Circular Industry 4.0: An integrative framework

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Abstract
Both in theory and practice Circular Economy and Industry 4.0 have been historically considered as isolated mechanisms for economic growth, although some scientific contributions have recently highlighted strong synergetic relationships between them. Despite the existence of roadmaps for sustainable operations in Circular Economy through Industry 4.0 or of conceptual frameworks of Industry 4.0 in Circular Economy contexts, we still lack an integrative framework of Industry 4.0 and Circular Economy. Thus, we examine whether and to what extent Industry 4.0 is interdependent and interrelated with Circular Economy and can support the value creation and capture in Circular Economy business models.

Keywords: Circular economy, Industry 4.0, Circular economy business model, Digital technologies, digital transformation.

1. Introduction
Transition towards Circular Economy and Industry 4.0 has recently commenced (Ghisellini et al. 2014; Smart et al. 2017; Liao et al. 2017). As such, Circular Economy has been emerged as a new industrial paradigm for decoupling economic growth from finite resource constraints by providing opportunities for business regarding new ways of value creation, revenue generation, cost reduction, resiliency and legitimacy (Manninen et al. 2018). Besides, Industry 4.0 initiated by means of rapidly digitalizing economy and society, while exploiting digital technologies, to help industry achieves competitiveness by reaching time reduction, flexibility, cost reduction, productivity and quality (Moeuf et al. 2017; Kache & Seuring 2017; Liao et al. 2017; Wuenderlich

et al. 2015). Accordingly, these two industrial paradigms have attracted many diverse sectors, organizations and even governments. Obviously, the engagement of practitioners and politicians on these topics are far more developed compared to that of academics. Yet, in theory and practice, Circular Economy and Industry 4.0 are isolated from each other despite their strong synergetic relationships. As we are still using more resources than we can replace (Murray et al. 2015), the increasing pace of production and consumption which is led by Industry 4.0 might indicate an obligation for both paradigms to co-evolve. In addition, several perspective studies are aimed to answer to the research question of "Can Industry 4.0 tools, which include cyber-physical systems, the Internet of Things (IoT), cloud computing and cognitive computing and concepts, drive the deployment of a new generation of Circular Economy initiatives?" (Tseng, et al., 2018, p. 146). In addition, although other contributions have tried to provide roadmaps for sustainable operations in Circular Economy through Industry 4.0 (Jabbour, et al., 2018) or to propose conceptual theoretical frameworks of Industry 4.0 (Robleck, et al., 2016; Müller, et al., 2018) also in the light of improving logistics of products and supply chain efficiency (Flügel and Gehrmann, 2009), we still lack an integrative framework of Industry 4.0 and Circular Economy. Thus, scientific research with a holistic view on this topic is especially crucial to guarantee reaching intended outcomes or more, in short and long term for both the transition processes.

Accordingly, we attempt to examine in this paper whether and to what extent Industry 4.0 is interdependent and interrelated with Circular Economy and can be helpful for supporting the value creation and capture in Circular Economy business models.

Departing from these premises, the purpose of this paper is to integrate Circular Economy and Industry 4.0 within a novel conceptual framework by having in mind the value creation and capture perspectives in Circular Economy business models (Urbinati et al., 2017). Accordingly, the research question is posed as: *"Whether and to what extent Industry 4.0 may facilitate the process of value creation and capture in circular economy business models?"*

The paper is structured as follows. In section 2, we review the most recent contributions on Circular Economy business models and Industry 4.0. Afterwards, the methodology is briefly presented in Section 3. It is followed in Section 4 by the findings of our research that propose the conceptual theoretical framework that integrates the two paradigms. In the Conclusions of Section 5, we finally summarise the main implications of our research and point out avenues for further research.

2. State-of-the-art

In this Section, we focus on the research streams of Circular Economy business model, as "a well-designed business model that creates an overall picture of the firm and its operations with a consistent logical structure for executing the strategy" (Richardson 2008, p.141) in a Circular Economy context. Thus, we aim to map the managerial practices that companies adopt to favour the creation and capture of value in their Circular Economy business model. Then, we present an overview of the Industry 4.0 pillars that can be conceived in a Circular Economy context to support the creation and capture of value in Circular Economy business models.

Circular economy business models (CEBM)

Circular Economy has emerged as a new industrial paradigm as an alternative to linear "take, make and dispose" model (Ghisellini et al. 2014). Thus, Circular Economy offers new ways of value creation and capture that are decoupled from resource depletion and social impact.

