# Supply chain management in the era of circular economy: the moderating effect of big data

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## Abstract

**Purpose** – This paper analyzes the effect of circular economy practices on firm performance for a circular supply chain and explores the moderating role that big-data-driven supply chain plays within these relationships.

**Design/methodology/approach** – This study uses data collected through an online survey distributed to managers of 378 Italian firms that have adopted circular economy principles. The data are processed using multiple regression analysis.

**Findings** – The results indicate that the three categories of circular economy practices investigated – namely circular economy supply chain management design, circular economy supply chain relationship management and circular economy HR management – play a crucial role in enhancing firm performance from a circular economy perspective. A big-data-driven supply chain acts as a moderator of the relationship between circular economy HR management and firm performance for a circular economy supply chain.

**Originality/value** – This study makes a number of original contributions to research on circular economy practices in a big-data-driven supply chain and provides useful insights for practitioners. First, it answers the call to capture digital transformation trends and to extend research on sustainability in supply chain management. Second, it enhances the literature by investigating the relationships between three different kinds of circular economy supply chain practices and firm performance. Finally, it clarifies the moderating role of big data in making decisions and implementing circular supply chain solutions to achieve better environmental, social and economic benefits.

**Keywords** Supply chain management design, Circular economy, Supply chain relationship management, Big data

**Paper type** Research paper

## Introduction

In recent years, business management has been increasingly influenced by the key concept of sustainability. In order to achieve sustainable development, more attention is being paid to circular economy, which allows resource usage and waste production to be reduced (Gupta *et al.*, 2019). The concept of circular economy represents a substantial change in the way firms



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are run, since it requires the integration of economic activities and environmental well-being (Jabbour *et al.*, 2019a) and calls for the definition of new business models that lead to higher performance in environmental, social and economic terms (Stahel, 2016; Teixeira *et al.*, 2016). In this perspective, circular economy is strongly related to supply chain management practices, as both are based on effective business process management. Traditionally, to achieve sustainability, firms have focused on a vertical integrated system for their supply chain. In contrast, in a circular economy perspective, firms are building sustainable cross-industry networks that allow the setting up of interconnected supply chains that use resources according to the 3Rs strategy: recycle, reduce and reuse (Tseng *et al.*, 2018).

Although previous studies have argued for the need to combine circular economy and supply chain management (De Angelis *et al.*, 2018; Sauvé *et al.*, 2016; Schulte, 2013), empirical studies are still scarce. Limited attention has been given in the academic literature to the embodiment of circular economy principles within the supply chain (Aminoff and Kettunen, 2016; De Angelis *et al.*, 2018; Lewandowski, 2016). Therefore, the circular supply chain remains an underexplored area of research (Geissdoerfer *et al.*, 2018).

Moreover, adopting circular economy principles along the supply chain requires the acquisition, elaboration and use of adequate information and knowledge to implement the desired changes in business operations effectively (Gupta *et al.*, 2019; Sumbal *et al.*, 2019). Disruptive technologies, such as the Internet of things, big data analytics and artificial intelligence, are affecting the way supply chain managers make strategic and operational decisions (Forbes Insights, 2018). In particular, big data made available by the spread of cloud computing, mobile digital business platforms, business analytics and social networks have not only significantly changed the *modus operandi* of many firms but have also been used to achieve better performance by optimizing circular economy supply chain solutions (Müller *et al.*, 2018; Tseng *et al.*, 2018). Recently, there has been debate as to whether and how the emergence of big data and disruptive technologies will affect supply chain practices, management and outcomes in order to strengthen knowledge and relevance (Gammelgaard, 2019; Swanson *et al.*, 2018). Although disruptive technologies are affecting all value chains (Bologa *et al.*, 2017; Erol *et al.*, 2016; Scuotto *et al.*, 2020; Stock and Seliger, 2016), the relationship between circular economy and data-driven supply chains is of recent conceptualization, and it focuses mainly on the effects of a single dimension of the so-called *triple bottom line* (environmental, economic and social sustainability). In addition, although the role of big data in effective decision-making processes has been acknowledged (Gupta *et al.*, 2019; Khan and Vorley, 2017; Waller and Fawcett, 2013; Wang *et al.*, 2016; Zhong *et al.*, 2016), few empirical studies have focused on how big data can be leveraged to support the circular economy supply chain performance of firms in environmental, social and economic terms. Therefore, further advances remain necessary if we are to understand the link between circular economy supply chain management, big data and firm performance (Chen *et al.*, 2008; Chen and Delmas, 2012; de Camargo Fiorini and Jabbour, 2017; Jabbour *et al.*, 2019a).

To address this gap in the literature and to answer the call for a better understanding of how supply chain management combines with circular economy principles, the present study proposes a conceptual model that integrates circular economy practices and big data for circular supply chain performance. Specifically, the paper explores the effects of circular economy practices on firm performance in a circular supply chain, and it investigates the moderating role that a big-data-driven supply chain plays within these relationships. The focus is on three different categories of circular economy supply chain practices: circular economy supply chain management design, circular economy supply chain relationship management and circular economy human resource (HR) management. Their direct effects on firm performance and the effect of big-data-driven supply chains as a moderator are investigated by means of multiple regression analysis on data collected from a sample of 378 managers operating in Italian firms that have already adopted circular economy principles.

