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Exploring the transition towards circular supply chains through the arcs of integration

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ABSTRACT

The Circular Economy aims at fostering the development of a new economic system characterised by regenerative and cyclical flows of materials and energy. Such a paradigm shift is expected to signal an industrial transformation that will incorporate different product designs and end-of-life strategies intending to narrow, slow, and close resource loops. Within this context, the development of circular supply chains extends beyond traditional linear supplier-manufacturer-customer networks to include new actors and facilitate horizontal collaboration across different industrial sectors. The current literature has identified collaboration and coordination as fundamental components of a systemic transition to a Circular Economy. Thus, it is imperative to increase the capacity of companies involved in the supply chain to share information and knowledge in order to reduce uncertainty and resource dependency. While the literature points towards the role of supply chain integration in facilitating the adoption of Circular Economy practices, this concept has typically been defined within traditional linear supply chains. As such, the objective of this paper is to critically examine the supply chain integration concept and assess its suitability for the analysis of circular supply chains. To this aim, by using the case of four real-life companies, we point to the direction of the arcs of integration as a tool that could enable the simultaneous examination of the level of integration for both forward and reverse supply chains. According to the results, three propositions are then developed based on the type and degree of supply chain integration, which pave the way for implications and future research avenues.

1. Introduction

The Circular Economy (CE) concept aims to transform the linear characteristics of the prevailing production-consumption model and foster the development of a new economic system characterised by regenerative and cyclical flows of materials and energy (Geissdoerfer et al., 2017). Such a paradigm shift is expected to signal an industrial transformation that will incorporate different product designs and end-of-life strategies intending to extend the product's lifetime and reduce waste, thus minimising the extraction of resources and ultimately displacing primary production (Bocken et al., 2016; Zink and Geyer, 2017). These cyclical flows correspond to combinations of different industrial activities which synergistically co-exist using as inputs the by-products of one another (Sauvé et al., 2016).

The global economy has evolved into a network of interconnected supply chains, often transcending national borders and regulations. The transition towards a CE necessitates a profound transformation in the way supply chains are designed and managed (Genovese et al., 2017). As such, the translation of CE principles into practical applications heavily relies on the development of circular supply chains (CSCs). These extend beyond the traditional linear supplier-manufacturer-customer networks to include new actors such as remanufacturers, collection and sorting contractors, with the potential to foster a horizontal collaboration across different industrial sectors (De Angelis et al., 2018). However, to develop these synergies and realise a shift towards CSCs, it is imperative to increase the capacity of involved companies to share and manage information and knowledge across them (Herczeg et al., 2018; Berardi and de Brito, 2021).

Acknowledging supply chains as a building block for the CE, supply chain integration (SCI) has been identified as a key strategy for fostering collaboration among supply chain partners (Flynn et al., 2016). The literature broadly defines SCI as *"the degree to which a manufacturer strategically collaborates with its supply chain partners and collaboratively manages intra- and inter-organisation processes"* (Flynn et al., 2010). However, given that the introduction of the SCI concept happened well before the emergence of the CE agenda, there might be challenges to the

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applicability of SCI to a circular supply chain management context. Indeed, the SCI concept was developed according to linear thinking around inputs (suppliers) and outputs (customers) which entails only a forward physical flow of deliveries from suppliers to customers and a backward flow of information in the form of orders (Frohlich and Westbrook, 2001). Furthermore, the introduction of new actors (e.g., waste collectors, sorters, recyclers, and remanufacturers) in circular supply networks adds a layer of complexity as the direction and type of these flows significantly vary (Braz and de Mello, 2022). At the same time, a higher degree of planning is required so that firms can identify and evaluate how they could utilise each waste output as an input to their production processes (Herczeg et al., 2018).

Having as a starting point Frohlich and Westbrook's (2001) (hereafter F–W) conceptualisation of SCI, the key objective of this paper is to highlight the need to further explore the idea of SCI in the context of CE. Following a review of the evolution of SCI within the literature (presented in Section 2), the paper assesses its suitability for the analysis of circular supply chains and draws the connection between them. Then, using the case of four real-life companies (according to the methods presented in Section 3), we point to the direction of F–W's arcs of integration as a tool that could enable the simultaneous examination of the level of integration for both forward and reverse supply chains (Section 4). According to the results, three propositions are then developed (Section 5) based on the type and degree of supply chain integration, which pave the way for implications (Section 6) and future research avenues (Section 7).

2. Literature review

2.1. The evolution of the supply chain integration within the literature

F–W's arcs of integration concept were seminal to the development and understanding of SCI (Fig. 1). Considering the strategic importance of developing shared supply chain activities, F–W aimed to investigate the degree of supply chain integration (SCI) for industrial goods manufacturers based on two individual dimensions, upstream (i.e., supplier) and downstream (i.e., customer) integration. Depending on the direction (either towards suppliers or customers) and level of manufacturers' integration activity, authors identified five SCI arc configurations, namely "outward-facing", "supplier-facing", "customer-facing", "periphery-facing", and "inward-facing". Through this conceptualisation, they were the first to empirically demonstrate that a higher level of SCI is associated with superior levels of operational performance, which until then was just an assumption in the SCM literature. In terms of theory, F–W's findings showed the importance for businesses to consider aligning their manufacturing strategy horizontally across their supply chain partners, rather than vertically within the boundaries of the business itself.

Putting SCI in the spotlight of operations and SCM literature, subsequent research focused on developing multivariable models to

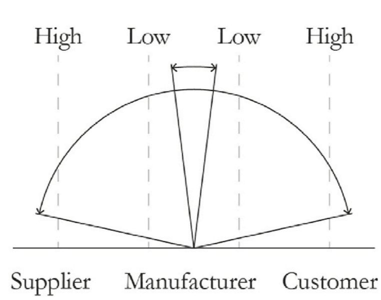


Fig. 1. Arcs of integration (adapted from Frohlich and Westbrook, 2001).

examine the relationship between different types of supply chain integration and performance. However, despite the initial results of empirical papers that suggested a positive linear relationship between these variables, later studies challenged this unconditional assumption. This inconclusiveness was attributed to the evolving conceptualisations of SCI characterised by a variability of constructs and measurement items (van der Vaart and van Donk, 2008). Most studies adopted F–W's conceptualisation that differentiated between upstream and downstream integration, while others treated it as a uniform construct (supply chain integration) (Vickery et al., 2003; Li et al., 2009). Other studies adopted a broader perspective introducing different types of integration, such as information integration and logistics integration (Jayaram and Tan, 2010; Prajogo and Olhager, 2012; Liu et al., 2016), operational integration and strategic integration (He and Lai, 2012; Lockström and Lei, 2013; Vanpoucke et al., 2017), as well as system and process integration (Huo et al., 2013; Han et al., 2017; Rajaguru and Matanda, 2019). Another stream of authors emphasised the overlooked dimension of internal integration (II) (Flynn et al., 2010; Wong et al., 2017). In detail, Flynn et al. (2010) concentrated on the inconsistencies of previous research regarding the correlation between SCI and performance, attributing it to the tendency to focus on supplier (SI) and customer integration (CI) completely disregarding the role of internal integration. Considering the interactions of both internal and external integration with operational and business performance, authors enhanced the understanding of the impact of SCI on performance. Analysing these relationships from a configuration perspective, they validated and extended F–W's taxonomy by including internal integration, revealing that the effect of SCI on operational performance is cumulative. Specifically, they found that businesses can only realise a significant improvement in operational performance once a threshold level of SCI is achieved. Childerhouse and Towill (2011) set out to verify the relationship between SCI and performance by triangulating F-W's findings using data from other industrial sectors, and explore whether some integration states are more common than others. Acknowledging the breadth of barriers that companies need to overcome to integrate with their supply chain, they sub-divided the periphery-facing arc into supplier facing and customer facing proposing a route that could support firms' transition from lower (inward-facing) to higher (periphery-facing) levels of SCI. Similarly to Flynn et al. (2010), they emphasised the importance of internal integration as a starting point, followed by upstream before downstream integration. Aiming to understand their influence on performance, Wong et al. (2017) empirically examined the differences in arcs of integration across industries using Flynn et al. (2010) classification between balanced (same level of SI, II, and CI) and unbalanced SCI patterns.

