Environmental collaboration with suppliers and cost performance: Exploring the contingency role of digital orientation from a circular economy perspective

Abstract

Purpose – To examine the interplay between sustainable supply chain management (SSCM) and circular economy, this research conceptualises and empirically tests an integrative framework of environmental information exchange with suppliers (ES), environmental product design (EPD) and cost performance (CP) with the contingency effect of digital orientation (DO). The associations proposed in the integrative framework provide a configuration of SSCM practices that support circular economy's restorative processes in the digital age.

Design/methodology/approach – The resource orchestration theory (ROT) and contingency theory (CT) are used to investigate the mediation and moderating effects, which were tested by a moderated mediation analysis of survey data of 100 firms in Australia.

Findings – The results indicate that EPD fully mediates the relationship between ES and CP. Further, DO was found to moderate the relationship between EPD and CP, but not the relationship between ES and EPD.

Practical implications – Our empirical findings offer an effective SSCM practice configuration for firms seeking to target advanced circular business models and economic benefits. Managers should be aware that ES may not be enough to improve cost performance; EPD is a required mechanism to translate the ES benefits into cost superiority. Managers should also stimulate a DO culture to develop effective EPD capabilities, which leads to improved CP and a foundation for companies seeking to target circularity.

Original/value – This study advances prior theoretical and practical knowledge. We propose and empirically test an integrated SSCM and circular economy model that incorporates mediation and moderation effects to clarify inconsistent findings in prior work, which provides a more holistic and practical understanding of SSCM practices in the digital context. Furthermore, the SSCM literature recommends the adoption of circular economy principles. Our integrated model provides a bridge between SSCM and circular economy.

Keywords Environmental information exchange with suppliers; Environmental product design; Cost performance; Digital orientation; Circular economy; Circular supply chains

1 Introduction

There is a growing recognition that the prevailing linear transformation system (e.g., take, make and dispose) is unsustainable (Paul et al., 2022). The paradigms of sustainable supply chain management (SSCM) and circular economy aim to compensate for the weaknesses of linear transformation (Sehnem et al., 2019). The environmental dimension of SSCM (also referred to as green supply chain management) is considered in the current work. Despite similar objectives, the literature suggests differences between circular economy and SSCM mostly in their intent. Circular economy is radical and targets the continuous restoration of resources whereas SSCM is more incremental and it partially addresses the restoration of resources (Genovese et al., 2017). There is an overlap, however, between circular economy and SSCM practices. For example, SSCM integration practices to reuse, recycle and recover are regarded as essential mechanisms of circular supply chains as well as main facilitators of circular economy (Hussain and Malik, 2020). Similarly, environmental information exchange with suppliers (ES) and environmental product design (EPD) are also central to both SSCM (Liu et al., 2018a) and circular economy (Sehnem et al., 2019). The literature is also suggesting that a stronger nexus between SSCM and circular economy provides opportunities to improve economic-related performance as main objective of both paradigms (Bag et al., 2022). This research is motivated by this line of inquiry because the extent to which SSCM practices configurations currently support circular economy's restorative processes remains underexplored (Batista, et al., 2018). Thus, to address the research gaps, this study proposes and empirically tests an integrated SSCM and circular economy framework that combines ES and EPD with the objective of improving cost performance (CP).

In the era of Industry 4.0, the applications of advanced emerging digital technologies (such as big data analytics, internet of things, blockchain, artificial intelligence, and machine learning) have significantly changed the ways businesses manage their supply chain processes (Arcidiacono et al., 2022). The literature suggests that digital technologies (i.e., internal technological resources) facilitate environmental information collection and sharing (Li et al., 2020), and enable the creation of superior EPD capabilities (Joshi and Gupta, 2019) for efficient outcomes (Li et al., 2020). There is also a growing recognition in the literature that the possession of technology needs to be supplemented by a firm's active orientation to technology (Kindermann et al., 2021). Particularly in the context of circular economy, both digital technologies (Rosa et al., 2020) and an innovative organisational orientation towards circular economy are considered as key drivers facilitating the transition towards circular economy (Hussain and Malik, 2020). In this research, we suggest that digital orientation (DO), defined as the willingness and proactiveness to identify and implement digital technologies (Kindermann et al., 2021), could represent such digital-driven posture.

