capture value in circular business models, and highlights the need to conceive a systemic perspective on the implementation of these practices, especially for companies operating in the manufacturing industry. Moreover, the paper shows to managers willing to embrace circular economy principles how the implementation of managerial practices for circularity can support the design of the manufacturing companies' business model within which they operate. Finally, the paper argues about the role of a peculiar external condition, i.e., the environmental regulation, in influencing the way companies implement the managerial practices for circularity.

1. Introduction

Circular economy represents an economic system that is based on business models that replace the "end-of-life" concept with reducing, alternatively reusing, recycling, and recovering materials in production, distribution and consumption processes (Kirchherr et al., 2017). Circular economy promotes different closed-loop production patterns where materials, components and products are reused, recycled or recovered at the end of their useful life, without becoming waste (Su et al., 2013; Geissdoerfer et al., 2017). In any case, waste becomes a source of value for other stakeholders in the supply chain, or for those operating in similar or different supply chains (Ünal et al., 2019; Ghisellini et al., 2016).

In recent decades, policymakers and practitioners focused their attention on opportunities and challenges associated with this paradigm, especially in terms of promoting industrial ecology (Geng et al., 2009; Yu et al., 2014), cleaner production (Geng and Doberstein, 2008; Prendeville et al., 2014), eco-industrial systems (Conticelli and Tondelli, 2014; Geng et al., 2014), waste management (Caprile and Ripa, 2014; Song et al., 2015) and collaborative consumption (Dupont-Inglis, 2015; Tukker, 2015). This attention resulted in a huge proliferation of policies and regulations driven by circular economy principles (Ellen MacArthur Foundation, 2014, 2015; Gregson and Crang, 2015; Murray et al., 2017). Circular economy can operate at a macro-level (i.e., city, region, nation and beyond), a meso-level (i.e., eco-industrial parks) and a micro-level (i.e., products, companies, consumers), with the aim to accomplish a sustainable development that implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations (Merli et al., 2018).

At the micro-level, however, only more recent studies have addressed the circular economy concept and its principles from a strategic management or business model perspective while taking the company as unit of analysis (e.g., Ranta et al., 2018; Bocken et al., 2016; Witjes and Lozano, 2016). In this case, circular economy can significantly affect the transition of companies towards new business models, leveraging peculiar dimensions of companies' business model, such as the value network and the customer value proposition & interface. Thus, companies are called to adopt circular economy-driven managerial practices within their business model in order to: (i) achieve a more effective

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sustainability-oriented strategy, (ii) exploit natural resources more efficiently and (iii) improve the "recycling, reuse or recovery" options (Crainer, 2013; Linder and Williander, 2015; Vermeulen, 2015). Therefore, the experts who recently opened up the research stream of circular business models started to show the mechanisms of value creation and capture in a business model that is designed according to circular economy principles (Centobelli et al., 2020; Rosa et al., 2019a). Based on their findings, the creation of value happens within the value network dimension of a companies' business model and can be reached both through the management of the supply chain and key relationships with suppliers, manufacturers and retailers (Goldsworthy, 2014; Parkinson and Thompson, 2003; Vermeulen, 2015). Again, the capture of value happens within the customer value proposition & interface dimension of a companies' business model and can be reached through the management of relationships with customers, and reinforced by new mechanisms of value capture, such as pay-per-use (Tukker, 2013; Williams, 2007).

Even if scientific works about circular business models are increasing, many more efforts are still needed in terms of empirical investigation to gain an understanding of how companies create and capture value in a circular economy. Among the several theoretical taxonomies on circular business models recently proposed in literature, this paper takes as reference the one proposed by Urbinati et al. (2017), already used by several scientific contributions for empirical analyses (i.e., Henry et al., 2020; Olsson et al., 2018; Ünal et al., 2018). Thus, the paper tests and strengthens its empirical suitability on three European case studies operating in the manufacturing industry, an industry particularly interesting to analyze from the point of view of circular economy. In addition, the paper argues about the role of a peculiar external environmental condition, that of environmental regulation, in influencing how companies implement the managerial practices for a circular business model.

From a theoretical perspective, the paper adds a remark on previous studies about the need to conceive both a systemic perspective on the implementation of the managerial practices, especially for companies operating in the manufacturing industry, to further the creation and capture of value in their business model, as well as to design a circular business model, as well as to enhance a higher degree of circularity of their business model. In addition, the paper provides a further evidence of the applicability of the conceptual taxonomy under investigation in the peculiar context of manufacturing industry, which particularly needs a transition towards circular economy.

From a managerial perspective, the paper shows managers who are willing to embrace circular economy principles how the implementation of peculiar managerial practices for circular business models can support the design of the manufacturing companies' business model within which they operate. Moreover, the paper discusses the role of customer involvement and interaction, as the customer represents a key stakeholder in a circular business model.

The paper is structured as follows. Section 2 presents an overview of the most recent theoretical taxonomies on circular business models (Section 2.1) and the reference taxonomy used as theoretical guide for the empirical investigation (Section 2.2). Section 3 explains the rationale of the methodology (Sections 3.1, 3.2 and 3.3) and presents a brief description of the sampled case studies (Section 3.4). Section 4 summarizes the main results deriving from the analysis of their circular business models in the light of the reference taxonomy (Sections 4.1 and 4.2) and sheds light on the role of the environmental regulation, which played a key role in influencing the design of the circular business model and the adoption of the managerial practices of each sampled case (Section 4.3). Finally, Sections 5 and 6 respectively discuss the theoretical and managerial implications of the obtained results and depict the concluding remarks.

2. Conceptual development

2.1. Theoretical taxonomies on circular business models

To the best of knowledge of the authors, in the most recent research in the intersection between circular economy and business models there are only a few attempts so far to classify circular business models.