This study makes two important contributions to the literature. First, by empirically investigating the relationships between three different kinds of circular economy supply chain practices and firm supply chain performance, it contributes to the nascent knowledge about circular economy supply chains and provides useful insights for practitioners. In this way, it sheds light on the embodiment of circular economy principles within the supply chain. Second, this study answers the call to extend research on the link between the circular economy supply chain, big data and firm performance; it also intervenes in the debate as to whether and how big data may affect supply chain practices and outcomes. In fact, it sheds light on the moderating role of big data usage in making informed decisions with regard to the creation of a supply chain model that takes into account circular economy principles.

The paper is structured as follows. It starts with a review of the literature on the key constructs of the conceptual model. It goes on to describe the research sample, illustrate the data collection procedure and set out the variables under investigation. Then, the models for analysis are described, and the empirical results are presented and discussed. Finally, the paper ends with a discussion of the findings, drawing theoretical and practical implications and making recommendations for future research.

## Literature review

Over the last decade, a trend that has gained significant attention from both the academic and practitioner communities is circular economy, a crucial component of sustainable development that revolves around regenerative, restorative and sustainable business activities (Gupta *et al.*, 2019; Petit-Boix and Leipold, 2018; Zeng *et al.*, 2017). Circular economy emphasizes that business models have to go far beyond the traditional linear economy approach based on production–consumption–disposal; they must move to a model based on the 3Rs of recycle, reduce and reuse (Geissdoerfer *et al.*, 2018; Pagoropoulos *et al.*, 2017; Teixeira *et al.*, 2016; Tseng *et al.*, 2018). Circular economy is a means of conserving and optimizing the use of resources (Geng *et al.*, 2009). It thus represents a new concept of more sustainable development, since it aims to increase the efficiency of resource use in order to achieve economic, environmental and societal development by balancing and taking into consideration economic, environmental, technological and social factors (Geng *et al.*, 2009; Ghisellini *et al.*, 2016; Su *et al.*, 2013).

Firms willing to adopt a circular model are required to move toward technologies and business models characterized by longevity, renewability, reuse and repair in order to optimize the ways in which resources and materials already on the market are used and to reduce the consumption of raw materials and related waste (Gupta *et al.*, 2019; Stahel, 2016). At the level of the firm, circular economy implies the adoption of cleaner production and distribution (supply chain) patterns, especially by introducing better technologies. This leads to the adoption of new business models that require a broader and much more comprehensive look at the design of radically alternative solutions, network relationships, the engagement of individuals over the entire cycle of any process and radical changes in practices (Ghisellini *et al.*, 2016). Therefore, circular economy is a key element of the sustainable development that can give firms a superior competitive advantage, since it enables them to redesign and reorganize their operations (including manufacturing, supply chain management and training) by minimizing resource inputs, waste and emissions leakage (Geissdoerfer *et al.*, 2018; Jabbour *et al.*, 2019a). In order to achieve this, firms need to be organized in such a way that their processes are capable of benefiting from circular economy principles, resource exchange and interactions (Ghisellini *et al.*, 2016). In this connection, The Ellen MacArthur Foundation and McKinsey Company (2012, 2014) have emphasized the importance of progressing from sustainable supply chain management to a circular supply chain, defining it as the power of circling longer (i.e. a lengthening of the period of time during which materials are used).

Firms are trying to carry out different strategies, implement new organizational practices and cooperate with other firms over their supply chains (Winkler, 2011). In particular, within a firm's supply chain, circular economy supply chain design, relationships and HR management are the main practices to be considered in preparation for moving toward circular economy (Zeng *et al.*, 2017). However, few empirical studies have considered the integration of circular economy principles within the supply chain (Aminoff and Kettunen, 2016; De Angelis *et al.*, 2018; Lewandowski, 2016). Most of them deal with case studies of circular economy adoption and implementation rather than attempting to understand how circular economy practices embedded within the supply chain affect a firm's performance for circular supply chain as an indicator of the firm's environmental, social and financial performance (Ghisellini *et al.*, 2016). A review of the literature indicates that, in order to develop a supply chain that could work in a circular economy perspective, it is necessary for a firm (a) to encourage the introduction of solutions that make the cycle of domestic production more sustainable (circular); (b) to act on a plurality of fronts to promote collaboration with external stakeholders in developing a supply chain that also has circular economy objectives; and (c) to train and manage employees so that they are aware, involved and interested in the green and sustainable objectives of the firm. Therefore, this study assumes that the circular supply chain will bring the best performance results if all elements of the firm's supply chain are aligned to support these three circular economy practices.

To develop an effective circular economy supply chain, big data are certainly worthwhile; they allow rich, accurate and valuable information and insights to be extracted, and they make it possible to capture and manage knowledge for decision-making in logistics, manufacturing and order fulfillment (Gupta *et al.*, 2019; Khan and Vorley, 2017; Liu *et al.*, 2017; Pauleen and Wang, 2017; Renaud *et al.*, 2019). In particular, big data should be used to emphasize stakeholder orientation (Ameri and Patil, 2012; Brettel *et al.*, 2014; Holmström; Partanen, 2014; Pankaj *et al.*, 2013), develop more efficient, faster and better synchronized logistics processes (Fawcett *et al.*, 2011) and optimize the sustainable solutions that firms adopt for their supply chain management (Tseng *et al.*, 2018).