Cost and economic efficiency has been described as a main motivator for most firms that pursue environmental solutions (Green et al., 2012). Firms do not want their sustainable efforts to be expensive, and cost efficiency can be transferred to final customer through competitive prices (Liu et al., 2018a). As an internal SSCM practice, EPD has been a central theme of corporate environmentalism, which targets environmental benefit but also cost improvements (Green et al., 2012). EPD is also a core tenet of circular economy because *'it closes, slows and dematerialises energy and material loops'* (Hazen et al., 2021) by radically changing the way products are manufactured (Zhu et al., 2022). EPD refers to an integrated approach where every stage of the product life cycle considers sustainable benefits (Conteras et al., 2009). Despite this, the effect of EPD on cost is not straightforward (Wong et al., 2020a), and empirical work has often offered inconsistent (e.g., Graham and Potter, 2015; Liu et al., 2018a) and contradictory results (e.g., Wong et al., 2020b; Esfahbodi et al., 2016). ES has been identified as a facilitator of EPD (Wong et al., 2020a). ES refers to the exchange of information about goals, responsibilities, strategies, benefits, best practices, and performance standards related to environmental issues with suppliers (Wong et al., 2015). While ES may contribute to designing easy-to-recycle products with a reduced number of components (Lai et al., 2015), existing empirical work still offers inconsistent results (e.g., Liu et al., 2018a; Wong et al., 2020a), which suggest that the ES benefits may vary.

A possible interpretation of this lack of consistency in the literature lies in that the research conceptualisation tends to concentrate on either consequences or antecedents and thus on individual links (Paulraj et al., 2017). The exploration of integrated models that propose mediation effects, however, remains under-researched in the literature (Wong et al., 2020a). The mediation argument is also supported by the relationships ES-EPD and EPD-CP identified so far, which implies the mediation effect of EPD. The main argument for the mediation role is that ES affects CP through the leveraging mechanism of resource orchestration theory (ROT). ROT explains *how* (rather than *what*) resources are managed and orchestrated, which ultimately creates competitive advantage (Malik et al., 2021). Specifically, ES requires developing environmental internal orchestration capabilities as enhancing and coordinating mechanisms for executing ES, which in turn generate cost advantage. External information resources thus may not be enough; an internal product design capability is required to translate the ES benefits into cost efficiency (Batista et al., 2019, Zhu et al., 2022). Stated differently, while ES provides strategic external environmental information, EPD provides adaptive and coordinative mechanisms to leverage efficient environmental efforts in the supply chain. In addition to the above relationships, ES has also been directly associated with CP as collaboration with suppliers for the reduction of energy use and consumption of materials could naturally lead to the reduction of the associated costs (Esfahbodi et al., 2016). Despite this, empirical support to this effect is still ambivalent (Lai et al., 2015), which suggests the need to further investigate the mechanisms through which ES leads to cost performance.

A complementary view to ROT and the lack of consistency in the SSCM literature is provided by contingency theory (CT), which suggests that organisations are open systems, in that they are exposed to factors that determine how orchestrating resources and capabilities affect performance (Aragón-Correa & Sharma, 2003). Specifically, a moderated-mediation analysis explains how the conditional direct and indirect effects (mediation) of an explanatory variable on an outcome variable are contingent upon moderating variables (Calantone et al., 2017). We specifically propose the contingency role of DO on the ES-EPD-CP mediation model. While digital technologies have been shown to increase the availability of environmental information, which can enhance the integration of external (i.e., ES) and internal processes (i.e., EPD) for environmental and resource efficiency (i.e., CP) solutions (Li et al., 2020), we argue that an orientation component will better direct and motivate firms to engage in and use digital technologies (Khin and Ho, 2020).

Given the above, rooted in the ROT and CT, this research contributes to the body of knowledge on SSCM and circular economy by answering the following two research questions:

RQ1: Does EPD mediate the relationship between ES and CP?

RQ2: Does DO moderate the relationship between ES, EPD and CP?