For example, Ranta et al. (2018) have developed a conceptual framework for analyzing business models in the circular economy context, which also enables circular economy business operations, such as take-back systems or services and recycling. In addition, the study of Bocken et al. (2014) proposed archetypes of sustainable business models, some of which fit within the circular economy context as it refers to the creation of value from waste. In this regard, Bocken et al. (2016) proposed a taxonomy of business models strategies aimed to close, slow, and narrow the resource loops. Furthermore, Lewandowski (2016) advanced a conceptual framework of circular business model based on the business model Canvas of Osterwalder and Pigneur (2010) to highlight both the ways through which circularity is applied to each dimension of the business model "Canvas" and the additional elements that are crucial for circular economy implementation, i.e., take-back systems and adoption factors. Moreover, Witjes and Lozano (2016) depicted a circular business model framework, based on the collaboration between sustainable public procurement and sustainable business models, which leads to "reductions in raw material utilisation and waste generation, whilst promoting the development of more sustainable business models", thus better contributing to making societies more sustainable" (p. 42). Finally, Planing (2015) developed a framework of business model innovation in a circular economy that highlights both the categories of business model aimed towards the transition of a circular economy and new business models aimed towards a more efficient use of resources, i.e., ownership-, access- or usage-, performance- and result-based. Finally, based on the shift of the solutions offered from the producer to the customer, i.e., delivering functionality rather than ownership, the research on product-service systems-based business models has also advanced categories of business model combining economic prosperity and sustainable resource management, which are product-, use- and result-oriented (Pezzotta et al., 2018).

Table 1 provides a summary of the above studies.

However, from the best knowledge of the authors, the above-mentioned taxonomies lack a detailing of a comprehensive-exhaustive set of practices for business model implementation and the way they interact to maximize its effectiveness.

In contrast to the above studies, the taxonomy of Urbinati et al. (2017) seems to offer a more comprehensive view of the phenomenon of circular business model design, as it has a level of detail in the identification of relevant managerial practices that fits with the purpose of this study. Accordingly, this taxonomy, which is further detailed hereafter, was chosen by the authors as a reference framework for the study and used as a theoretical guide for the empirical investigation.

2.2. The reference taxonomy

The reference taxonomy (Urbinati et al., 2017) taken into account by this paper maps a set of relevant managerial practices for circular economy within two main dimensions of companies'

business model: (i) the value network and (ii) the customer value proposition & interface (Osterwalder and Pigneur, 2005, 2010; Zott et al., 2011). The value network represents the dimension within which a company designs its key resources, activities and supply chain relationships with the stakeholders to enhance the creation of value, i.e., a product or peculiar qualities of the product that address specific customers' needs (Bowman and Ambrosini, 2000). Instead, the customer value proposition & interface stands for the dimension within which a company designs its value proposition towards customers to capture value, i.e., the monetary amount that a company reaches when the exchange of the product with its customers takes place (Bowman and Ambrosini, 2000), and by leveraging mostly price and promotion strategies and initiatives (Tukker, 2013; Williams, 2007).

The value network dimension brings together the following managerial practices (Mayyas et al., 2012; Zhu et al., 2010; Lieder and Rashid, 2016; Moreno et al., 2016):

- The reduction of greenhouse gas emissions and environmental impact by looking into energy efficiency initiatives, such as the design of key performance indicators monitoring the energy consumption (Li et al., 2010; Su et al., 2013; Stahel, 2013; Sassanelli et al., 2019a);
- The usage of eco-friendly materials, which are natural, recyclable, durable, and easy to separate, to enhance the biological and technical cycle of products and a sustainable closed loop (Bocken et al., 2016; McDonough and Braungart, 2002);
- Involvement of supply chain stakeholders in value creation initiatives, to co-create awareness, skills and capabilities for circular economy (Singh and Ordoñez, 2016; Antikainen and Valkokari, 2016; Bocken et al., 2018);
- Implementation of practices related to the effective communication with the supply chain stakeholders and upstream partners, enabled by shared value and trust, to enhance a systemic view for circular business model design (Ghisellini et al., 2016; Van Dijk et al., 2014; Bocken et al., 2018);
- Implementation of Design for "X" practices and capabilities intended to facilitate the design of circular products and components, such as Design for Recycling, Design for Remanufacturing and Reuse, Design for Disassembly, and Design for Environment (Sassanelli et al., 2020; De los Rios and Charnley, 2017; Moreno et al., 2016).

The customer value proposition & interface dimension can be further detailed looking both at price and at promotion strategies and initiatives.

In the first case, the following managerial practices can be adopted (Williams, 2007; Tukker, 2004, 2015; Tukker and Tischner, 2006):

- The direct sale of products, allowing customers to become owners of products and to hold the responsibility for their use during – and at the end of – their lifecycle (Ormazabal et al., 2018);
- The sale of products by adding complementary services, such as financing, maintenance, and take-back programs, in order to enhance the long-term relationships between the producer and the user, by guaranteeing the recovery of products from users to producers (Kunz et al., 2018);
- Activities of leasing or renting products, allowing producers to own the control over the products throughout the entire useful life and customers to benefit from products without worrying about what to do at the end of their life (Tukker, 2015);
- Activities of pay-per-use, allowing customers to benefit from the usage of products without worrying at all about what to do at the end of their life (Stahel, 2016; Tukker, 2015).

In the second case, the following managerial practices have been mapped (Heerde et al., 2013; Kumar and Venkatesan, 2005; Baxendale et al., 2015):

- Exploitation of the company website to promote the value proposition;
- Activities of advertising and in-store sales by the company's personnel;
- Initiatives on sustainability and circular economy themes, by involving customers;
- Initiatives on sustainability and circular economy themes, by exploiting all the available communication channels.