From a managerial perspective, big data have emerged as a key element that can support the implementation of circular economy within firms, rationalize operations and develop sustainable solutions (Gupta *et al.*, 2019; Jabbour *et al.*, 2019a). In the specific field of logistics and supply chains, big data represent the digital revolution that exponentially increases the realization of new products and processes (Gupta *et al.*, 2018; Hashem *et al.*, 2016; Ismagilova *et al.*, 2019; Jimenez-Jimenez *et al.*, 2019; Lamba and Singh, 2017, 2018; Luthra *et al.*, 2018; Mangla *et al.*, 2018; Rajput and Singh, 2019; Witkowski, 2017). Moreover, big data management and sharing among supply chain members are fundamental elements in the so-called industrial sustainability (Despeisse *et al.*, 2017a, b). Although the role of big data in effective decision-making in the field of supply chain has been acknowledged (Gupta *et al.*, 2019; Khan and Vorley, 2017; Waller and Fawcett, 2013; Wang *et al.*, 2016; Zhong *et al.*, 2016), further advances are still necessary (Jabbour *et al.*, 2019a). There is very limited understanding of how big data can be leveraged to support firm performance for the circular economy supply chain. This lack of knowledge of the links between circular economy supply chain practices, big data and firm performance reflects a substantial gap in understanding, theory and practice. Therefore, the understanding of this relationship is fertile ground that needs to be cultivated (Chen *et al.*, 2008; Chen and Delmas, 2012; de Camargo Fiorini and Jabbour, 2017; Jabbour *et al.*, 2019a).

Some recent contributions have highlighted positive returns for firms that arise from the management of big data from a sustainability perspective (Dubey *et al.*, 2019; Jeble *et al.*, 2018). As Hazen *et al.* (2016, p. 593) pointed out, "it is time to move beyond examining how big data and predictive analytics (BDPA) can be used to enhance operational – and financial –

based supply chain outcomes to examination of how BDPA can increase measures of supply chain sustainability that are becoming increasingly important in today's global marketplace." Nonetheless, in terms of the integration between circular economy and supply chain management, there is still a conceptual gap regarding the related combination mechanisms (Aminoff and Kettunen, 2016; Farooque *et al.*, 2019).

*Circular economy supply chain design, relationship management and firm performance for circular economy supply chain*

When the concepts of circular economy and sustainable supply chains are combined, a circular supply chain is seen to include circular supply chain design and circular supply chain relationship management (Zeng *et al.*, 2017). In particular, successful implementation of a circular supply chain requires an appropriate design. Key circular supply chain design practices include optimization of supply chain facilities to reduce demand for logistics, efficient and circular modes of transportation and recycling of waste materials and spare parts. These elements are critical in the development of circular economy (Gupta *et al.*, 2019). Circular supply chain design management consists of a proactive and effective strategy for creating circular systems that facilitate the 3Rs (reduce, reuse and recycle) and emphasize environmental, social and economic requirements (Zhu *et al.*, 2010). In many cases, the implementation of a circular supply chain requires changes in design management, which can be achieved by means of new restorative and regenerative system with less environmental impact (Pagoropoulos *et al.*, 2017). In the design of the whole supply chain, firms should optimize all design factors in order to minimize resource consumption and maximize circular economy friendliness (Ying and Li-jun, 2012), focusing on materials, products and systems design as well as on the design for reuse (Ripanti and Tjahjono, 2019).

Moreover, circular supply chain relationship management improves the coordination of the supply chain network and helps firms to meet circular economy targets by controlling information and risk, selecting the right suppliers on the basis of environmental, social and economic standards and meeting customer expectations through value cocreation in a circular economy perspective (Zeng *et al.*, 2017). Circular supply chain relationship management is one of the fundamental bases of the circular supply chain, since it allows firms to select suppliers that consistently demonstrate behavior that is circular economy friendly and to engage with sustainability activities by enabling best practices to be adopted (Genovese *et al.*, 2017). Circular supply chain relationship management also allows firms to cooperate with the other members of the supply chain to strengthen their competitiveness, thus ensuring the long-term generation of economic opportunities, as well as offering societal and environmental benefits (Ripanti and Tjahjono, 2019; Ying and Li-jun, 2012; Zhu *et al.*, 2010). Through the circular supply chain relationship management, information and knowledge flows are planned, organized and coordinated among supply chain members in ways that optimize resource allocation, increase benefits and achieve the goals of the circular economy paradigm (Ying and Li-jun, 2012).

The literature has suggested that circular economy supply chain practices, and in particular design and relationship management practices, have a lasting positive impact on business outcomes (Zeng *et al.*, 2017). In fact, from a managerial perspective, by improving the management of the design and relationships within the supply chain, firms can improve their performance and achieve a sustainable competitive advantage (Ying and Li-jun, 2012). According to Zeng *et al.* (2017), circular supply chain design management and relationship management have emerged as crucial practices for firms seeking performance improvements toward circular economy.

The present study argues that circular supply chain design and circular supply chain relationship management enable the development of the holistic principles of circular

economy within a firm and that they enhance firm performance for circular supply chain as an indicator of performance that reflects firm's environmental, social and financial performance. Therefore, the study makes the following hypotheses:

*H1.* Circular economy supply chain design is positively related to firm performance for circular economy supply chain.

*H2.* Circular economy supply chain relationship management is positively related to firm performance for circular economy supply chain.