In line with previous authors who argued that a high level of SCI does not always constitute an ideal state that could lead to increased performance (van Donk and van der Vaart, 2005; Das et al., 2006), later research investigated the influence of contingency factors on SCI-performance relationship (Wong et al., 2011; Wiengarten et al., 2014; Kauppi et al., 2016). Kauppi et al. (2016) extended F-W's arcs of integration to include also risk management practices and examined their combined impact on operational performance. Their findings supported F-W's hypothesis that greater arcs of SCI are associated with higher levels of performance, highlighting at the same time the potential to gain complementarity effects by combining SCI with other SCM practices. To solidify the empirical reliability of the extent to which this SCI-performance relationship is contingent on a company's competitive priorities, Wiengarten et al. (2019) adopted a cross-sectional quasi-longitudinal design using data from multiple rounds of the International Manufacturing Strategy Survey (IMSS) survey. Their analysis showed that it is questionable whether external integration can always lead to improve performance as their relationship is dependent on strategic priorities and other contextual factors such as environmental uncertainty (Wong et al., 2011) or country-specific infrastructural differences (Wiengarten et al., 2014).

2.2. The need for supply chain integration in the transition towards a circular economy

Evidence regarding the importance of SCI for the transition towards a circular economy can be traced back to early conceptual antecedents such as industrial symbiosis networks (Chertow, 2007). These networks refer to symbiotic relationships between industries in close geographical proximity aiming at the systemic reduction of virgin resources through the exchange of by-products used as input in the production processes of one another. Central to the development of such networks is the high level of coordinated planning through which involved firms can identify and assess innovative ways for utilising waste outputs (de Abreu and Ceglia, 2018; Herczeg et al., 2018). Such coordinated planning activities are much needed to hedge against uncertainty in the quality and quantities of by-product flows (Herczeg et al., 2018).

In contrast to EIPs, which can be regarded as quasi-closed systems, the transition from a linear to a circular economy at a market level entails a significant supply chain complexity. As a future industrial paradigm, CE aims to provide the impetus for replacing the dominant linear model of production and consumption with a system characterised by a cyclical and regenerative material flows (Geissdoerfer et al., 2017). Within such a system, different material flow patterns are identified each one pertaining to different strategies, such as design for product-life extension or dis- and reassembly, as well as different circular business models (CBM) based on repair, maintenance, remanufacturing, reuse, and redistribution (Bocken et al., 2016). A common characteristic of companies participating in CBMs is that they deal simultaneously with both forward and reverse flows of materials and used products denoting a state that entails a significant level of complexity (de la Fuente et al., 2008). In linear supply chains, forward flows proceed from raw materials, which are then converted into final products through various processing and manufacturing phases. Finally, they end up to consumers through retailing and distribution channels.

In the case of a reverse supply chain, the direction of these flows is not predetermined as relative reverse processes could be offered by an external business provider rather than the OEM itself (Blackburn et al., 2004). Furthermore, introducing new agents with different roles and positions leads to new hybrid supply networks that combine features from closed-loop and open-loop configurations (Braz and de Mello, 2022). In such networks, the key reverse processes are governed by the original manufacturer and its immediate partners as well as new agents belonging to other industries.

Coordinating the corresponding flows involves the development of different reverse information and material flow systems between multiple organisations in various supply chain tiers. By increasing the level of integration with their partners, industrial sectors that exhibit a higher concentration of CE practices could facilitate the transfer of knowledge and practices across their immediate and extensive supply chain network of suppliers and customers. This transfer of knowledge could trigger a coevolution spiral that could result in the systemic diffusion of similar business models into the mass market (Lüdeke-Freund et al., 2019). The interplay of integrability, scalability, replicability, and imitability characteristics that frame business models' innovation dynamics could set the foundations for the propagation of such a sustainable paradigm on a macro-level scale (Schaltegger et al., 2016).

The linear conceptualisation of SCI comprises two bidirectional forms of integration: the backward flow of information of orders from customers to suppliers and the forward physical flow of deliveries from suppliers to customers (Frohlich and Westbrook, 2001). However, due to the heterogeneity of relationships as well as the participation of additional actors involved in circular business models, the direction and type of these flows significantly vary (Berardi and de Brito, 2021; Braz and de Mello, 2022).

2.3. Supply chain integration: Are we accounting for circularity?

Prior to the emergence of the CE discourse in the supply chain management literature, isolated practices that constitute part of the circular economy, namely material recovery, product returns, refurbishing, remanufacturing, reuse, and recycling, were found in Green Supply Chain Management (GSCM) domain. Several studies investigated and validated the positive influence of SCI on their adoption after incorporating them into different GSCM-related processes such as green product innovation (Wu, 2013; Wong et al., 2020; Kong et al., 2021; Zhao et al., 2021), green process innovation (Wu, 2013; Wong et al., 2020; Kong et al., 2021; Junaid et al., 2022), and green design (Liu et al., 2018). Other studies looked into the impact of SCI on the adoption of closed-loop practices (Gorane and Kant, 2017; Shaharudin et al., 2019), verifying the positive relationship between them.

Given the traction gained by the CE concept in the literature, a few studies have emerged looking at the direct relationship between SCI and circular practices. Elia et al. (2020) used a multi-factor clustering method on a sample of EMF CE100 companies and found that a higher level of SCI corresponded to a higher number of CE objectives pursued in their business activity. Pinto and Diemer (2020) provided a different depth of analysis, examining from an ownership and operations management perspective the impact of varying SCI approaches on increasing material circularity in the steel industry. Kamble et al. (2021) focused on the overlooked dimension of internal integration underlying the positive role of big data-driven CE practices in improving planning for reuse, recovery, and recycling, thus reducing raw materials use and process waste. The relevance of SCI to the adoption of CE was also verified by Calzolari et al. (2021), who used secondary data from corporate sustainability reports, proposing it as a moderator in the relationship between institutional pressures and the adoption of circular practices. Lastly, Di Maria et al. (2022) investigated the mediating effect of SCI in the relationship between Industry 4.0 technologies and CE. While authors verified the mediating impact of SCI on smart manufacturing, results showed its limited mediation between data-processing technologies and CE. Their analysis suggested that this was due to the partial substituting effect of data-processing technologies for the role of SCI due to the prevalence of information sharing, coordination, and cooperation elements that characterise it.

While these studies attempt to establish a link between SCI and CE, scholars have not moved away from the linear conceptualisation of SCI which follows a take-make-dispose approach. As Berardi and de Brito (2021) pointed out, the majority of empirical studies on the implementation of CE practices view them as isolated actions in the context of a linear system as a means to improve existing end-of-life strategies. This view is consistent with the dominant reductionist interpretation of CE within the SCM literature, as evidenced by previous studies (Genovese and Pansera, 2021). Perceiving circular business models as revenue model configurations, this reductionist lens shifts the attention from the mechanisms that could foster a long-term system of regional exchanges between different industrial sectors (Pieroni et al., 2020). Given the heterogeneity of capabilities across different organisations (De Angelis et al., 2018), it is imperative to develop a high level of SCI across supply chain partners to combine the technical knowledge and skills required for such a systemic change. However, in order to connect the concept of SCI to the principles of intersectoral circularity, it is necessary to disentangle it from the current view of linear supply chains and explore its suitability for fostering the inclusion of circular flows.