Table 2 summarizes the managerial practices characterizing the value network and the customer value proposition & interface dimensions.

On the basis of past research on business model design, and as already highlighted by previous studies in the intersection between business model and circular economy (Ünal et al., 2019), a circular business model configuration has to find consistency between its internal configuration and external environmental conditions, i.e., industry-, country- and society-level conditions, such as local and cultural settings, regulatory frameworks, level of market competition. In particular, Morris et al. (2005) have argued that "consistency can be described in terms of both internal and external 'fit,' where the former is concerned with a coherent configuration of key activities within the firm and the latter addresses the appropriateness of the configuration given external environmental conditions" (p. 372). Accordingly, in this research the authors do not only examine the adoption of the above practices, but also if a peculiar external environmental condition, that of environmental regulation, has played a role in influencing the design of a circular business model and the adoption of the managerial practices in each of the sampled case. The authors aim to do so because, although some light has already been shed on which managerial practices relevant for circular business models have to be adopted, much more empirical effort has to be put into the analysis of the external environmental conditions that can influence the extent to which a

Table 1
Summary of the analyzed circular business models' taxonomies.

Reference	Circular business models' taxonomy
Ranta et al. (2018)	Conceptual framework for business models in the circular economy context
Bocken et al. (2014)	Archetypes of sustainable business models
Bocken et al. (2016)	Taxonomy of business models strategies
Lewandowski (2016)	Conceptual framework of circular business model
Witjes and Lozano (2016)	Circular business model framework
Planing (2015)	Framework of business model innovation in a circular economy
Pezzotta et al. (2018)	Product-service systems-based business models

Table 2
The reference theoretical taxonomy.

Value network		Customer value proposition & interface	
Energy efficiency initiatives		Price strategies and initiatives	Direct sale of products
Usage of friendly materials, which are natural, recyclable, durable, and easy to separate			Sale of products by adding complementary services
Involvement of supply chain stakeholders in value creation initiatives			Activities of leasing or renting products
Practices related to the effective communication with the supply chain stakeholders and upstream partners			Activities of pay-per-use
Design for "X" practices	Design for Recycling	Promotion strategies and initiatives	Exploitation of the company website to promote the value proposition
	Design for Remanufacturing and Reuse		Activities of advertising and in-store sales
	Design for Disassembly		Initiatives on sustainability and circular economy themes, which involve customers
	Design for Environment		Initiatives on sustainability and circular economy themes by exploiting all the available communication channels

circular business model is designed. In particular, the authors focused on the environmental regulation as it has recently emerged as a critical, although under-researched, condition that influences the anatomy of circular economy implementation at business model level (Centobelli et al., 2020).

3. Methodology

3.1. Multiple case study methodology

The paper adopts a multiple case study methodology, assessing three different European case studies operating in the manufacturing industry. According to Creswell (2013), "the case study method explores a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information … and reports a case description and case themes" (p. 97). In particular, a multiple case study analysis was conducted in this paper for a number of reasons (Gustafsson, 2017). A multiple case study analysis allows to analyze data both within each situation and across situations and can be used to either forecast contrasting results for expected reasons or forecast similar results in the studies (Yin, 2003). Moreover, multiple case study allows for cross-case comparison, which allows to understand the differences and the similarities between multiple cases (Baxter and Jack, 2008; Stake, 1995) and the researchers to provide the literature with an important influence from the contrasts and similarities (Vannoni, 2015). In addition, the nature of the sampled cases, which operate in novel supply chains, calls for an exploratory analysis, which is particularly suitable through case study analysis (Cousin, 2005). Furthermore, this methodology is particularly useful to adopt for qualitative analyses and theory-testing approach, which facilitate the understanding of complex phenomena (Yin, 2003; Siggelkow, 2007), as in the case of the topic under investigation. Finally, multiple case studies allow for the collection of data in real-time and avoid the weaknesses inherent in retrospective reconstruction and associated reinterpretation errors (Alblas and Wortmann, 2014). Table 3 shows the steps, activities and sub-activities that have been performed for conducting the multiple case study analysis.

For confidentiality reasons, the cases are named "Case A″, "Case B″ and "Case C". In particular, Cases A and B are two small-medium sized enterprises, whereas Case C is a technological centre. Table 4 summarizes the key information about the cases.

Together, the three sampled cases represent interesting complementary options of exploitation of all the recoverable materials from the recycling process of electronic wastes, such as Printed Circuit Boards. In addition, all the sampled cases are relevant not only in terms of circular economy implementation on current operations, but also in terms of final outputs they generate.

3.2. Sample identification and selection

The identification of the cases was based on a convenient sampling criterion, allowing for easy accessibility and availability of information at a given time (Voss et al., 2002). However, in case study research, case selection based on a set of specific criteria is deemed to be important (Veldman et al., 2011). In particular, the criteria for the case selection for the research included: (i) size of the case study, whereby case studies are homogeneous from the point of view of the revenues dimension, mainly small and micro ones; (ii) industry, whereby case studies are homogeneous from the point of view of the sector of activity within which they operate; (iii) each case study belongs to the FENIX H2020 project.[1] In particular, this project has among its main objectives to demonstrate on a small-scale the real benefits coming from the adoption of circular economy principles in manufacturing supply chains. In particular, the FENIX project is based on three major strategic directions. First, the project is aimed to develop new business models and industrial strategies for novel supply chains, detailed hereafter in Section 3.4, in order to enable value-added product-services (Rocca et al., 2020; Sassanelli et al., 2019a). Second, the project is aimed at developing a set of success stories coming from the application of circular economy principles in industrial sectors (Rosa et al., 2019b, 2019c). Third, the project is aimed at integrating key enabling technologies for the efficient recovery of secondary resources (Rosa et al., 2020). Therefore, given the strong relation that the FENIX H2020 project has with the scope of this paper, the three analyzed case studies were selected from it.