*Circular economy HR management and firm performance for circular economy supply chain*

In addition to circular supply chain design and relationship management, successful implementation of circular supply chain practices depends on intelligent use of HR, a caring approach and adequate circular economy training (Ripanti and Tjahjono, 2019; Teixeira *et al.*, 2016). The literature has emphasized the role played by HR management in favoring the achievement of business goals and strategies, as well as the impact of HR management practices on firm performance (Duff, 2018; Huselid, 1995; Jabbour *et al.*, 2019b).

According to stakeholder theory and resource-based theory, green and sustainable HR management that contributes to greater employee engagement in sustainability management can help firms to overcome barriers to adopting green and sustainable supply chains (Nejati *et al.*, 2017; Teixeira *et al.*, 2016). Green and sustainable HR management plays a crucial role in establishing a firm's sustainability practices (Jackson *et al.*, 2014), since it involves aligning HR management practices with the firm's sustainability goals, as well as with targets for employee empowerment and organizational culture (Renwick *et al.*, 2013, 2016). The effective implementation of green and sustainable supply chains can be achieved through green HR management that consists of hiring the right people with the right skills and competences, equipping firms with sustainability consciousness and engaging employees to enhance environmental, social and economic performance (Ashraf *et al.*, 2015; Nejati *et al.*, 2017). In this way, by addressing the "human side of sustainability" (Jabbour *et al.*, 2019b, p. 794), HR management can support the adoption and implementation of sustainable supply chain systems as a fundamental aspect of the circular economy paradigm (Jabbour and de Sousa Jabbour, 2016; Nejati *et al.*, 2017). Previous studies have also found that green HR management positively influences a firm's sustainability performance in terms of achieving better environmental, social and economic performance (Jabbour *et al.*, 2019b; Kim *et al.*, 2019; Moraes *et al.*, 2019; Roscoe *et al.*, 2019).

Among the HR practices that contribute to achieving better sustainable performance in the context of supply chain, training on relevant environmental topics has emerged as crucial to the adoption of advanced sustainable/green practices (Teixeira *et al.*, 2016). Training, combined with performance management and rewards, is essential for increasing employees' motivation and commitment and allowing them to assume greater responsibility for their tasks and decisions in ways that support personal sustainability objectives and the objectives of the firm (Moraes *et al.*, 2019).

In terms of green supply chain management, it may be supposed that circular economy HR management practices, and in particular training, are positively correlated with circular supply chain performance, since circular economy HR management tends to help firms improve their circular supply chain management and, thus, their performance. Therefore, the present study makes the following hypothesis:

*H3.* Circular economy HR management is positively related to firm performance for circular economy supply chain.

*Moderating effects of big-data-driven supply chains*

Big data now affect all business sectors and functionalities, including supply chains, logistics, consumer and market insights and innovation development (McAfee *et al.*, 2012; Sumbal *et al.*, 2017; Tian, 2017). Big data are a critical issue in supply chain management (Wang *et al.*, 2016), since they enable new ways of organizing and analyzing supply chain processes to achieve better supply chain performance (Yu *et al.*, 2018). Insightful information for decision-making, such as big data and big data analytics, can help firms in creating circular economy business systems (Fosso Wamba *et al.*, 2017; Gunasekaran *et al.*, 2017; Gupta *et al.*, 2019). In the context of supply chains, big-data-driven supply chains enhance productivity and growth and impact on overall firm performance.

Big data play a prominent role in improving a firm's overall performance, particularly in logistics and supply chain management (Wang *et al.*, 2016). Previous studies have noted that big data have a positive impact on supply chain and environmental, social and economic performance (Akter*et al.*, 2016; Gupta and George, 2016; Jeble *et al.*, 2018; Song *et al.*, 2017; Zhao *et al.*, 2017). According to Raffoni *et al.* (2018), big data, if used with appropriate care, can help firms to achieve better performance. Big data have also been recognized as a facilitator of informed and reliable decisions for the adoption of circular economy strategies and for the implementation of circular economy business practices (Gupta *et al.*, 2019; Jabbour *et al.*, 2019a).

Firms can more effectively take advantage of new insights gained from big data when they leverage and exploit it to drive their supply chains. Firms with better big-data-driven supply chains have better capabilities to improve their circular supply chain than those that rely on decisions based on limited data sets. In fact, big data can be used to better understand how to design supply chain processes, coordinate operations and networks, allow supply chain members to cooperate and engage employees with the circular economy paradigm (Gupta *et al.*, 2019; Wang *et al.*, 2016). The challenge is that the higher the usage of big data, the more likely a firm is to undertake circular economy practices and that different levels of big data usage determine different levels of firm performance (Yu *et al.*, 2018).

Given the aforementioned theoretical evidence, this study proposes that big data will enhance the effects of circular economy practices on firm performance (in other words, big data will exert a moderating effect).

Therefore, the study makes the following hypotheses:

*H4a.* A big-data-driven supply chain moderates the positive relationship between circular economy supply chain management design and firm performance for circular economy supply chain.

*H4b.* A big-data-driven supply chain moderates the positive relationship between circular economy supply chain relationship management and firm performance for circular economy supply chain.

*H4c.* A big-data-driven supply chain moderates the positive relationship between circular economy HR management and firm performance for circular economy supply chain.