3. Research methods

The term "Circular Economy" has emerged as a contested concept (Korhonen et al., 2018). Given the limited theoretical developments regarding the relationship between SCI and the adoption of CE practices, it is, therefore, appropriate to investigate the level and direction of this type of integration using a multiple case study method (Eisenhardt and

Graebner, 2007). Having as a starting point the need to explore the role of SCI in the context of the transition towards a CE (and, therefore, towards circular supply chains), the main objective of these case studies is to investigate the level of integration for forward and reverse flows separately. The examination of these cases aims to hypothesise a route that supply chains can follow in order to transition from linear to circular through subsequent levels of integration maturity that simultaneously consider both forward and reverse flows.

Drawing from the work of Stuart et al. (2002), Voss et al. (2002) and Ketokivi and Choi (2014), this paper has adopted the following three stages to conduct case study research and ensure a rigorous process: (1) case selection, (2) data collection, (3) data analysis.

3.1. Case selection

Given the limited theory and conflicting evidence regarding the relationship between SCI and adoption of CE practices, case selection was based on a theoretical sampling process (Eisenhardt, 1989). According to Eisenhardt's (1989) suggestion, a number between 4 and 10 cases can set an adequate balance between the depth and breadth of observations without compromising the ability to cognitively process the collected information (Fernández Campos et al., 2019). Four agri-food industry companies were selected for this research (Table 1). The selection of these cases was based on the following criteria:

- The chosen companies should be operating in the food industry and situated in the region of South Europe;
- The companies ideally should represent a variety of activities and, thus, should correspond to different stages of the food supply chain. Hence, case A is a company specialising in the production of food additives, case B is a cooperative focusing on the marketing of Protected Geographical Indication (PGI)-certified lemons, case C is operating in the collection and conversion of used cooking oil (UCO) into biodiesel, and case D specialises in private label programs and the export of food products mainly from Italy to North America.

3.2. Data collection

Access to the four case companies was gained through a set of Horizon 2020 European Union-funded projects involving a cohort of academic and industrial partners aiming to provide insights related to the applicability of the CE paradigm in the agri-food supply chains. Data was collected through several approaches.

First, semi-structured interviews with top management with knowledge of the company's operations, its circular economy initiatives, and its relationship with suppliers and customers were held. As Eisenhardt and Graebner (2007) suggest, interviews constitute an efficient way to collect rich, empirical data, mainly when the phenomenon of interest is characterised by limited theory and conflicting evidence. These interviews aimed to gain a comprehensive understanding of each company's operations, a deep knowledge of their supply chains, an overview of the CE practices each company has adopted and, successively, an investigation of how SCI with respect to forward and reverse flows can facilitate their adoption.

Several rounds of interviews were carried out during field visits to the companies' premises between October 2020 and May 2022. The first round of data collection took place with a focus on each company's production process and implemented circular economy practices. The second round focused on the level of integration with suppliers and customers in the context of their forward and reverse supply chains. The third and final round of data collection emphasised follow-up questions seeking further clarification on the previous rounds of data collection. Table 2 reports the number of interview sessions for each company. Participating researchers conducted a minimum of 10 hours of interviews for each company. These interviews were conducted mainly face-to-face in the company's mother language, and involved taking notes and digital recordings. Recordings were transcribed and translated into English and were then e-mailed to each participant in order to validate the content. Besides these formal interviews, several rounds of e-mails and telephone calls also took place when clarifications or supplementary information was required.

All interviews were performed using pre-designed guidelines to ensure data reliability and validity (Yin, 2008). Reliability and validity are vital when designing a case study and analysing data (Gibbert et al., 2008). Reliability of the collected data was achieved through a structured research design and interview question protocol (a brief synthesis is available in Appendix A), while the interviewees ensured validity through content verification. All researchers who participated in the data collection followed the agreed process to maintain a high quality whilst allowing for replication.

Given its prominence in the SCI literature, we used the measurement items from the last round of the IMSS survey (IMSS-VI) as a benchmark

Table 1
Overview of case companies.

Case	Characteristics	Country	No. of employees	Revenues
Company A	Food technology company focusing on the meat industry	Greece	10-49	€2-9M
Company B	Agricultural lemon Cooperative	Italy	50-250	€2-9M
Company C	Waste treatment and regeneration facilities for animal by-products, vegetable oils and exhaust oils.	Italy	50-250	€10-49M
Company D	Distribution of Italian food products in foreign markets	Italy	50-	> €50M

Table 2
Overview of the interviewees and respective firms.

Case Company	Interviewee	Number of interactions	Total time per interviewee	Total interview time per company
Company A	Purchasing Manager	5	5h30min	11h30min
	Quality Assurance and Research & Development Manager	5	6h00min	
Company B	Cooperative President	2	2h30min	14h05min
	Managing Director	5	5h45min	
	Financial Controller	2	1h15min	
	Quality Control Manager	4	3h25min	
	Chief Agronomist	2	1h10min	
Company C	Director of Operations	3	4h35min	10h15min
	Plant Manager	1	50min	
	Logistics Engineer	3	4h50min	
Company D	Sales and Marketing Director	4	4h30min	10h35min
	Marketing Specialist	4	4h30min	
	Supply Chain Analyst	2	1h35min	

for investigating the level of forward and reverse integration (Wiengarten et al., 2019). The involved measurement items are listed below:

- Sharing information with key suppliers/customers (about sales forecast, production plans, order tracking and tracing, delivery status, stock level);
- Developing collaborative approaches with key suppliers/customers (e.g., supplier development, risk/revenue sharing, long-term agreements);
- Joint decision-making with key suppliers/customers (about product design/modifications, process design/modifications, quality improvement, and cost control);
- System coupling with key suppliers/customers (e.g., vendor-managed inventory, just-in-time, Kanban, continuous replenishment).

All these measurement items represent core elements for participating companies in circular networks to recover, store, process, and re-use by-products (Herczeg et al., 2018). Availability and direct access to information for all supply chain partners are central to improving the efficiency of return flows, end-of-use activities (e.g., refurbishment, repair, reconditioning), design of modular products as well as enhancing the capacity to accurately forecast and plan (Bressanelli et al., 2019). Therefore, SCI should consider the double purpose of a CSC and the presence of processes and relationships both in the forward and reverse supply chain. In analogy to the forward supply chain, actors in the reverse supply chain could be integrated to a greater or lesser degree; hence, it is critical to define integration comprehensively for all flows involved.

For each of the measurement items, interviewees were asked to provide specific examples of integration practices; and indicate the level of implementation for these practices (both for customers and suppliers, and for forward and reverse elements) on the basis of a three-point scale (1 – low; 2 – medium; 3 - high). Overall integration levels were also calculated on this basis (as shown in Tables 4–7), *averaging* values across items.

In addition to interviews, the research team conducted an in-depth observation of the case companies' operations. For each company, at least one of the research team members was seconded to the organisation for a minimum period of one month. These secondments allowed the research team members to gain access to various data resources (Table 3), comprehensively overview the company's operations and further validate the data collected through the interviews. This was particularly relevant to validate further responses provided by interviewees in relation to integration levels.

Table 3
Additional data resources per case company.

Case	Additional resources
Company A	Historical sales data; production specifications; bills of materials; energy consumption of the main production site; full access to supply chain partners.
Company B	Participation in the general assembly of the cooperative and minutes of previous meetings; historical sales data; production specifications; bills of materials; energy consumption of the main production site; full access to supply chain partners (including visit of key customer sites).
Company C	Full list of WCO providers and provided quantities for the 2018, 2019, 2020 and 2021 years.
Company D	Full customer orders for the 2019 and 2020 financial years; full overview of logistical movements at the company cross-docking platforms; full visibility of supply chain partners.

3.3 Data analysis

Data analysis was conducted following the process proposed by Miles and Huberman (1994), involving both within-case and cross-case analysis. First, each case was analysed based on CE and integrative practices with suppliers and customers. Cross-case comparisons were then conducted to detect commonalities and differences between the level of integration and adoption of CE practices.