In addition, the manufacturing industry is particularly interesting to analyze from the point of view of circular economy. Starting from the diffusion of the globalization, the European manufacturing sector is facing an increasing lack of stability in the market, as well as a need for quicker responses to customer demands (Rosa et al., 2019a). Over time, these two elements disincentivized long-term investments of companies and shifted their attention to higher-value markets characterized by lower volumes. Then, production was moved abroad, and the use rates of plant capacity dropped quickly. This negative scenario has affected the overall performance of small-medium sized enterprises, which are, however, called to remain competitive into the markets (European

[1] Future business models for the **E**fficient recovery of **N**atural and **I**ndustrial secondary resources in e**X**tended supply chains contexts (www.fenix-project.eu).

Table 3
Process of multiple case study analysis.

Step	Activity	Sub-activity
1	Identification and selection of the case studies	- Definition and analysis of the criteria for selecting the case studies - Analysis of the manufacturing sector's characteristics and its relevance from the circular economy perspective
2	Data gathering	- Establishment of a semi-structured interview protocol with open-ended questions - Identification and selection of the key respondents - Conduction of the interviews (recorded and transcribed) - Analysis of secondary documents
3	Data analysis	- Coding process, within-case and cross-case analysis - Triangulation of the interviews with the secondary sources of information

Table 4
Key information about the cases.

Case	Sector of activity	Year of foundation	Revenues	EBIT (Earnings Before Interests and Taxes)
A	Metal powders for additive manufacturing	1994	3.85 mln €	320 k€
B	3D printed customised jewellery	2008	1.1 mln €	80 k€
C	Additive manufacturing materials and 3D printing filaments	1990	4.5 mln €	90 k€

Commission, 2012). In parallel, in Europe there has been an increasing awareness about the environmental impact of products and processes, as well as about the importance of a sustainable consumption of resources (Reuter et al., 2013). In this context, the circular economy approach is more and more successful (Lieder and Rashid, 2016), especially because empirical evidence forecasts "an annual net material cost savings opportunity of up to USD 380 billion in a transition scenario and of up to USD 630 billion in an advanced scenario, looking only at a subset of EU manufacturing sectors" (MacArthur, 2013, p. 6). Accordingly, the companies were selected because they are designing a circular business model and develop industrial strategies in novel supply chains of the manufacturing industry.

3.3. Data gathering

From the analysis of extant research, a semi-structured interview protocol with open-ended questions for the interviews with the companies' key respondents was established. The interview protocol is available in the Supporting Material (Table 1A). Six first-line managers and senior researchers were identified and interviewed. The decision to interview first-line managers and senior researchers was made because they are the ones inside a company with a legitimate right to decide on the implementation of managerial practices for business model design (Helfat and Martin, 2015; Augier and Teece, 2009; Massa and Tucci, 2013). Considering the actual dimension of the case studies and the novelty of the supply chains within which they operate, the number of first-line managers and senior researchers involved in the interviews was sufficient to enhance the credibility, transferability, dependability and confirmability of all of the gathered information (Guba and Lincoln, 2004; Morse, 1994, 2000). Each key respondent was interviewed at least twice. Interviews lasted from one and a half to 2 h, totalling over 20 h. The list of the interviewed managers is reported in the Supporting Material (Table 2A).

All the interviews were recorded and transcribed. Then, a coding process in content analysis was performed to capture all the relevant information (Guest et al., 2006). In the case of unclear information, the interviews were followed-up with clarifying questions given to key respondents through emails or phone calls. Next, a within-case analysis was performed, and a cross-case analysis was conducted to identify, corroborate and compare the recurrent patterns of useful information (Weber, 1990).

All the information gathered from the key informants was triangulated with secondary sources of information to avoid post-hoc rationalizations (Yin, 2003), and to add various secondary documents and archival records (Amankwah-Amoah, 2016) regarding the case studies to the interview data (Eisenhardt and Graebner, 2007). The triangulation process of information followed the steps suggested by Tellis (1997). Initially, each author independently reviewed all the information of the transcribed interviews and all the secondary sources to verify their validity and avoid potential ambiguous and equivocal data being included in the database. Then, each author contrasted or corroborated his own analyses with each other to reach a shared understanding and interpretation of the whole information under investigation. Finally, all the accepted information was triangulated.

3.4. Case studies empirical analysis

3.4.1. Case A: The metal powders company

Case A is a manufacturer of metal powders for additive manufacturing processes. The company was born starting from an innovative principle of solid-state synthesis and over time developed a portfolio of technological systems and an industrial structure capable of producing innovative metal powders that found very extensive applications in several industrial sectors, such as coatings, composites and materials for energy storages. Metal powders produced by Case A are characterized by a high technological content, with unique characteristics, suitable to be subsequently transformed into new products. Case A offers the market innovative materials that can be processed using conventional processes of powder metallurgy and deposition, such as laser sintering, thermal spraying and sintering. The powdered materials produced find application in a series of different supply chains, such as conventional and rapid sintering, laser sintering and coating deposition. The production process starts from electronic scraps that are brought to the plant by either private or industrial customers and finishes with metal powders as final products. The peculiarity of Case A is that the metallic material entering the manufacturing process is recovered from different kinds of wastes coming from the mass electronics sector. These wastes, once disassembled to recover hazardous components, are reduced into powders. Then, the powders are separated into metal and non-metal powders, and only some specific metals present in powders are refined completely through bio-hydrometallurgical processes and optimized by classification and jet-mills to be used in industrial 3D printing, thermal spraying or sintering processes.