## Methodology

*Research sample and data collection*

The purpose of this paper is to investigate the effect of circular economy practices on firm performance for circular supply chain and the moderating role of big-data-driven capability. The study therefore adopts a quantitative approach, using multiple regression analyses to test the hypotheses on data retrieved from a sample of Italian firms. Italy was chosen as a

suitable research setting, since in 2018 it registered a substantial improvement in circular economy practices by adopting innovative waste management practices and implementing new business and consumption models centered around the sharing economy, thereby reducing waste and use of secondary raw materials (The Circular Economy Network, 2019). Among the top five European economies, Italy ranks first in terms of circularity of production; in terms of domestic consumption, it ranks third, ahead of Germany (The Circular Economy Network, 2019). Accordingly to the Eco-Innovation Observatory, a platform promoted by the European Commission to collect and analyze a wide range of eco-innovation and circular economy information from the European countries, Italy ranks seventh in adopting policies dedicated to the transition toward circular economy, making its national economy more sustainable and competitive (Spaini, 2018). Italy is a pioneer in the implementation of circular economy with regard to the supply chain (Bianchi, 2018), and the Italian government has made efforts to adopt structural changes that enable more efficient use of resources and more circular and sustainable patterns of business processes. Moreover, Italy is one of the key countries in the European big data market (Bergamaschi *et al.*, 2016). With firms increasingly aware of the importance of big data, the big data market in Italy, especially in terms of infrastructure investments, experimentations and production projects, is growing constantly; in 2018, it had a total value of around 1.4bn euros, an increase of 26% compared to 2017 (School of Management del Politecnico di Milano, 2018). Therefore, the Italian setting is appropriate for the aim of the present study.

A sample of Italian firms was recruited from an opt-in panel by one of the larger global market research companies, which has a community of over 5,000 clients in 90 markets, from small and medium firms to multinational companies. The panel members were recruited from both business-to-business and business-to-consumer firms. Data were collected through a web-based survey. After a pretest in which three academics and two professionals checked the reliability and usability of the questionnaire, the survey was distributed to a population of managers working in firms that have started to adopt circular economy principles. Data were collected in one wave that lasted for five months, from June 2018 to October 2018. Three screening questions were used to ensure that each participant was qualified to participate in the survey. These questions concerned whether the individual was employed or unemployed, his/her job position and the firm's adoption of circular economy principles. The surveyed population consisted mainly of manufacturing (36.5%) and service (33.6%) firms, most of them (50.8%) large. The data collection process yielded 378 valid responses.

The self-reporting questionnaire was developed according to previous literature on sustainable supply chain management, circular economy and data-driven supply chain and based on the scales and key indicators used in previous studies. The questionnaire was structured in two parts: the first investigated the constructs under observation and the relationships among them, and the second addressed general information about the firms (such as field of activity, number of employees and sales revenue). To avoid cross-cultural methodological issues, the back-translation procedure (from English to Italian and back to English) was used to ensure consistency between the Italian and English versions of the questionnaire (Brislin, 1970; Tyupa, 2011), as the majority of the respondents were Italian-speaking.

Since the questionnaire collected self-reported responses from informants, four different approaches were applied to control for nonresponse bias. First, by enrolling five experts in pretesting the questionnaire, each question was clarified to minimize its ambiguity, and the questionnaire was designed to distribute the independent and dependent variables across its different sections (Jahanmir and Lages, 2016). Second, any information that could be used to identify the respondents was removed, guaranteeing their anonymity. Third, respondents were not aware of the purpose of the study during data collection. Fourth,

Harman's single-factor test was performed to check whether the variance of all variables was explained by only one component (Podsakoff *et al.*, 2003). Loading all the measures into an exploratory factor analysis (EFA) indicated that the total explained variance of a single factor was 50.91%, confirming that common method bias was not a major concern in this study.

*Variables*

All measures were evaluated on a seven-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree). The proposed model includes five exogenous variables adapted from the literature to suit the research context: circular economy supply chain management design, circular economy supply chain relationship management, circular economy HR management, big-data-driven supply chain and firm performance for circular economy supply chain. In particular, the dependent variable (firm performance for circular economy supply chain) was evaluated using a three-item scale taken from Zeng *et al.* (2017). Respondents had to evaluate their firm's overall circular economy performance in terms of improvement of the production–consumption–recycling/reuse model within their supply chain process.

With regard to the independent variables, circular economy supply chain management design and circular economy supply chain relationship management were measured using three-item scales adapted from Zeng *et al.* (2017). The circular economy supply chain management design scale focused on the approach to optimizing transportation between logistics facilities, their localization and the adoption of innovative solutions for recycling spare parts and waste materials across the entire supply chain. The circular economy supply chain relationship management scale focused on the selection of suppliers, which relies on working with partners that have set environmental, social and economic key performance indicators (KPIs) and are doing their best to achieve these in a circular economy perspective. The other explanatory variable adopted was circular economy HR management. This three-item construct was adapted from Kim *et al.* (2019) and provides a measure of firms' and employees' circular economy consciousness, commitment and competences for minimizing waste through efficient and effective use of resources.

The measurement scales of the moderator, namely big-data-driven supply chain, were adapted from the study of Yu *et al.* (2018). The construct was measured using four items evaluating the extent to which firms build consistent interoperable and cross-functional department databases, aggregate customer data and make them widely available to improve service levels, implement advanced demand forecasting and supply planning across suppliers and implement lean manufacturing and new business model in a circular economy perspective.