In detail, we use F–W's arcs of integration as a tool to enable the simultaneous examination of the level of both forward and reverse integration and identify potential combinations. In F–W's seminal contribution, SCI configurations were identified by classifying firms into "high", "medium", and "low" levels of supplier and customer integration. We use the same approach to examine the level of firms' integration with their reverse supply chain. We use the terms forward integration (FI) and reverse integration (RI) to distinguish between them. Based on the definition provided by Flynn et al. (2010), we define RI as "*the degree to which a manufacturer strategically collaborates with its supply chain partners and collaboratively manages intra- and inter-organisation processes regarding reverse operations*". These reverse operations entail the sum of different practices that fall under the umbrella of closed-loop and circular economy-related processes, such as product returns, recycling, remanufacturing, and reduction of raw materials use.

The level of forward and reverse integration with suppliers and customers can be graphically represented using a two-dimensional Cartesian plane (Fig. 2). The latter is divided into two quadrants by two perpendicular lines, namely the x-axis and the y-axis. According to

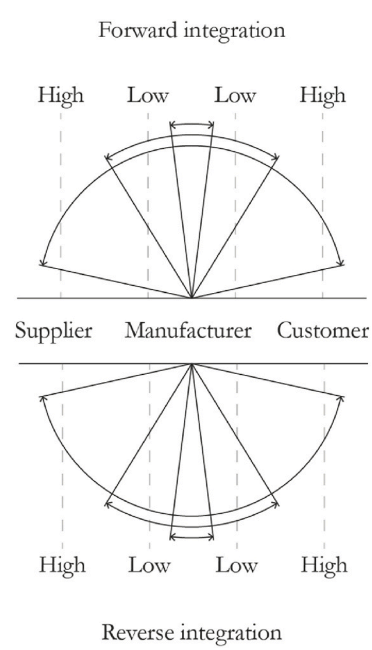


Fig. 2. Arcs of circular integration.

the contemporary conceptualisation of the arcs of integration, the vertical axis (which is not shown in Fig. 2) separates the direction of integration; left towards suppliers (upstream) and right towards customers (downstream). On the other hand, the x-axis divides the plane into two distinct regions that indicate the type of integration: the top quadrants refer to the integration for forward flows, and the bottom quadrants refer to the integration related to reverse flows. Consequently, the vertical dichotomy indicates the degree of circular integration with either suppliers or customers. The horizontal division allows the simultaneous examination of the degree of supply chain integration concerning forward and reverse flows separately.

Similar to the F–W's concept, the degree of integration is assessed by subdividing each of the four quadrants into three levels. The four quadrants resulting from these two perpendicular axes are conceptualised as follows: the upper left and right quadrants correspond to the degree of supplier and customer integration regarding forward flows while the lower left and right quadrants correspond to the degree of supplier and customer integration for reverse flows. The degrees of integration for each direction (i.e., forward, or reverse flows) are illustrated on the Cartesian plane by a conjoint (narrow, medium or wide) arc that results from the combination of the underlying levels of supplier and customer integration in each flow category.

These combinations are illustrated in the four case studies based on the type (forward or reverse) and degree (low, medium, high) of SCI. Findings are then used to develop some propositions concerning the route through which supply chains can transition from linear to circular through subsequent levels of integration maturity that simultaneously consider both forward and reverse flows.

4. Within-case analysis

In the following, each of the four case studies is analysed in detail, based on the adoption of CE and integrative practices with suppliers and customers.

4.1. Case Company A

Company A (Table 4) is a food additives processor based in the northern region of Greece. Its final products mainly involve multicomponent dry mixes for meat products, including starches, condiments, preservatives, stabilisers, and marinades. Its supplier base is primarily located abroad, accounting for 14% in Greece, 72% in other EU countries and 14% from the rest of the world. In comparison, its customers are located mainly domestically (75%), with only 25% exported to other EU countries.

Adopted CE practices mainly revolve around re-using raw materials and final products through the development of re-manufacturing and repackaging processes. As the Purchasing Manager noted: *"One of the key advantages of our production process is the long product life of the raw materials we use, as well as the fact that they can be used in more than one different final product categories"*. Stocked raw materials and final products go through a continuous inventory monitoring, chemical testing, and grading process two months prior to their expiration date. Depending on the results of the grading process, the company either extends their expiration, re-uses them in alternative production lines, or, when re-marketing is not possible, employs them for sampling purposes from the R&D department. The same process applies in the case of product returns. Provided that they have not reached their expiration date or there is a problem with the quality of the mix itself (e.g., foreign matter contamination), returned products are either incorporated into new mixes or are re-packaged and re-sold to the market. On the other hand, raw material returns are not typical, as most of the suppliers are located abroad. Raw materials and final products that have either expired or do not pass the grading process are sent to a local company for incineration.

As shown in Fig. 3, Company A exhibits a medium level of forward integration (resulting by the adoption of several good practices), and a low level of reverse integration both with supplier and customers (resulting from the almost total absence of integration practices in the reverse supply chain). This results in a medium arc of forward integration, and in a narrow arc of reverse integration.

The uncertainty and fragmentation of operations that characterise the way supply chains operate in the post-pandemic period, has led the company to pursue a closer collaboration with its suppliers and customers. Based on its sales forecast, the company shares its production plans with its key suppliers two months in advance in order to ensure that the required raw materials are delivered on time. The company has also attempted to replicate the same strategy with its customers. Similarly to the case of suppliers, this has only been feasible with their key customers as they correspond to the largest proportion of the focal company's production volume. The remaining customers are sharing their production forecasts in advance only for the summer months when the demand is expected to reach its peak. The company's involvement in the development of new products with suppliers and customers has also been significant. According to the Quality Assurance and Research & Development Manager: *"The company is participating in ingredient testing and sampling training sessions with suppliers to explore different ways of how raw materials could be used in new mixes. We use this knowledge in close collaboration with customers for the development of new customised products in an attempt to increase our market share or create a new market segment. This approach has also been an effective way for us to deal with risks related to current market fluctuations"*. Apart from product returns, the company has not developed any collaborative approach or joint decision-making process with suppliers or customers that could further eliminate surpluses or reduce waste. Such strategies are applied only occasionally when the need occurs and circumstances allow.

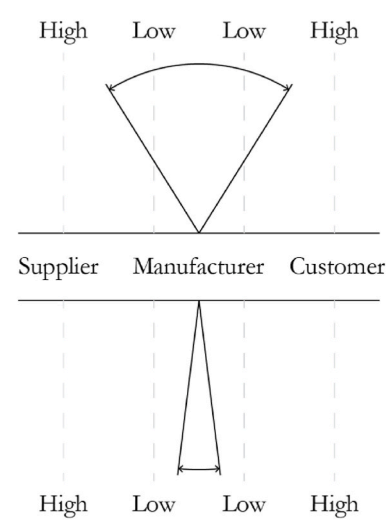


Fig. 3. Arcs of circular integration for Company A.