3.4.2. Case B: The customised jewellery company

Case B is a start-up specialized in 3D printing and 3D scanning processes. The purpose of Case B is to provide professional 3D printing and 3D scanning services, develop 3D printing materials (i.e., filaments as well as binders and powders), customize 3D printing and 3D scanning solutions (both hardware and software), and offer 3D design and support/training services. Case B is also characterized by extensive operational experience in helping to refine systems for taking orders automatically through localized points of sales, and processing and printing these orders in 3D centrally through a cloud-based system. The production process of Case B is similar to that of Case A, but instead of finishing with metal powders as final products, it finishes with 3D printed jewellery. Case B is related with the production of 3D printed jewellery from "green" precious metals.

3.4.3. Case C: The 3D printing advanced filaments company

Case C is a technological centre focused on production technologies. It contributes to the know-how related to engineering and technology management in a high-tech environment. Its institutional goal is to provide technological tools and support promoting synergies between the different stakeholders (e.g., companies, universities, and users). Case C develops products and technological processes using a wide range of advanced manufacturing technologies and materials. Case C is related to the production of either additive manufacturing materials or 3D printing filaments from wasted materials. The production process is similar to that of Cases A and B but, instead of finishing respectively with metal powders or 3D printed customized jewellery as final products, it finishes with the previous two types of products, i.e., additive manufacturing materials or 3D printing filaments.

4. Results

To present the empirical evidence collected, the authors decided to strictly follow the reference framework proposed in Section 2.2. For this reason, Sections 4.1 and 4.2 re-organize the information about the case studies according to the circular business model dimensions of the reference taxonomy. In addition, in line with the second objective to analyze the influence of a peculiar external environmental condition on circular business model design, Section 4.3 sheds light on the role of environmental regulation.

4.1. Value network

The value network dimension presents the same managerial practices across the sampled cases, with very slight differences. All the managerial practices mapped into the value network dimension of the reference taxonomy seem to be simultaneously embraced. Table 5 highlights the managerial practices that are put into practice by each case.

In particular, the case studies look into energy efficiency initiatives (Li et al., 2010; Su et al., 2013; Stahel, 2013) as key activities of their business model. They are also aware of the materials they use in their additive manufacturing processes, ensuring they are in line with the biological and technical cycle of their products (Bocken et al., 2016; McDonough and Braungart, 2002), such as the bio-hydrometallurgical processes of specific metals (Case A), precious metals (Case B) and specific set of non-metal materials present in powders (Case C).

Suppliers and employees represent the main stakeholders in all the sampled cases. Whereas suppliers are mostly key partners and oversee co-creating value in the cases' business model (Singh and Ordoñez, 2016; Antikainen and Valkokari, 2016; Bocken et al., 2018) by providing electronic scraps (for Cases A and C) and green precious metals (for Case B), employees are the key resources in charge of implementing the practices for value creation, such as 3D printing experimentation.

Thus, although the value network dimension deserves attention to strengthen the applicability of the proposed conceptual taxonomy in one of the main dimensions of the companies' business model, for the sampled cases the most interesting insights for cross-case comparison, and both from a theoretical and managerial point of view, are related to the customer value proposition & interface dimension. Accordingly, the findings associated to this dimension are presented in the following section.

4.2. Customer value proposition & interface

The customer value proposition & interface dimension of the analyzed cases presents idiosyncratic characteristics, especially as far as the value proposition and the customer relationships are concerned. Table 6 highlights the managerial practices associated with the customer value proposition & interface dimension that are put into practice by each case.

Across the sampled cases the target market is always the same, i.e., either companies or final users in a Business-to-Business-to-Customer market. In addition, all of them adopt the easiest managerial practices associated with the promotion strategies and initiatives, i.e., promotion of the value proposition through the company website, as well as advertising and in-store sales.

However, in Case A, the product is owned by the producer and is sold directly to the customer (Williams, 2007). In addition, in this specific case, there is no direct customer involvement in the circular economy initiatives of the company (Kumar and Venkatesan, 2005).

As for Case B, the value proposition leverages price strategies and initiatives that are leasing or renting (Tukker, 2015). Moreover, the customer is directly involved in the circular economy initiatives of the company (Baxendale et al., 2015) and in a sort of "customer-push" involvement: the producer pushes the customer to perceive the efforts of its value creation activity. Case B develops innovative and customized hardware and software, allowing for the detailed 3D scan of human faces, by reproducing a highly accurate 3D mesh of it. Subsequently, the scanned image is transformed into a fully customizable jewellery object. In addition, a software platform supports the value proposition related to customizable face jewellery being ordered from each hardware installation. The software platform enables direct sales of custom-made jewellery both online and from the retailers (i.e., it enables clients to custom design or order jewellery directly from an existing catalogue from the hardware kiosk complementary to the 3D face-related jewellery, which will then be sent to the 3D printing facility for processing).

As for Case C, the value proposition leverages price strategies and initiatives that is pay-per-use (Stahel, 2016). Moreover, the customer is directly involved in the circular economy initiatives of the company (Baxendale et al., 2015) and in a sort of "customer-pull" involvement: the customer pulls the producer to create products based on circular economy principles. In the same way of Case B, also Case C leverages a software platform to offer custom-made printing filaments.

4.3. The role of environmental regulation

The interviews demonstrated that the business model dimensions and the associated adoption of managerial practices for circular economy transition were both influenced by the environmental regulation (either as in the case of the value network dimension for Cases B and C, or as in the case of the value network and the customer value proposition & interface dimensions for

Table 5
Managerial practices associated to the value network dimension that are put into practice by Cases A, B and C.