Business model is considered as a holistic and system level approach to "how firms do business" (Zott et al. 2011). Accordingly, CEBMs are defined as "business models that aim at solutions for sustainable development by creating additional monetary and non-monetary value by the pro-active management of a multiple stakeholders and incorporate a long-term perspective - that are specifically aiming at solutions for the Circular Economy through a circular value chain and stakeholder incentive alignment" (Geissdoerfer et al. 2018, p. 713). It is noted that the value in the context of Circular Economy is not only limited with economic one but also includes natural resource regeneration and wellbeing of the society as an integral part of the nature (Geissdoerfer et al. 2018).

In the emerging field of Circular Economy business models, Urbinati et al. (2017) propose a new taxonomy of the degree of circularity, which is aimed at classifying the degree of adoption of circular economy principles at micro-level, i.e. the company is the unit of analysis. In particular, they build this taxonomy by leveraging on the business model perspective (Osterwalder & Pigneur 2005, 2010; Zott et al. 2011) and identify two major dimensions featuring Circular Economy business models:

1. The value creation, which refers to the degree a company leverages its key resources, activities and upstream partners to enhance the circularity of its products and processes;
2. The value capture, which regards the degree to which a company makes visible to the customers its compliance to the circular economy principles. In particular, the authors consider the variables of price (how much of the price is based on pay-per-use?) and promotion (how much content around the circular economy is promoted through marketing campaigns) to measure this dimension.

Each dimension highlights some relevant managerial practices for creating (Mayyas et al. 2012; Zhu et al. 2010; Lieder & Rashid 2015; Moreno et al. 2016) and capturing (Williams 2007; Tukker 2004; Tukker 2015; Tukker & Tischner 2006; Heerde et al. 2013; Kumar & Venkatesan 2005; Baxendale et al. 2015) value in CEBMs (Table 1).

Table 1 – Managerial Practices for creating and capturing value in CEBMs.

Value Creation	**Value Capture**
Establishment of effective communication with suppliers, retailers and end-of-life materials managers, such as the waste industry, as well as with all the actors involved in the supply chain	Sale of single products
Support of all partners to develop awareness and new skills, hence rendering the business model more viable, i.e. circular, for all the actors involved in the supply chain	Sale of products with additional complementary assets
Energy efficiency-driven practices to reduce emissions and environmental footprint	Leasing / renting
Friendly material usage-driven practices, i.e., natural, recyclable, durable, easy to separate	Pay-per-use
DfX practices (Design for recycling, Design for remanufacturing and reuse, Design for disassembly, Design for environment etc.)	Promotion on company website
	Communication in store through advertising and sales personnel
	Customer involvement in circularity initiatives
	Communication of circularity through all channels

Industry 4.0 in a Circular Economy context

Several studies examine how new emerging digital technologies (or pillars) of Industry 4.0 can be useful to support the Circular Economy adoption by companies (Nobre & Tavares 2017) also to enhance sustainable competitiveness and smart growth (Gerlitz 2016; Seele & Lock 2017). In particular, Big Data and Internet of Things (IoT), although their practical effects are still unclaimed and under experimentation (Groves et al., 2013), can support the monitoring, analysis and control of products' data in order to support their lifecycle and extend their replacement along the entire supply chain. These activities can be also due to the application of Product Lifecycle Management systems (PLMs) (Urbinati et al. 2018), which focus on the use of IoT to allow intelligent products and devices to interact among them, in order to promote environment benefits, such as energy usage optimization and impacts reduction of CO2 emissions (Främling, et al. 2013), after the analysis and elaboration of data exchanged between them. As underlined by Tseng et al. (2018, p.146), "data-driven analysis can potentially be used to optimize the sustainable solutions intended to reduce the resource and emission intensities of industrial systems".

Furthermore, Big Data and its main characteristics of volume, velocity, variety, and veracity (4V) find applicability in the ReSOLVE (i.e., Regenerate, Share, Optimise, Loop, Virtualise, Exchange) framework for Circular Economy transition (Jabbour et al. 2017)), to support information flows along the supply chain, and the collection and share of data among the stakeholders' network (Despeisse et al. 2017). Moreover, IoT can be used as digital enabler of circular economy to allow (i) system optimization models, (ii) real-time measurement, (iii) big-data analysis and process control, (iv) smart integration of tools and methods, which help quantifying resource efficiency (Reuter 2016).

In addition, additive manufacturing technologies (also known as 3D printing) can be used to support the design for assembly and re-assembly, by producing modular and customized products for customers also in places that are close to them, thus exploiting a localization advantage. In this way, indeed, manufacturing of products becomes decentralized, and allows a lower distribution costs and raw materials savings (Nobre & Tavares 2017).

Some scholars point also out how some companies, whose core business is based on digital technologies and Information and Communication Technologies (ICT) implementation, can identify, evaluate and priorities sustainable business model innovations for Circular Economy (Heyes et al. 2018) Thus, some ICT and digitally-enabled companies mostly leverage on on-line advertising and websites to promote their value proposition, based on value added services such as software sale, plus installation, hardware sale, and repair.