Table 4
Overview of Company A

	Forward integration		Reverse integration	
Measurement items	Supplier	Customer	Supplier	Customer
Sharing information	• High: Based on its forecasts, Company A shares its production plans with its key suppliers to ensure the timely availability of sufficient quantity of raw materials	• Medium: Key customers share their production forecasts only due to the summer months when demand is expected to reach its peak. Throughout the low-demand months, Company A plans its production using sales data from previous periods	• None	• None
Developing collaborative approaches	• High: Company A has participated in ingredient testing and sampling training sessions organised by its key suppliers to explore different ways in which raw materials could be utilised.	• High: Company A plays a role in the process of customer development by proposing new products that could increase their market share	• None	• High: Company A is supporting the returns of un-used products from key customers through flexible return agreements
Joint decision-making	• Medium: Company A indirectly participates in the modification and improvement of raw materials through sharing its research and development reports	• High: Company A and its key customers are collaborating in the development of new products	• None	• None
System coupling	• None	• None	• None	• None
Overall	Medium	Medium	Low	Low

4.2. Case Company B

The company in case study B (Table 5) is a cooperative located in the Campania region of Italy. Since then, it has been marketing the Protected Geographical Indication (PGI)-certified "Oval Lemon of Sorrento", produced in the associated farms in the territory of the Sorrento peninsula and on the island of Capri. The cooperative harvests around 2000 tonnes of lemons annually and distributes them across national and foreign markets more attentive to quality (e.g., the United States, France, and Japan). They also produce lemon-based products: 20 tonnes of lemon-infused olive oil and 100,000 jam jars every year, which are supplied directly to restaurants, hotels, and shops of typical high-quality products both in Italy and in the rest of the world.

Company B's production process is entirely circular and aims to extract as much value as possible from lemons. As stated by the President of the cooperative: "*We are extremely constrained with the yields our farmers can get; our lemons can just grow in a specified area and we have a very strict protocol. As such, we cannot grow our production. To give our farmers the best deal, given our competitive market, it is like we need to sell each lemon twice. That's why we need to come up with new products and solutions, in close collaboration both with customers and farmers*". Starting with the cultivation and harvesting of lemons at the associated farms, the product's aggregation occurs either through direct contributions from the farmers, who bring the lemons to the main site through their vehicles, or collection operated by the company's fleet. The first step involves the electronic weighing of lemons delivered by the members of the cooperative. Following a first visual quality check to eliminate substandard lemons (which could be employed in juice production), they are then transferred to the washing area. Afterwards, they are stored and sorted for different uses. In detail, one part is sold as is while another is fed to essential oil and juice extractors. The extracted pulp and peels from these extractors are used to produce jams, spoon sweets and lemon-infused olive oil. The remaining part is sold to a partner company, where it is peeled and used for the production of limoncello liquor. The peeled lemons are then returned to Company B and fed to the extractors for the previously explained purpose and to produce lemon juice, which is either sold as a final product or as an ingredient to other companies operating in the food processing industry. "*No part of our lemons is thrown away*", proudly said the President of the cooperative.

From Table 5, it can be understood Case B represents a company extensively integrated with its forward (both with suppliers and customers) and reverse (mainly with customers) supply chain. This results in a wide arc of forward integration, and in a medium arc of reverse integration (Fig. 4).

The ecosystem of the cooperative comprises a diverse cohort of stakeholders: farm owners, on-farm maintainers, equipment manufacturers, chemists and managers. Their relationship is characterised by a high level of shared information and an increasing level of collaborative approaches regarding the development of new products. Key customers (mainly big supermarket chains) share their sales forecasts and negotiate purchasing prices with Company B for highly seasonal premium products. Based on these market prices, Company B shares its overall plans with its suppliers (cooperative members) in order to support them in obtaining the required yields. In this way, it directly participates in the farmers' production process by sharing its research and development reports (also resulting from the collaboration with local universities) regarding production yields and innovative agricultural methods; sales plans are also discussed in the democratic assembly of the cooperative. Their close collaboration based on its expertise has enabled Company B to avoid or reduce treatments while protecting the landscape and the national cultural heritage connected with the PGI Sorrento lemons. At the same time, it shares the lemons' availability with other customers (limoncello producers) throughout the year to plan their production. In addition, the company directly supports its suppliers and customers by sharing its logistical infrastructure for the collection and storage of lemons as well as for packaged products prior to delivery.

The extensive application of circular processes that involve the re-use of lemon by-products has created alternatives to the sale of fresh produce (e.g., jams, essential oils, limoncello), thus increasing the profitability of all involved parties. This is quite evident in the case of the partner company that is involved in the production of limoncello. By returning the peeled lemons to Company B for reprocessing, it actively participates in the development of new products (e.g., lemon juice). Especially in the case of lemon juice, customers are returning delivery crates and containers to be re-used for the same process.

The company recognises that, in order to completely close the loop, some further practices could be adopted; for instance, the few production by-products (currently sent at an anaerobic digestion plant), along with pruning residuals at associated farms, could be composted on-site to produce fertilisers that could be used by producers. "*This is something we are keen to explore – said the Managing Director – however, we would need to involve our producers for utilising this product. In a way, we should integrate them in the handling of this reverse flow, co-designing some composting scheme together, which is something we are not doing at the moment*".

4.3. Case Company C

The company in case study C (Table 6) is located in the Metropolitan City of Naples (Italy). It specialises in the recovery and further

Table 5
Overview of Company B.

	Forward integration		Reverse integration	
Measurement items	Supplier	Customer	Supplier	Customer
Sharing information	• High: Based on market prices, Company B shares its overall plans with producers, in order to support them to obtain required yields.	• High: Key customers share their sales forecasts and negotiate purchasing prices with Company B for premium products. Company B shares its raw product availability with other customers (limoncello producers) throughout the year.	• None	• High: Company B and its customers share data about peeled lemons returning to Company B for further reprocessing (e.g., for lemon juice production) after these have been processed at customers for the production of limoncello.
Developing collaborative approaches	• High: Company B directly participates in the production process at its suppliers through sharing its research and development reports (for instance, regarding production yields and innovative agricultural methods).	• High: Company B is participating in ingredient testing and sampling training sessions organised by its key customers to explore different ways in which raw materials could be utilised.	• Low: Company B recognisises the value of a developing collaborations on the management of reverse flows (i.e., farming and processing by-products); however, no specific practice has been implemented.	• High: Its key customers (in the fresh juice segment) are returning the delivery crates to Company B to be re-used for the same process.
Joint decision-making	• High: farmers associated to Company B directly participate in its decision-making through a democratically-run general assembly.	• High: Company B and its key customers are collaborating in the development of new products (e.g., jams and other processed products obtained from Sorrento lemons).	• None	• High: Key customers actively participate in the development of Company B's products (i.e., peeled lemons from the limoncello company are returned to Company B's oil and juice extractor.
System coupling	• High: Company B directly supports its key suppliers by sharing logistical infrastructure (for collection and storage of fresh lemons).	• High: Company B directly supports its key customers by providing intermediate storage facilities for packaged products ready to be sent to customers.	• None	• High: Company B shares its logistical infrastructure to facilitate the reuse of processed products (i.e., limoncello company returns peeled lemons to Company B)
Overall	High	High	Low	High

processing of animal and vegetable oils and fats, such as used cooking oil (UCO) for producing biodiesel, fuel for cogeneration plants, and lubricants for agricultural machinery. These oils originate mainly from commercial businesses and industrial companies, such as restaurants, hotels and food processors situated across the metropolitan area of Naples. Their collection is performed by the company's fleet of vehicles of various loading capacities.

Depending on the business, the collection takes place both periodically (weekly, bi-weekly, or monthly) and on demand. Due to the absence of an automated system that could inform the company when the suppliers' collection containers are full, collection notifications are sent through instant messaging applications or telephone; however, the system is entirely reactive. The heterogeneity of customers in terms of seasonality, location, and storing capacity has not allowed the company to perform a customer segmentation aimed at optimising collection efficiency. Also, fluctuations in the price of UCO (which is very much linked to economic cycles and other commodities traded on energy markets) make it extremely difficult for Company C to stipulate long-term contracts with its suppliers, even large ones. *"A good number of competitors operate in our area; this means that whoever first visits the supplier takes the bin. In theory, we could arrange some sort of long-term deals, but these can be extremely problematic due to the volatility of the market; as such, despite some arrangements we have with our key providers, we are not very integrated, but we operate in a competitive market"*, stressed the Operations Manager of the company. Seasonal variations in UCO collection see a significant increase during the summer months, however, differentiate across touristic and non-touristic areas. Similar localised patterns have also been observed to vary depending on different neighbourhood-level factors such as demographic characteristics and income.