Finally, in order to avoid bias and in line with the review of the literature, several control variables were included. Firm size could affect firm performance for circular economy supply chain, since differences in dimensions may determine a different set of circular economy practices, resources and capabilities. Firm size was evaluated using both sales revenue and number of full-time employees: micro (1–9 employees), small (10–49 employees), medium (50–249 employees) and large (250+ employees). This study also takes industry as a control variable, since field of activity seems to shape the adoption of circular economy business models and the availability of big data (Urbinati *et al.*, 2017). Table A1 presents the items for each construct analyzed in this study.

*Models and methodology*

The study investigated the research hypotheses presented in Figure 1 through multiple regression analysis using SPSS 25.0.

Before running the multiple regression analysis, checks were carried out for potential correlations between the variables included in the model. Table 1 shows the correlation

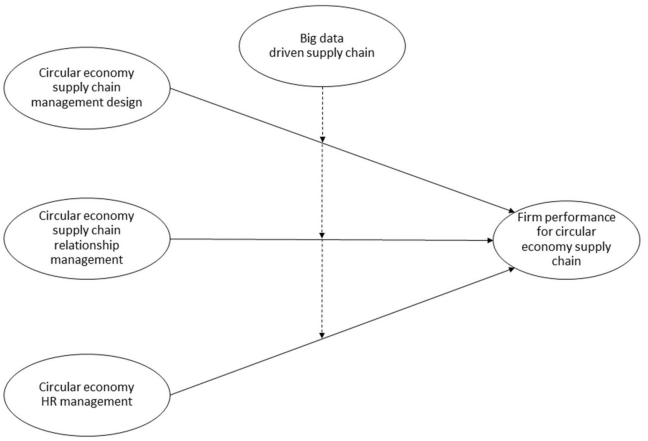


**Figure 1.**
Conceptual model

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| 1. Circular economy supply chain management design | 1 | | | |
| 2. Circular economy supply chain relationship management | 0.573** | 1 | | |
| 3. Circular economy HR management | 0.629** | 0.537** | 1 | |
| 4. Big-data-driven supply chain | 0.527** | 0.629** | 0.621** | 1 |

**Table 1.**
Correlation matrix

**Note(s)**: *$p < 0.05$; **$p < 0.001$

matrix. Since the VIF statistics were in no case higher than 5 (Hair *et al.*, 2010), multicollinearity among the variables was not an issue, and the model fits the data.

## Results

The results of the multiple regression analysis are shown in Table 2. Model 1 exhibits a moderate goodness of fit ($R^2 = 0.437$). It shows that circular economy supply chain management design, circular economy supply chain relationship management and circular economy HR management are positively and significantly associated with firm performance for circular economy supply chain, thus confirming H1, H2 and H3.

Model 2 shows an adequate goodness of fit ($R^2 = 0.561$). It tests the moderating effect of big-data-driven supply chains on the relationship between circular economy supply chain management design and firm performance for circular economy supply chain, which is not significant ($B = 0.036$; $T = 0.947$; $p > 0.01$). H4a is therefore rejected.

Model 3 presents an acceptable goodness of fit ($R^2 = 0.560$). It tests the moderating effect of big-data-driven supply chains on the relationship between circular economy supply chain relationship management and firm performance for circular economy supply chain, which is not significant ($B = 0.015$; $T = 0.468$; $p > 0.01$). H4b is therefore rejected.

Model 4 explains 56.7% of the variance ($R^2 = 0.567$). It tests the moderating effect of big-data-driven supply chains on the relationship between circular economy HR management and firm performance for circular economy supply chain, which is positive and significant ($B = 0.088$; $T = 2.209$; $p < 0.05$), thus confirming H4c.

## Discussion

In recent years, it has become important to better understand how the adoption of circular economy principles in the supply chain can influence firm results in terms of improving their

| | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| Constant | 1.279 (4.230)** | 0.874 (2.044)* | 0.684 (1.828) | 1.263 (3.011)** |
| Circular economy supply chain management design (CESCMD) | 0.135 (2.200)* | 0.251 (2.271)* | 0.153 (2.784)** | 0.136 (2.477)* |
| Circular economy supply chain relationship management (CESCRM) | 0.327 (6.771)** | 0.164 (3.529)** | 0.118 (1.085) | 0.160 (3.481)** |
| Circular economy HR management (CEHRM) | 0.437 (7.346)** | 0.249 (4.403)** | 0.246 (4.349)** | −0.007 (−0.055) |
| Big-data-driven supply chain (BDDSC) | | 0.430 (2.668)** | 0.522 (4.299)** | 0.269 (1.802) |
| CESCMD * BDDSC | | 0.036 (0.947) | | |
| CESCRM * BDDSC | | | 0.015 (0.468) | |
| CEHRM * BDDSC | | | | 0.088 (2.209)* |
| Size (employees) | −0.146 (−2.805)* | −0.078 (−1.662) | −0.080 (−1.705) | −0.073 (−1.565) |
| LogSales Revenues | 0.022 (0.796) | 0.013 (0.524) | 0.013 (0.516) | 0.010 (0.411) |
| Industry – manufacturing | 0.147 (0.744) | 0.226 (1.275) | 0.204 (1.163) | 0.251 (1.433) |
| Industry – service | 0.230 (1.166) | 0.230 (1.302) | 0.209 (1.195) | 0.236 (1.357) |
| Industry – commercial service | 0.313 (1.342) | 0.220 (1.053) | 0.198 (0.953) | 0.225 (1.092) |
| Industry – primary and energy | 0.298 (1.202) | 0.405 (1.826) | 0.381 (1.730) | 0.426 (1.943) |
| Industry – construction | −0.051 (−0.169) | −0.047 (−0.177) | −0.068 (−0.254) | −0.022 (−0.082) |
| $R^2$ | 0.437 | 0.561 | 0.560 | 0.567 |