By addressing these research questions, this study advances prior theoretical and practical knowledge on three fronts. First, drawing upon ROT and CT, our integrated model that incorporates mediation and moderation effects broadens the SSCM and circular economy literature into the digital context, but also reinvigorates circular economy with SSCM energy and vice versa. The literature has called for the consideration of moderated-mediation effects to clarify inconsistent findings but also to provide a more holistic and practical understanding of SSCM practices (Calantone et al., 2017). Therefore, the integrated model provides a more complete explanation to how ES and EPD could be constructed as a joint mechanism to create competitive advantage for CP, and hence, we provide a clarification to the inconclusive empirical results in the literature. Second, our prosed integrated framework explains how SSCM practices, which centre on supply chain circularity principles, could interplay with economic benefits. Moreover, this research is timely because of increasing interest in understanding the role of digital technologies in SSCM and circular economy. Specifically, by exploring the moderating role of DO, this research complements ROT with a contingency view as a potential theoretical lens to further explain the SSCM phenomenon in a digital context. Third, from a theoretical perspective, our empirical findings offer an effective SSCM practice configuration for firms seeking to target more advanced circular business models and economic benefits. The ultimate objective for most firms is to obtain potential synergies between environmental and cost-related objectives; however, managers are continually challenged by how to efficiently organise their environmental resources to meet those ends. The results of this study offer a potential answer to this question by providing managers with an understanding of how external environmental integration efforts can be greatly complemented by internal mechanisms for cost effectiveness, and how digital technologies and firm proactiveness can bolster the effects in the era of Industry 4.0.

2 Theoretical framework and literature review

2.1 Theoretical framework

Our integrated model is grounded in ROT which addresses RQ1 (the meditation analysis) and CT which addresses RQ2 (the moderation analysis). ROT extends the resource-based view and, by extension, the natural resource-based view (NRBV), which argues that sustainable advantage could be gained from bundles of environmental inimitable resources (Hart, 1995). Interpreting NRBV more broadly, sustainable advantage could be assessed through both environmental and economic-related advantage (Chavez et al., 2020). While necessary, bundles of natural resources may not be sufficient to sustain competitive advantage (Sirmon et al., 2011). Instead, *how* resources are bundled creates competitive advantage, which is stressed by ROT (Malik et al., 2021). Thus, ROT extends NRBV by explaining *how* natural resources are managed and orchestrated, which ultimately creates sustainable advantage (Asiaei et al., 2021). Orchestrating resources refer to three distinct dimensions: structuring a portfolio of resources, bundling resources to build capabilities, and leveraging those capabilities, and the third dimension is regarded as a key mechanism to generate competitive advantage (Chirico et al., 2011).

Despite its popularity, it has been argued that resource-based arguments and, by extension, ROT do not necessarily consider the context. In other words, ROT may lack an explanation to the conditions under which orchestrating capabilities and resources are more valuable (Aragón-Correa and Sharma, 2003). Addressing this context-dependent notion, CT suggests that internal and external factors can influence how resources and capabilities affect performance, and thus frameworks in the contingency research tradition focus on the effect of contingency variables strengthening or weakening the association between independent and dependent variables (Chavez et al., 2021).

Drawing upon the logic expressed in ROT, we suggest that environmental internal capabilities (i.e., EPD) could act as an enhancing and coordinating internal mechanism for executing ES, which in turn generates CP improvement. Further, we complement ROT with CT to further explain the associations in our model when DO is considered as a contingency variable. Thus, we draw upon ROT and CT to develop an integrated framework that incorporates mediation and moderation effects (see Figure 1), which provides a more comprehensive explanation for inconsistent findings in the SSCM collaboration-performance relationship, and insightful practical guidance for mangers to implement SSCM practices in the digital age.