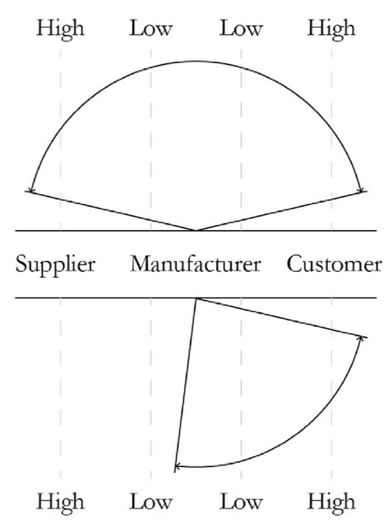


Fig. 4. Arcs of circular integration for Company B.

Company C is characterised by narrow arcs of both forward and reverse integration (Fig. 5). In detail, it represents a case where no integration with its forward supply chain is present. Indeed, due to the lack of extended producer responsibility, Company C has no relationship with the producers of cooking oils; as such, the implementation of CE practices by Company C can be related to the principles of open-loop circular supply chains. Nonetheless, Company C exhibits some attempts to integrate with the suppliers in its reverse supply chain.

In detail, the company shares data about forthcoming collections in

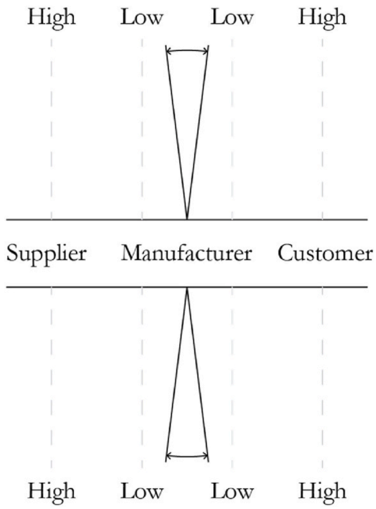


Fig. 5. Arcs of circular integration for Company C.

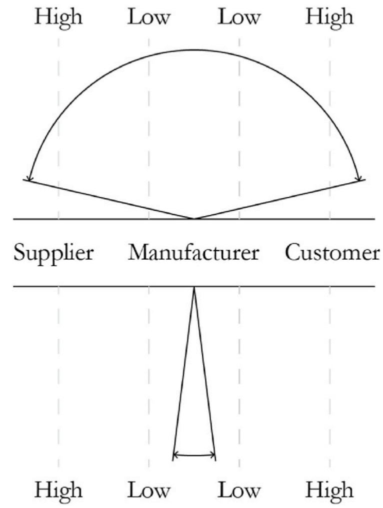


Fig. 6. Arcs of circular integration for Company D.

their area while suppliers of UCO promptly inform Company C when required volumes are ready for collection. Furthermore, to secure a constant supply of UCO, the company constantly reviews its suppliers' contributions in terms of production volume. This information is used in a rudimentary system that the company employs to forecast future collections and to tailor occasional incentives aimed at increasing suppliers' loyalty. *"We would very much benefit from some level of further integration"*, said the Logistical Coordinator at Company C. *"Intelligent bins, which could tell you when to visit a provider for collection; or even a simple mobile phone app, linked to a routing optimisation system, that could tell our drivers when to visit a given establishment and work out an optimal plan. However, we operate on very tiny margins, and it has been difficult to plan such investments"*. As such, the coupling of information systems with providers has been completely absent so far, although Company C recognises that the development of intelligent integrated systems for UCO collection, capable of sharing real-time information about stocks at the suppliers' level, would be highly beneficial.

Furthermore, the integration of Company C with its customers in the reverse supply chain is absent: *"We have never felt the need for integration. What comes out of our plant is a semi-finished good that can be used for several purposes. The market completely absorbs it, so the need for information sharing and other types of practices is extremely limited"*.

4.4. Case Company D

Company D (Table 7) is located in the Metropolitan City of Naples (Italy) and is a major distributor of Italian food products in foreign markets, mainly serving large supermarket chains. Apart from its own-branded range of products, the company offers to its customers private label ranges. These involve monitoring the sourcing and production processes, creation of brand identity, packaging design, and delivery to the final customer. Product categories include pasta, extra virgin olive oil, wine vinegar and PGI-certified products such as balsamic vinegar.

Managing an extensive network of certified and trusted Italian and European suppliers, the company can offer a wide range of services from the procurement of raw materials and shipping to the automatic replenishment of customers' warehouses. The company provides intelligence services to suppliers and customers to highlight existing gaps and provide the most updated information and trends on raw materials and innovations that have not yet reached the market. Its close collaboration with producer associations, enables Company D to transform this knowledge into tailor-made products. The company's dense network of suppliers from different locations allows the daily monitoring of the global materials market. In this way, Company D can anticipate price and material fluctuations in advance, thus procuring for customers the necessary raw materials at the most competitive prices. Testing and monitoring procedures are in place to ensure that the

Table 6
Overview of Company C.

	Forward integration		Reverse integration	
Measurement items	Supplier	Customer	Supplier	Customer
Sharing information	• None	• None	• Medium: Company C constantly reviews its suppliers' contributions in terms of UCO production. Suppliers of waste cooking oil inform Company C when containers of UCO are ready for collection.	• None
Developing collaborative approaches	• None	• None	• Low: Company C uses historical data and forecasts to tailor contracts and incentives which are aimed at increasing suppliers' loyalty; however, this activity is rather unilateral.	• None
Joint decision-making	• None	• None	• None	• None
System coupling	• None	• None	• Low: Company C would be interested in the development of an intelligent integrated system for UCO collection, capable of sharing real-time information about stocks of UCO at suppliers; however, this seems unlikely due to the investment requested.	• None
Overall	Low	Low	Low	Low

Table 7
Overview of company D.

	Forward integration		Reverse integration	
Measurement items	Supplier	Customer	Supplier	Customer
Sharing information	• High: Based on customer orders, Company D shares its overall sales plans with producers, to aid them with their production capacity management and materials procurement.	• High: Key customers (e.g., big supermarket chains) share their sales forecasts and negotiate purchasing prices with Company D for premium products. Stock availability at regional distribution centres and point-of-sale are shared between Company D and key customers through a fully integrated cloud-based information system.	• None	• None
Developing collaborative approaches	• High: Company D has participated in recipe and product development in order to develop new private-label lines aimed at satisfying key customer requirements.	• High: Company D has participated in sampling sessions organised by its key customers to explore customer preferences and potential new product lines through private-label arrangements.	• Low: Company B recognisises the value of developing collaborations on the management of reverse flows (i.e., forecasting food waste); however, no specific practice has been implemented.	• None
Joint decision-making	• High: Company D directly participates in production mix decisions its suppliers through sharing market intelligence, forecasts and customer preference.	• Medium: Company D directly participates in marketing mix decisions its customers.	• None	• None
System coupling	• High: Company D directly supports its suppliers by sharing logistical infrastructures for intermediate storage, consolidation and cross-docking optimisation.	• High: Company D directly supports its customers by sharing logistical infrastructures for intermediate storage, consolidation and cross-docking optimisation.	• None	• None
Overall	High	High	Low	Low

standards requested by customers are met in accordance with certification bodies. Company D also acts as a logistical consolidator for suppliers and customers, providing a cross-docking facility for intermediate storage and load optimisation.