**Note(s)**: *$p < 0.05$; **$p < 0.001$; $T$-values in parentheses

**Table 2.**
Regression results

production–consumption–recycling/reuse model. The specific purpose of this study is to investigate whether and how firms can achieve additional benefits when they decide to use big data to make decisions about their supply chain and, in particular, to enhance their supply chain performance in a circular economy perspective. Thus, this paper explores the effects of three different circular economy supply chain practices (circular economy supply chain management design, circular economy supply chain relationship management and circular economy HR management) on firm performance for circular economy supply chain and the moderating role of big-data-driven supply chains.

Although not all the hypotheses were confirmed, the empirical results strongly support a positive and direct effect of the three different kinds of circular economy supply chain practices on firm performance. In line with previous studies, this indicates that a circular economy supply chain proactive approach that facilitates a reuse and recycle paradigm can contribute effectively to developing a sustainable supply chain and to improvements in firm performance (Gupta *et al.*, 2019). In fact, in response to the increasing attention to circular economy and the relationship between circular economy and supply chain management, supply chain management design, supply chain relationship management and HR management are important ways in which firms can integrate and allocate resources and improve overall performance (Zeng *et al.*, 2017). First, managing circular economy supply chain design and relationships can allow firms to achieve a balance of internal sustainable efficiency, minimizing resources used, waste created, emissions produced and negative environmental impacts across the whole supply chain. Second, developing a strong commitment of firms to circular economy encourages both management and employees to adopt a positive attitude toward corporate sustainability. In line with previous studies (Jabbour and de Sousa Jabbour, 2016; Kim *et al.*, 2019; Nejati *et al.*, 2017), these findings

provide evidence of the fundamental role played by circular economy HR management in favoring circular economy initiatives, in reducing barriers to the adoption of circular economy supply chains and, therefore, in fostering firm performance.

This study also tests the moderating effect of the big-data-driven supply chain, since it is possible to assume that firms with a higher propensity to use big data in driving their decision-making process in the field of supply chain may develop circular economy supply chain practices differently in order to achieve their sustainability goals. The findings suggest that a big-data-driven supply chain positively moderates the effect of circular economy HR management on firm performance. The positive moderation observed indicates that the effect of HR management on firm performance increases when considering a high level of big-data-driven supply chain practices. A possible explanation is that firms that use more big data to guide their decision-making process in the field of supply chain benefit more from the HR management (especially in terms of circular economy training) in achieving environmental, social and economic outcomes. Moreover, employees with insight into and understanding of circular economy initiatives and practices can help in taking data-driven decisions, running and implementing sustainable operations and developing new resources.

In fact, in line with previous research, the findings indicate that big data are a key driver and a valuable asset for making informed and effective decisions that can support the implementation of circular economy supply chain practices (Attia and Essam Eldin, 2018; Forbes Insights, 2018; Gupta *et al.*, 2019). In particular, big data is transforming the ways in which firms deliver value to their customers by enabling them to make better decisions in logistics and supply chain management (Fosso Wamba *et al.*, 2015; Wang *et al.*, 2016). By using data and involving employees, firms can increase supply chain responsiveness, integration and coordination in a circular economy perspective. Big data can contribute to improving the capabilities of employees, and this in turn can help circular economy and supply management initiatives to increase firm's environmental, social and economic performance (Jeble *et al.*, 2018).

## Conclusions

### *Theoretical and managerial implications*

This study makes a significant theoretical contribution to research that relates circular economy practices along the big-data-driven supply chain. Specifically, it answers the call to capture present changes and transformations and to extend research on sustainability issues along the supply chain (Gammelgaard, 2019; Swanson *et al.*, 2018). Contemporary academic debate has highlighted the need to combine circular economy principles and supply chain management (De Angelis *et al.*, 2018; Sauvé *et al.*, 2016; Schulte, 2013), suggesting that big data act as a facilitator of firms' decision-making processes (Gupta *et al.*, 2019; Khan and Vorley, 2017; Waller and Fawcett, 2013; Wang *et al.*, 2016; Zhong *et al.*, 2016). However, previous studies have reported limited knowledge on the embodiment of circular economy principles within the supply chain (Aminoff and Kettunen, 2016; De Angelis *et al.*, 2018; Geissdoerfer *et al.*, 2018; Lewandowski, 2016), and there has been little discussion of whether and how big data can be leveraged to support firm circular economy supply chain performance in environmental, social and economic terms (Chen *et al.*, 2008; Chen and Delmas, 2012; de Camargo Fiorini and Jabbour, 2017; Jabbour *et al.*, 2019a). To advance this body of knowledge, the present study proposes and empirically tests a conceptual model that attempts to link circular economy supply chain practices and big data, as a moderator, with firm performance for circular supply chain as an indicator of firm performance that reflects firm's environmental, social and financial performance.