Finally, cyber-physical systems and cloud manufacturing can play a key role in enabling Circular Economy transition. As underlined indeed by Lopes de Sousa Jabbour et al. (2018) "cyber-physical technological systems enable the integration of cyber space, physical processes and objects in order to connect machines and devices in production lines as a network, thus making real data available for decision-making, such as for the prioritization of production orders, optimisation of tasks, reporting of maintenance needs, etc. (Ahmadov & Helo 2016; Lee et al. 2015). Sensors and actuators are responsible for gathering and distributing this data in real-time (Yu et al. 2015)" (p. 5). In addition, "cloud manufacturing is a technology that creates a virtual and global space for enabling a shared network of manufacturing resources and capabilities through the internet. The logic of cloud manufacturing is service-based, meaning that suppliers

and customers interact in order to sell and buy services—for instance, design, simulation, manufacture, and assembly of products. Cloud manufacturing is recommended for its e-commerce features (Yu et al. 2015), and also involves other technologies from Industry 4.0, such as additive manufacturing" (Lopes de Sousa Jabbour et al. 2018, p.5).

According to the state-of-the-art of the existing research on Circular Economy business models and Industry 4.0 in Circular Economy contexts, we explain in Table 2 the relationships between Industry 4.0 pillars and Circular Economy business model in relation with the process of value creation and capture.

Table 2 – Deployment of Industry 4.0 on Circular Economy business model.

		Circular Economy business model	
		Value Creation	*Value Capture*
Industry 4.0 pillars	*Cyber Physical System*	-Resource, energy and capacity efficiency -Sharing data through partners among supply chain to enhance skills and capabilities	-Supporting the service models for customers through highly integrated physical goods with smart algorithms
	Cloud manufacturing	-Effective collaboration through value chain for design, assembly and manufacturing while capturing new skills	-Enabling active customer engagement in Circular Economy activities -Active e-commerce enabled promotion of circularity
	Internet of Things –IoT	-Better communication and exchange of data through value chain	-Enables the service models through collecting real-time information on location, condition and availability of assets
	Additive manufacturing	-Facilitating the DfX practices for CE (design for disassembly, recycling etc.) -Resource, energy and capacity efficiency -Friendly material usage as a substitution to mainstream toxic ones in the market	- Unique parts-solutions that can't be produced with conventional methods for sale of single products as well as service -Enabling active customer engagement in Circular Economy activities as the parts are tailored for specific customer

3. Methodology

This paper leverages on conceptual theory-building approach by deducing from literature review a set of concepts or models representing or describing an event or process which enables to seize the nature of the relevant themes (Meredith 1993). According to Meredith (1993), it has more interpretive power compared to formal traditional research methods. In business model literature, conceptual models and theory building approach are widely used for adaptive complex systems (Sodhi 2015). Given the complexity and nature of the relationship between Circular Economy and Industry 4.0 paradigms, a systems approach (Mingers & White 2010) is required to cluster seminal studies that match these research streams and to create a conceptual framework for future research..

4. Findings

We propose in Figure 1 the integrative framework for Circular Industry 4.0.

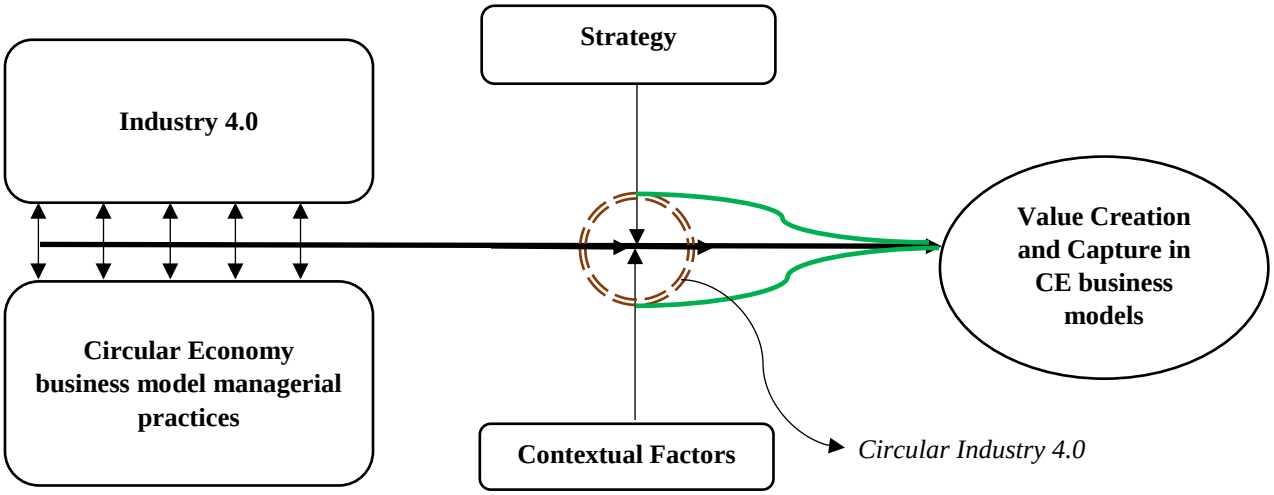

Figure 1 – Circular Industry 4.0: An Integrative Framework.