Value network	Case A	Case B	Case C
Energy efficiency initiatives	The nature of materials and novelty of the production process allow for reduction of greenhouse gas emissions and environmental impact	The nature of materials and novelty of the production process allow for reduction of greenhouse gas emissions and environmental impact	The nature of materials and novelty of the production process allow for reduction of greenhouse gas emissions and environmental impact
Usage of friendly materials, which are natural, recyclable, durable, and easy to separate	Case A takes care of the material used in the production process for the generation of metal powders (i.e., the material entering the process is recovered from different kinds of waste)	Case B takes care of the material used in the 3D printing process for the generation of the 3D printed jewellery (i.e., the material entering the process is a "green" precious material)	Case C takes care of the material used in the additive manufacturing process for the generation of additive manufacturing materials or 3D printing filaments (i.e., the material entering the process is recovered from different kinds of waste)
Involvement of supply chain stakeholders in value creation initiatives	Suppliers are involved in the production process after providing electronic scraps	Suppliers are involved in the production process after providing green precious materials	Suppliers are involved in the production process after providing electronic scraps
Practices related to effective communication with the supply chain stakeholders and upstream partners	Communication is especially required for receiving materials and during the testing phase of the production process	Communication is especially required for receiving materials and during the experimentation phase of 3D printing	Communication is especially required for receiving materials and during the experimentation phase of 3D printing
Design for "X" practices	Metal powders allow for Design for Recycling, Remanufacturing, Reuse and Disassembly	3D printed jewellery from "green" precious metals allows for Design for Environment	Additive manufacturing materials or 3D printing filaments allow for Design for Recycling, Remanufacturing, Reuse and Disassembly

Table 6
Managerial practices associated with the customer value proposition & interface dimension that are put into practice by Cases A, B and C.

Customer value proposition & interface		Case A	Case B	Case C
Price strategies and initiatives	Direct sale of products	Case A holds the ownership of the products until they are sold to the customers	Case B does not sell the products directly to customers	Case C does not sell the products directly to customers
	Sale of products by adding complementary services	The products sold by Case A do not have related additional services	Case B leverages a software platform to offer custom-made jewellery	Case C leverages a software platform to offer custom-made printing filaments
	Activities of leasing or renting products	Products are directly sold to customers; no leasing or renting mechanisms are available	Case B holds the ownership of the products as long as customers pay for their usage	Case C holds the ownership of the products as long as customers pay for their usage
	Activities of pay-per-use	Products are directly sold to customers; no pay-per-use mechanism is available	Customers pay for the usage of the products; associated performances are less important	Case C holds the ownership of the product as long as customers pay both for their usage and associated performances
Promotion strategies and initiatives	Exploitation of the company website to promote the value proposition	Case A promotes its value proposition through its proper website	Case B promotes its value proposition through its proper website	Case C promotes its value proposition through its proper website
	Activities of advertising and in-store sales	Case A promotes its value proposition through advertising and in-store sales	Case B promotes its value proposition through advertising and in-store sales	Case C promotes its value proposition through advertising and in-store sales
	Initiatives on sustainability and circular economy themes, which involve customers	Customers are not involved in Case A sustainability and circular economy initiatives	Case B involves customers in its sustainability and circular economy initiatives ("customer-push" involvement)	Case C involves customers in its sustainability and circular economy initiatives ("customer-pull" involvement)
	Initiatives on sustainability and circular economy themes by exploiting all the available communications channels	Case A exploits just website and advertising and in-store sales	Customers are mostly involved in the production processes	Customers are mostly involved in the production processes. Case C supports promoting synergies between companies, universities, and users

Case A).

In Case A, for example, the responsibility of the product is completely handed over to the customer, who becomes the owner. In this case, the way through which both the practices of value creation and capture were implemented had to be compliant with the environmental regulation in order to comply with the regulatory objectives of energy-efficiency, reduction of greenhouse gas emissions and supply chain sustainability. On the contrary, considering the Cases B and C, the producer owns the control over the product throughout the entire useful life. In this case, the environmental regulation influenced more how the practices of value creation were implemented, and mostly related to the energy-efficiency and the reduction of greenhouse gas emissions.

In addition, each business model dimension, i.e., either the value network or the customer value proposition & interface, is more likely to be associated with peculiar industrial benefits than others. Moreover, environmental regulation has had a different influence on these industrial benefits. For example, the managerial practices that the case studies have adopted within the value network dimension, such as the Design for "X" practices, the energy efficiency practices, or the friendly material usage-driven practices, allowed for reducing costs and environmental impact, as well as for lowering business risks and supply chain complexity. Simultaneously, they allowed for improving supply chain sustainability and energy efficiency and for developing new skills and capabilities. On the other hand, the managerial practices that the case studies have adopted within the customer value proposition & interface dimension, by leveraging price and promotion strategies and

initiatives, allowed for opening new revenue streams and for improving competitive advantage, as well as for enhancing reputation and brand value and reaching new markets and countries.

5. Theoretical and managerial implications

Based on the similarities and differences between each analyzed case, which are summarized in Table 7, the paper adds interesting theoretical and managerial implications, aimed at inviting management scholars to further future research in the field of circular business models.