Company D is characterised by a wide arc of integration for its forward supply chain, and by a narrow one for its reverse supply chain (Fig. 6). Company D exhibits a high level of integration with its forward supply chain (both with customers and suppliers); however, it displays no integration with its reverse supply chain (both with customers and suppliers). Based on customer orders, the company shares its overall sales plans with producers aiding them with their production capacity management and materials procurement. Key customers, mainly big supermarket chains, share their sales forecasts and negotiate purchasing prices for premium products. Also, stock availability at regional distribution centres and point-of-sale are shared between Company D and key customers through a fully integrated cloud-based information system. *"We offer our customers full visibility of the supply chain: they can trace the entire journey of the product from the production plant of our suppliers to their regional distribution centres through our shared cloud-based system"*, said the Marketing and Sales Director. There is also a wide range of collaborative approaches with both customers and suppliers. On the suppliers' side, the company has been participating in recipe and product development programmes to develop new private-label lines to satisfy key customer requirements. Similarly, it engages in sampling

Table 8
Combinations of different levels of forward and reverse integration.

Arc of Reverse integration (RI) \ Arc of Forward integration (FI)	Narrow	Medium	Wide
Narrow	=	FI > RI	FI ≫ RI
Medium	FI < RI	=	FI > RI
Wide	FI ≪ RI	FI < RI	=

Table 9
Combinations of different levels of forward and reverse integration.

Arc of Reverse integration (RI) \ Arc of Forward integration (FI)	Narrow	Medium	Wide
Narrow	Company C	Company A	Company D
Medium			Company B
Wide			

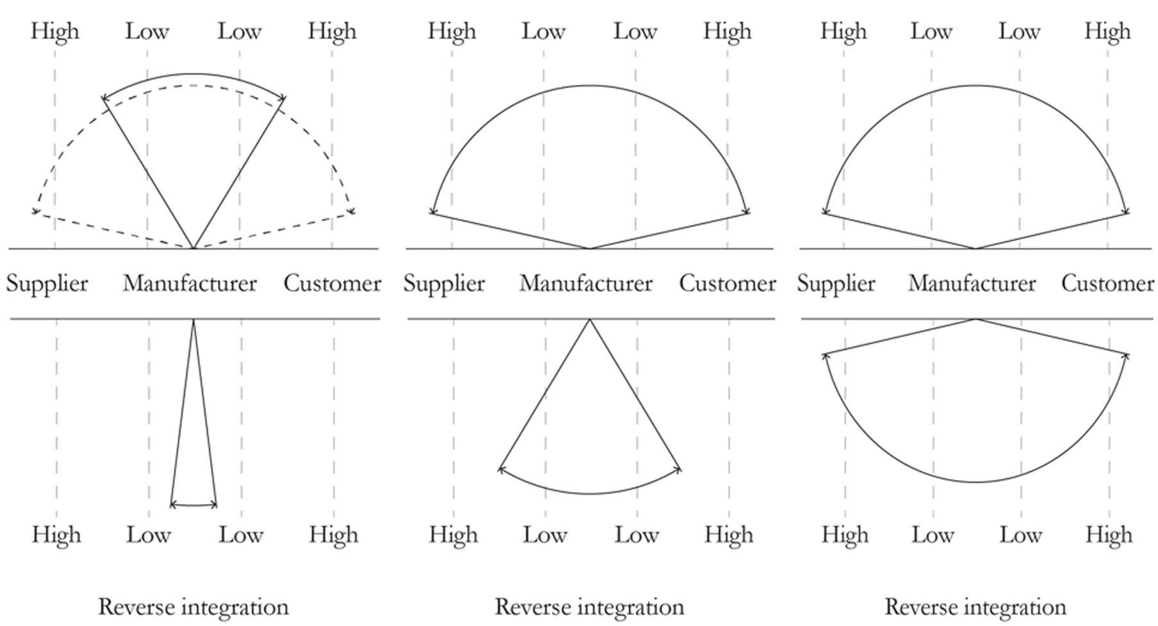
sessions organised by its key customers to explore customer preferences and potential new product lines through private-label arrangements. The knowledge acquired from these sessions culminates in the company's participation in production mix decisions with its suppliers and marketing mix decisions with its customers through sharing market intelligence and raw material forecasts. Following these decisions, Company D directly supports both its suppliers and customers by sharing logistical infrastructures for intermediate storage, consolidation, and cross-docking optimisation.

5. Cross-case analysis

5.1. Classifying the cases

The simultaneous assessment of forward and reverse integration leads to nine possible combinations, as shown in the following matrix (Table 8). Depending on their position on the matrix, these nine combinations of forward and reverse integration can be summarised into three notable cases. The main diagonal corresponds to firms that are equally integrated with their forward and reverse supply chains. Cases positioned above this diagonal correspond to firms that are more integrated with their forward rather than their reverse supply chain. Conversely, cases below this diagonal indicate higher integration with their reverse supply chain than their forward one.

This classification matrix enables the identification of combinations of forward and reverse integration for each case company (Table 9). Company A typifies a case of a firm that exhibits a medium arc of forward and a narrow arc of reverse integration. It pursues the development of integrative capabilities that could enable it to reduce stock losses (e.g., product returns, incorporation to alternative production lines), while increasing its market competitiveness (e.g., development of new products). Company B represents the archetype of a company operating in a potentially fully circular supply chain, where high levels of FI and RI (on the customer side) are supporting the implementation of advanced practices which aim to achieve zero-waste objectives. On the other hand, Company C, exhibiting narrow arcs of both FI and RI, provided us an interesting example of a company operating as a third-party provider in an open-loop supply chain where the implementation of CE



Proposition 1: Firms operating in traditional linear supply chains exhibit a higher level of FI compared to RI

Proposition 2: FI is a prerequisite for RI

Proposition 3: Firms operating in circular supply chains exhibit equally high levels of both FI and RI

Fig. 7. Overview of potential combinations between FI and RI.

practices is not supported by integration mechanisms, but rather being governed by market mechanisms. Conversely, Company D represents the contemporary case of a supply chain where priority is solely given to the integration of the forward supply chain. Focus is placed on developing information sharing capabilities and collaborative practices to achieve cost efficiency and optimisation in request processing and delivery of products; despite a wide FI arc, not much is achieved in terms of RI.

5.2. Development of propositions

Analysis of case studies in the previous sections enables the identification of three different propositions that involve potential combinations of forward and reverse integration related to the adoption of CE practices (Fig. 7). The starting point is the contemporary case of a linear supply chain where priority is solely given only to the integration of processes regarding forward flows. Subsequently, focal organisations are entering a transitional period from a linear to a circular supply chain where they are starting to integrate the operations of their reverse chain using existing processes in the forward supply chain. Having specified the required processes and sub-processes to develop reverse operations, an ideal "circular state" is reached where a series of suppliers, manufacturers, and customers simultaneously co-exist in extensively integrated forward and reverse supply chains. It should be noted that all combinations of forward and reverse integration presented below correspond only to cases where the coordination of all forward and reverse operations is performed only by the focal organisation.

- **Proposition 1:** *Firms operating in traditional linear supply chains prioritise the integration with their forward supply chain*

Traditional linear production systems constitute the foundation of the dominant "take, make, dispose" economic model where natural resources are extracted, manufactured, used, and then discarded as waste. Companies that follow such an approach are geared towards cost-efficiency and economies of scale and are concerned with generating profits based on production volume rather than on the extension of the utilisation period of goods within the market (Bocken et al., 2016; Millar et al., 2019). Consequently, end-of-life management operations and corresponding costs are externalised since the responsibility for them is shifted to secondary actors in the economic system (Fletcher et al., 2018). On the contrary, emphasis is placed on practices and activities that supply chain partners could be engaged in and lead to higher firm performance gains related to quality, delivery, flexibility, and cost (Wiengarten et al., 2019); this has been highlighted in the case of Company D discussed in the previous section.