The first contribution of the present study concerns the fact that very few studies have analyzed empirically the relationships between the three different kinds of circular economy

supply chain practices (namely design, relationship and HR management and firm supply chain performance). This study brings together circular economy supply chain practices that have so far only been studied separately, and it posits that firms seeking to enhance supply chain performance in a circular economy perspective should invest in supply chain design, build relationships with members of the supply chain network and engage with employees in a circular economy perspective. Hence, this study contributes to the literature by clarifying the embodiment of circular economy practices within the supply chain and the effects of these practices on firm performance.

Second, this research is a first attempt to provide an empirical test of the moderating role of a big-data-driven supply chain on the paths connecting circular economy supply chain practices and firm performance. It has thus responded to the research calls in the literature by addressing the need for a more holistic understanding of the effects of using big data to make informed decisions to implement a supply chain model developed in accordance with the circular economy principles. In doing this, the study contributes to the understanding of the specific circular economy practices under which a strong big-data-driven orientation can effectively improve firm performance. The present analysis of the moderating role of big data suggests that firms that handle big data derived from various sources are more likely to achieve better performance, especially through shrewd circular economy HR management. Further, the study provides empirical support for the claim that, under the influence of a big-data-driven supply chain, HR management can improve firm performance for circular economy supply chain. Acquiring, processing and applying statistical techniques to the substantial amounts of data collected through digital technologies can lead to a process optimization that helps firms to make better decisions and to develop innovative logistics and supply chain solutions. Hence, this study is a preliminary step in the exploration of whether and how big data can be leveraged to support firm circular economy supply chain performance in environmental, social and economic terms. It thus builds on the extant literature and will guide firms in their efforts to develop a circular economy supply chain.

The study's results also have important practical implications. First, firm management should adopt a circular economy and a data-driven view when approaching innovative supply chain solutions. To ensure the effective implementation of a circular economy supply chain, it is essential to enhance firm performance by linking circular economy practices with supply chain management practices. This study underlines the importance of circular supply chain management practices and, in particular, of HR management in managing useful insights and knowledge. To achieve high circular economy supply chain performance, firms must build value-added relationships, designing and promoting circular economy initiatives that, by exploiting big data, stimulate both management and employees to adopt a collaborative approach and specific practices that enhance performance. Therefore, managers should be aware that (re)designing supply chain processes and encouraging relationships with network member are important in establishing the transition toward a circular supply chain, in improving the operational efficiency and competitiveness of the firm as a whole and in implementing circular skills and jobs through training in HR management.

Moreover, when building a circular economy supply chain, managers who can exploit big data better than their competitors can expect their firms to achieve better performance. In this study, a big-data-driven supply chain combined with circular economy HR management emerges as a crucial element for fostering firm performance in a circular economy perspective. The findings indicate that a big-data-driven supply chain complements circular supply chain HR management in improving firm performance. Therefore, managers should pay careful attention to diverse circular economy supply chain practices so that they can harvest the benefits of a big-data-driven perspective in the form of sustainable performance by the firm. Hence, this study provides guidance for practitioners who are engaged in projecting future paths for circular business development.

*Limits and future research*

This research is subject to certain limitations, and these open up possibilities for future research. First, the data were collected through an online survey in which respondents self-reported their answers; subjectivity bias may therefore have affected the responses. Second, this study is context-specific, and the sample data are limited; accordingly, the results should not be generalized. Third, the constructs used here are relatively new and need further investigation. Future research should adopt a qualitative approach in order to provide in-depth knowledge, avoid contingency and increase the robustness of the findings. To further validate the research hypotheses, data could be collected from other countries. Finally, additional research should determine whether the constructs adopted here can be incorporated into further advances in circular economy supply chain studies.

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## Appendix

| Measurement items | $\alpha$ |
|---|---|
| *Circular economy supply chain management design* Zeng *et al.* (2017) | 0.924 |
| The firm optimizes supply chain facility to reduce the demand for logistics | |
| Efficient and circular modes of transportation between supply chain facilities are used | |
| The firm designs/optimizes ways to recycle waste materials and spare parts | |
| *Circular economy supply chain relationship management* Zeng *et al.* (2017) | 0.906 |
| The ability to provide circular economy friendly products of suppliers has been assessed | |
| The firm helps existing suppliers establish rules and regulations related to the circular economy principles | |
| The firm cooperates with suppliers technically to reduce the environmental, social and economic impact of product production and consumption | |
| *Circular economy HR management* Kim *et al.* (2019) | 0.881 |
| The firm provides adequate training to promote circular economy management as a core organizational value | |
| The firm considers how well the employee is doing at being circular economy friendly as part of their performance appraisals | |
| Employees fully understand the extent of the firm's circular economy policy | |
| *Big-data-driven supply chains* Yu *et al.* (2018) | 0.913 |
| The firm builds consistent, interoperable, cross-functional department databases to enable concurrent engineering, rapid experimentation and simulation and cocreation | |
| The firm aggregates customer data and makes them widely available to improve service level, capture cross- and up-selling opportunities and enable design to value | |
| The firm implements advanced demand forecasting and supply planning across suppliers | |
| The firm implements lean manufacturing and model production virtually to create process transparency, develop dashboards and visualize bottlenecks | |
| *Firm performance for circular economy supply chain* Zeng *et al.* (2017) | 0.859 |
| Waste produced in the manufacturing process or from customers is recycled | |
| Recycled waste and garbage are reprocessed | |
| Waste and garbage are used after reprocessing to manufacture new products | |

**Table A1.** Description of measures

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