From a theoretical perspective, the applicability of the conceptual taxonomy under investigation are confirmed by a theory-testing approach. Indeed, the taxonomy was able to interpret how the cases under investigation can create and capture value by leveraging relevant managerial practices that they implemented in the value network and in the customer value proposition & interface dimensions of their business models. First, the paper adds to the research on product-service systems-based business models (Reim et al., 2015; Sassanelli et al., 2019b), as all three cases above can adopt two types of product-service systems-based business models, which are especially product- or result-oriented. Depending on which product-service systems-based business model is adopted, different considerations can be made regarding the creation and capture of value based on the proposed theoretical taxonomy. Indeed, the final aim of the product-oriented business model is the simple selling of the final product, whereas the final aim of the result-oriented business model is the selling of several services (e.g., disassembly, materials recovery and additive manufacturing) related to those activities enabled by a plant. In addition, the three analyzed cases are complementary to each other and propose new business models, products and services that make full use of the entire range of by-products produced by the recycling of waste, namely precious metals, non-precious metals, as well as non-metallic fractions, and their reintroduction as new functional products for creating a circular economy loop. Together, the three cases allow for dealing with the full recovery of wasted metal and non-metal fractions by addressing the use of all the recovered metals (both precious and non-precious). In addition, non-precious metals can be used even without 100% purity for producing 3D printer filaments. From the business model point of view, the three cases create new supply chains that are fully compatible with the circular economy approach by targeting innovative markets with enormous growth potential, like additive manufacturing technologies, 3D printing filaments and customized jewellery markets. In addition, the paper adds to the literature of business model design (Massa et al., 2017) and underlines an observation made in previous studies (Ünal et al., 2018) about the fact that the managerial practices that companies implement for their business model should be orchestrated simultaneously to maximize the creation and capture of value for themselves and across the entire supply chain. Thus, the design of a business model for the transition towards circular economy conceives a systemic perspective (Velu, 2017) – which also involves the upstream and downstream stakeholders of the supply chain – especially when several environmental issues, such as energy efficiency, waste management, greenhouse gas emission, have to be faced simultaneously (Pan et al., 2015). Moreover, this research adds to the emerging research stream in the intersection between circular economy and Industry 4.0 (Ghisellini et al., 2016; Smart et al., 2017; Liao et al., 2017), especially from the point of view of highlighting the role of particular digital technologies, such as 3D printing, additive manufacturing, software platforms and cloud-based systems, in a circular economy context (Nobre and Tavares, 2017). The paper emphasizes the role that new emerging technologies can have to facilitate, as enablers of a circular business model transition, the process of value creation and capture (Heyes et al., 2018).

From a managerial perspective, managers willing to embrace circular economy principles can benefit from the highlighted managerial practices to support the design of manufacturing companies' business model within which they operate. Indeed, the paper maps the domains of business model within which the value can be created and captured, i.e., the value network and the customer value proposition & interface dimensions. Then, it highlights a set of relevant managerial practices, such as energy efficiency initiatives, usage of friendly material, Design for "X" practices, and pay-per-use models, that companies can implement to enable the creation and capture of value for themselves and for the upstream and downstream stakeholders of the supply chain. Moreover, the obtained results show how a business model assumes a different degree of circularity, or in other words, how the implementation of managerial practices to put into practice for a circular economy are peculiar for each kind of business model. For example, Case A seems to be more traditional, both in the value network and in the customer value proposition & interface dimensions of its business model, as it currently relies on the ownership of the product without direct customer involvement in the circular economy initiatives. On the contrary, Cases B and C appear to be more innovative, and to have a higher degree of circularity than Case A, especially in the customer value proposition & interface dimensions of their business model, as they currently rely on new mechanisms of value capture, such as leasing or renting or pay-per-use (in both Cases B and C) or pay-per-performance (just in Case C), with a direct customer involvement ("push" or "pull") in the circular economy initiatives. Thus, managers are also advised to pay special attention to the new mechanisms of value capture, in accordance with the context within which their companies operate, to enhance a more circularity compared to the degree allowed by a more traditional business model.

Finally, it is worth to highlight how external environmental conditions, especially that of environmental regulation, can influence how companies implement the managerial practices for a circular business model and, in a different way, for the specific business model dimensions and related industrial benefits. This result is particularly interesting to underline, as the Urbinati et al. (2017)' study clearly stated that contextual factors do not have an impact on circularity: "exogenous factors – such as the size, the industry, the geography and the age of the company – do not seem to matter in the adoption process" (p. 496). This notwithstanding, the authors invited "[…] future theoretical and empirical research to analyze whether in the case of circular economy the contextual factors could have, to some extent, an impact in terms of shaping circular business models" (p. 496). Accordingly, the empirical analysis of this paper shows how the environmental regulation can play a key role in influencing the shaping of a circular business model and the adoption of certain managerial practices. Of course, contrarily to previous studies (i.e., Urbinati et al., 2017), the present research relies on information collected from primary sources and allows for the opportunity to deepen – and strengthen – the influence of a particular external environmental condition on the design of a circular business model.

6. Conclusions

The paper aimed to investigate and present relevant managerial practices to create and capture value in circular business models and to shed light on the role of the environmental regulation in influencing their adoption. As already highlighted above, the authors analyzed the environmental regulation as it has recently emerged as a critical, although under-researched, condition that

Table 7
Results obtained from the empirical analysis.