The review of extant literature that has been positioned at the intersection between Industry 4.0 and Circular Economy advances the novel concept of Circular Industry 4.0. The term Circular Industry 4.0 is introduced and defined as, *"a democratized platform of managing strategic value creation and capture based on given context (in production and services) while exploiting digital enabling technologies, which stimulate competitiveness and flexibility for a regenerative economic growth decoupled from resource use and social impact"*. Accordingly, the conceptual theoretical framework depicted in Figure 1 above is aimed at exemplifying the proposed definition.

Unification and balanced interplay between Industry 4.0 and Circular Economy is essential to ensure viable outcomes from both the new industrial paradigms. It can be inferred that what can be gained through realization of Circular Industry 4.0 (integrated-manner) will be greater than the sum of the isolated outcomes of Circular Economy and Industry 4.0 stand-alone. Taking a holistic stance towards these paradigms would amplify economic growth and organizational performance.

Accordingly, we have suggested the theoretical integrative framework of Circular Economy and Industry 4.0 from value creation and capture perspectives. We argue that the *strategy* and *contextual factors* are determining the nature of value creation and capture as well as the proper coupling of the means of Industry 4.0 with the managerial practices of CEBMs. Accordingly, we explain the role of moderating variables in the relationship between Circular Economy and Industry 4.0 played by *strategy* and *contextual factors* in the following paragraphs.

Strategy

Strategy is defined as "a coherent set of analyses, concepts, policies, arguments, and actions that respond to a high stakes challenge" (Rumelt 2012, p. 6) Strategy is essential part of business models as Teece, (2017) points out "capabilities and strategy combine to create and refine a defensible business model, which guides organizational transformation" (p.44). With regard to Circular Economy, the managerial practices are mostly a choice rather than obligation, and strategy

plays a crucial role on determining the nature of value creation and business model design. Elkington, (1997) notes that synergies and trade-offs are essential for sustainable development in terms of environmental, economic and social goals in which the strategy plays a crucial role on how the managerial practices of Circular Economy are being implemented.

Contextual Factors

Value creation and capture in business models and especially in Circular Economy business models can be better understand from contingency perspective (Lepak et al. 2007) due to the fact that Circular Economy as a part of systems theories requires higher dependence to the internal and external environment. It includes the society as an inherent part of regeneration together with the resources perspective. The dynamic nature of business models, in essence the rationale of doing business, necessitates being responsive to the environmental changes and new demands (Hueske et al. 2015). Accordingly, there is no doubt that the contextual factors determine the nature of value creation and capture and the synergies between CEBMs and Industry 4.0, as they are included as a one of main elements of the theoretical framework. Based on the review of the business model research, the most prominent contextual factors are geography (Chesbrough 1999; Yu & Hang 2010), level of market competition (Porter 1979) and regulatory frameworks (Phillips & Scherer 1971; Scherer & Ross 1990) for external environment , whereas internally they can be listed as leadership and managerial commitment, industrial capabilities, learning and training mechanisms and company age and size (Foss & Saebi 2017; Teece 2017).

5. Conclusions

The paper presents an integrative framework of Circular Economy and Industry 4.0 from value creation and capture perspective in business models. The concept of "Circular Industry 4.0" has been introduced and defined by also considering the strategy and contextual factors as moderating variables of this relationship.

Both the industrial paradigms endanger the current way of making business as they require fundamental changes in the structure of business itself. Accordingly, we chose to integrate both paradigms by using a business model perspective, especially in terms of value creation and capture. Consequently, the integration of these two interrelated and interdependent industrial paradigms is indispensable for economic growth and prosperity decoupled from resource and social impact.

The theoretical framework introduced in this paper contributes to Circular Economy business model literature as well as to the sustainable operation management stream by explicating how and to what extent Industry 4.0 means can support the value creation and capture in Circular Economy business models. As practical implication of the framework suggested, the managers can leverage on Industry 4.0 pillars as key resources for shaping the creation and capture of value in their business model by with a well-defined strategy.

The study can be further expanded by testing the assumptions on which the framework is built in a statistically significant samples and in different industries and geographies.

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