Since companies operating within linear supply chains show no interest in exploring economically viable ways to retrieve and successively refurbish, recondition, repair as well as continue to reuse products and materials, they focus solely on the forward flows of materials and products (Campbell-Johnston et al., 2021). Therefore, the level of FI in these supply chains is expected to be significantly higher than the level of RI, as it concentrates on delivering the final products to the market in the most efficient way aiming at maximising profits while minimising costs; again, this has been shown in the case of Company D. It is important to note in this case that while we have no integration in the context of reverse flows, it is not impossible to have some extent of CE practices implementation. Nonetheless, this might be the case of open-loop configurations where here there is no integration in reverse flows, given that these are normally dealt with by other actors in the market. This is the case of Company C, which can be classified as a third-party actor, which is not integrated with actors in the forward supply chain, operating in a fully open-loop fashion.

- Proposition **2:** *FI is a prerequisite for RI*

The consideration of reverse flows in terms of volume, mix, quality, and time constitutes a challenging task that directly affects the level of planning in reverse operations (Bressanelli et al., 2019). Due to the limited degree of vertical integration by one actor in the supply chain, one of the key obstacles that companies are facing when they redesign their existing supply chains for implementing CE practices is associated with the level of coordination and information sharing among partners. However, there are considerable indications that companies that are already extensively integrated with their forward supply chain exhibit a higher level of development and adoption of circular practices. Since some general processes related to manufacturing, demand, and distribution management need to extend their scope rather than change to accommodate the consideration of reverse flows, existing processes in the forward supply chain could be used to start integrating the operations of their reverse chain (de la Fuente et al., 2008). Given the variety of organisational culture profiles, firms that have developed shared operational activities with their supply chain counterparts and are already co-managing intra- and inter-organisational processes, could enable them to incorporate the consideration of bidirectional material and information flows more easily (Rizzi et al., 2022). These adjustments can be further supported by the presence of interoperability infrastructure which can be modified as well as the high level of trust that characterise long-term supplier-customer relationships in integrated supply chains (Herczeg et al., 2018). This has been shown in the case of Company A, where some integration of forward activities is also providing a platform for an initial implementation of reverse integration; and in the case of Company B, where the high level of reverse integration is supported by an equally high level of forward integration with customers.

However, high levels of FI are not sufficient to achieve high levels of RI, as explained in the case of Company D. For this reason, high levels of FI are a necessary, but not sufficient characteristic for the achievement of RI in circular supply chains. Therefore, companies going through this transitional period where they are starting to integrate the operations of their reverse supply chain using existing forward supply chain processes are exhibiting a high level of FI towards suppliers and/or customers while the corresponding level of RI is above low.

- Proposition **3:** *Firms operating in circular supply chains exhibit equally high levels of both FI and RI*

Given the plurality and variety of actors involved in circular networks, central to the process of designing and planning for the transition from linear to circular supply chains is the high level of collaboration and coordination among all partners in the supply chain (Berardi and de Brito, 2021). A necessary condition for the transition from a linear to a circular supply chain is the simultaneous consideration of both forward and reverse upstream supplier and downstream customer integration. Specifically, a high level of reverse integration is needed to develop the necessary competencies and capacity to recover used products while minimising material leakages. On the other hand, an equal level of forward integration involving systems coupling, joint decision-making, and sharing information about sales forecasts, stock levels as well as production plans is imperative for reducing waste (Vachon and Klassen, 2006; Wiengarten and Longoni, 2015). From a proactive standpoint, the development of collaborative approaches in the forward supply chain can also foster the consideration of available recovery options from the early planning stages thus ensuring the timely design of necessary operations (Reike et al., 2018; Berardi and de Brito, 2021). Company B, thanks to its wide forward integration arc, along with some very developed reverse integration practices (at a customer level) is on the trajectory to implement a fully circular supply chain; this will also depend on its ability to further integrate its reverse operations with its suppliers, for implementing additional CE practices.

6. Implications

All cases presented in the previous section corresponded to the area from the main diagonal and above in Table 8, where FI is higher than RI. The underlying principle for the development of these subsequent levels of integration maturity from linear to circular supply chains was rooted in the premise that FI is a prerequisite for developing reverse capabilities thus increasing the level of RI. de la Fuente et al. (2008) showed that existing processes in forward integration can be used to incorporate reverse capabilities in an existing supply chain. Since the general processes related to manufacturing, demand, and distribution management are the same in both forward and reverse supply chains, existing processes are not necessary to change but extend their scope.

Focusing on the challenges in supply chain redesign for the CE, Bressanelli et al. (2019) highlighted the importance of coordination and information sharing among supply chain partners and noted that this is extremely challenging, especially within global configurations. Indeed, modern supply chains constitute global multi-tier network structures of increased complexity and dynamics characterised by increased competition among different tiers, information sensitivity, and poor planning (Choi et al., 2001). The geographic dispersion of business processes around the globe has decoupled the point of production and consumption. Given that the processes of recovery, repairing, reconditioning, and refurbishing are taking place at the point of consumption, there is also the possibility of manufacturers exhibiting a higher level of RI than FI. Pursuing a high level of integration in their reverse supply chain would be rational not only given the complexity entailed in the information and material flows but also due to the importance of spare parts availability and service times. Also, higher levels of RI could contribute to the implementation of more radical CE practices, which could, in turn, support the transition towards less resource intensive production systems and business models.

7. Conclusion and future research avenues

This paper has critically discussed the suitability of the SCI concept to the emerging CE discourse in the supply chain management literature. Its main theoretical contribution lies in using the F–W's arcs of integration concept to fit the CE paradigm by introducing a perspective that simultaneously considers both forward and reverse flows. As regards the contribution to practice, this extension demonstrates the need to rethink the way firms develop integrative strategies with their network of partners to implement circular processes. The propositions in the last section could act as a guide for companies to evaluate the degree of forward and reverse integration maturity with their immediate suppliers and customers.

Specifically, while the importance of SCI for companies is well established in the literature, the development of information sharing capabilities for reverse flows poses significant challenges (Kembro and Selviaridis, 2015). The most challenging aspect is related to the forecasting of product returns which adds an additional layer of complexity to production planning (de la Fuente et al., 2008). In contrast to the linear supply chains, the direction of information and material flows in CSCs is multidirectional across several network partners. As such, contemporary SCI measurement scales might not be suitable for CSCs and might need to be reconsidered, to better capture their characteristics. On the other hand, to validate the re-conceptualisation of the SCI constructs, along with the potential combinations of different levels of forward and reverse integration, the propositions that were presented in the previous section will need to be examined and empirically investigated. In this paper, specific supply chain configurations, which display different degrees of integration and implementation of circular economy practices across suppliers and customers, have been identified through exploratory case-study research. Such a link between integration and CE practices adoption could then be validated through large-scale sector-specific surveys, acknowledging the fact that integration mechanisms might take different forms across different industries or competing priorities (Wiengarten et al., 2019). Given the evolutionary and non-static view of supply chains throughout time (MacCarthy et al., 2016), another topic of interest could be a longitudinal study of the role of SCI towards the development of closed-loop orientations (Schmidt et al. (2021)).

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.

Data availability

The data that has been used is confidential.

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Appendix A

A. General information

1. Could you please provide us some information regarding a) number of employees; b) revenues; c) key product categories?
2. Which are your key raw material and final product categories?
3. Where are your suppliers and customers located?
4. Could you please describe the steps involved in your production process?
5. Could you please list the circular economy practices (reduce, reuse, recycle) you have implemented?

B. Supply chain integration

1 Differentiating between forward and reverse flows of products, please, indicate whether your company has implemented any practices related to the following processes:

- Sharing information with key suppliers/customers (about sales forecast, production plans, order tracking and tracing, delivery status, stock level);
- Developing collaborative approaches with key suppliers/customers (e.g., supplier development, risk/revenue sharing, long-term agreements);
- Joint decision-making with key suppliers/customers (about product design/modifications, process design/modifications, quality improvement, and cost control);
- System coupling with key suppliers/customers (e.g., vendor-managed inventory, just-in-time, Kanban, continuous replenishment).

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