	Case A	Case B	Case C
Value network	- The nature of materials and novelty of the production process allow for reduction of greenhouse gas emissions and environmental impact *(similar to Cases B and C)* - Case A takes care of the material used in the production process *(similar to Cases B and C)* - Suppliers involved in the production process *(similar to Cases B and C)* - Communication for receiving materials *(similar to Cases B and C)* and during the testing phase of the production process *(different from Cases B and C)* - Design for Recycling, Remanufacturing, Reuse and Disassembly *(similar to Case C, different from Case B)*	- The nature of materials and novelty of the production process allow for reduction of greenhouse gas emissions and environmental impact *(similar to Cases A and C)* - Case B takes care of the material used in the production process *(similar to Cases A and C)* - Suppliers involved in the production process *(similar to Cases A and C)* - Communication for receiving materials *(similar to Cases A and C)* and during the experimentation phase of 3D printing *(similar to Case C, different from Case A)* - Design for Environment *(different from Cases A and C)*	- The nature of materials and novelty of the production process allow for reduction of greenhouse gas emissions and environmental impact *(similar to Cases A and B)* - Case C takes care of the material used in the production process *(similar to Cases A and B)* - Suppliers involved in the production process *(similar to Cases A and B)* - Communication for receiving materials *(similar to Cases A and B)* and during the experimentation phase of 3D printing *(similar to Case B, different from Case A)* - Design for Recycling, Remanufacturing, Reuse and Disassembly *(similar to Case A, different from Case B)*
Customer value proposition & interface	- Case A holds the ownership of the products until they are sold to the customers *(different from Cases B and C)* - The products sold by Case A do not have related additional services *(different from Cases B and C)* - Products are sold directly to customers; no leasing, renting, pay-per-use and pay-per-performance mechanisms are available *(different from Cases B and C)* - Case A promotes its value proposition through its own website and through advertising and in-store sales *(similar to Cases B and C)*, no customers' involvement in sustainability and circular economy initiatives, no multichannel communication *(different from Cases B and C)*	- Case B does not sell the products directly to the customers *(similar to Case C, different from Case A)* - Case B leverages a software platform to offer custom-made jewellery *(similar to Case C, different from Case A)* - Case B holds the ownership of the products as long as customers pay for their usage; leasing, renting and pay-per-use mechanisms are available *(similar to Case C, different from Case A)* - Case B promotes its value proposition through its own website and through advertising and in-store sales *(similar to Cases A and C)*, customers are involved in sustainability and circular economy initiatives *(similar to Case C, different from Case A)*, no multichannel communication *(similar to Case A, different from Case C)*	- Case C does not sell the products directly to the customers *(similar to Case B, different from Case A)* - Case C leverages a software platform to offer custom-made printing filaments *(similar to Case B, different from Case A)* - Case C holds the ownership of the products as long as customers pay for their usage; leasing, renting, pay-per-use *(similar to Case B, different from Case A)* and pay-per-performance mechanisms are available *(different from Cases A and B)* - Case C promotes its value proposition through its own website and through advertising and in-store sales *(similar to Cases A and C)*, customers are involved in sustainability and circular economy initiatives *(similar to Case B, different from Case A)*, presence of multichannel communication *(different from Cases A and B)*
Environmental regulation	Practices of value creation and capture are compliant with the environmental regulation in order to comply with the regulatory objectives of energy-efficiency, reduction of greenhouse gas emissions and supply chain sustainability *(similar to Cases B and C with reference to the value creation dimension)*	The environmental regulation influences more how the practices of value creation are implemented, and mostly related to the energy-efficiency and the reduction of greenhouse gas emissions *(similar to Case C, different from Case A)*	The environmental regulation influences more how the practices of value creation are implemented, and mostly related to the energy-efficiency and the reduction of greenhouse gas emissions *(similar to Case B, different from Case A)*

influences the anatomy of circular economy implementation at business model level (Centobelli et al., 2020). Therefore, the paper tries to reach its objective by testing the theoretical taxonomy for circular business models proposed by Urbinati et al. (2017) on three European case studies operating in novel supply chains of the manufacturing industry. First, the paper shows the domains of business model within which the value can be created and captured, i.e., the value network and the customer value proposition & interface dimensions. Second, the paper highlights a set of relevant managerial practices that can be adopted, both in the value network and in the customer value proposition & interface dimensions of companies' business model of the manufacturing industry, to design a circular business model and enhance a higher degree of circularity in their business model. Third, the paper argues about the role of the environmental regulation in influencing how companies implement the managerial practices for a circular business model. This result is particularly interesting to underline, as previous studies have denied the role of contextual factors "in the adoption process" and their "impact in terms of shaping circular business models". Further research is invited to better understand the role that contextual factors play in other companies, and in other industries, which are shifting towards a circular economy paradigm. Finally, the paper discusses the role of customer involvement and interaction, as the customer represents a key stakeholder in a circular business model: a strong and sustainable relationship with the customer can allow companies to better deliver their value proposition and capture value from it over time in a more effective way. Future research may be needed to further the understanding of the dynamics of value creation and capture due to the "customer-pull" or "customer-push" involvement taking place in a circular business model.

Although interesting findings arise from this research, the paper has some limitations. First, it mostly leverages a theory-testing approach. This approach does not necessarily allow for building theory. In fact, the application of the Urbinati et al. (2017)'s taxonomy represents only the first step of the research, which helped identifying relevant managerial practices for circular business models. Indeed, from the empirical analysis, it additionally emerges that, when dealing with circular business models, scholars should also consider the influence of external environmental conditions, such as that of the analyzed environmental regulation, which allow for strengthening the effectiveness of a circular business model design. This second evidence is mostly coherent with theory-building scopes. Second, the qualitative methodology used in the present research does not allow for generalizing results to any population of companies and industries. Accordingly, a frequent criticism of case study methodology is represented by its dependence on qualitative analyses that characterize the research as being incapable of providing generalizable conclusions (Tellis, 1997). However, the generalization of results from multiple case study analysis, as in the present research, can be made for an "analytical generalization" instead of a "statistical generalization"

(Elia et al., 2020). Thus, although the "analytical generalization" does not explain the entire population, it is however part of the practice of qualitative research and characterized by the potential for several different ways of generalizing based on qualitative data (Halkier, 2011). In addition, qualitative analysis induces the paper to neglect quantitative elements that could strengthen the empirical findings and the interpretation of results. Accordingly, the authors invite future research to consider the adoption of quantitative methodologies and/or theory building approaches in the field of circular business models.

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CRediT authorship contribution statement

Andrea Urbinati: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Paolo Rosa:** Conceptualization, Investigation, Data curation, Funding acquisition. **Claudio Sassanelli:** Conceptualization, Investigation, Data curation. **Davide Chiaroni:** Validation, Supervision. **Sergio Terzi:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

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