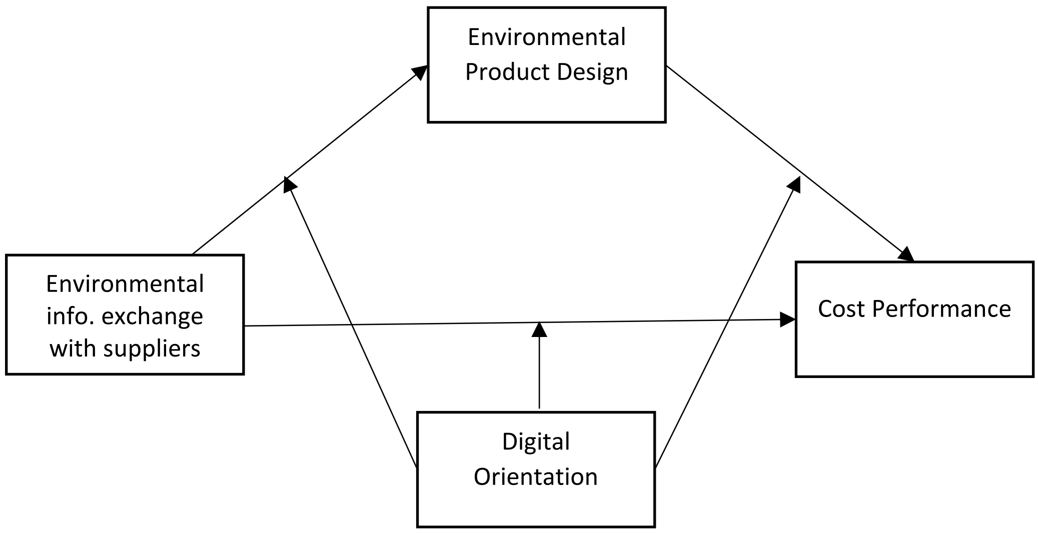

Figure 1: Proposed Research Model Depicting Moderated Mediation Relationships

2.2 Environmental information exchange with suppliers (ES)

Sustainable supply chain management (SSCM) refers to the management of internal and external sustainable practices for the reduction of environmental damage across the supply chain (Paulraj et al., 2017). The above definition and current study centres on the environmental dimension of SSCM, and among its central and representative external integration dimensions, environmental information exchange plays a crucial role in integrating the environmental supply chain process (Lai et al., 2015). Environmental information exchange refers to the voluntary exchange of information with customers and suppliers on environmental practices, standards and goals (Lai et al., 2015). In particular, ES allows firms to increase the visibility of environmental issues (Wong, 2013), and reduce the environmental impact (Gonzalez-Benito, 2008). ES contributes directly to environmentally friendly supply chain practices in terms of product design, the sourcing of materials, production and distribution (Wong et al., 2015). ES is essential for product life cycle and product recovery options (Lai et al., 2015) and thus circularity in supply chains (Sehnem et al., 2019). The current study concentrates on ES as a central SSCM practice and defines it as the exchange of information about goals, responsibilities, strategies, benefits, practices, and performance standards related to environmental issues with suppliers (Wong et al., 2015).

2.3 Environmental product design (EPD)

EPD is considered essential for the reuse, recovery and efficient use of resources in the supply chain (Paulraj et al., 2017). The traditional product design process formulates its operational-related objectives with a focus on efficiency; however, if environmental aspects are to be considered, they are often incorporated later in the design process (Vinodh and Rathod, 2010). In contrast, EPD requires an integrated approach where every stage of the product life cycle considers sustainable benefits (Conteras et al., 2009). Specifically, at an early stage of the product life cycle, EPD considers environmentally friendly materials, which can be easily disassembled, reused, recovered, recycled or even biodegraded (Hazen et al., 2021; Zhu et al., 2022). EPD also implies the internalisation of sustainable objectives into the company's overall strategy, and the use of formal environment guidelines and systems to improve and continuously reengineer product design to obtain environmental benefits (Gualandris and Kalchschmidt, 2014). Furthermore, EPD considers minimal energy consumption when using the product to further reduce environmental impact (Devanathan et al., 2010). Overall, EPD is regarded as part of the highest added value options in the reverse logistic hierarchy (Carter and Ellram, 1998) and circular economy (Sehnem et al., 2019; Zhu et al., 2022)

2.4 Digital orientation (DO)

Early work in the IT literature introduced the concept of technology orientation as the ability and willingness to adopt and use new technologies to develop new products (e.g., Gatignon and Xuereb, 1997; Zhou et al., 2005); however, the technology orientation concept has concentrated on technical aspects rather than managerial, human and organisational views (Khin and Ho, 2019). As an extended term of technology orientation (Khin and Ho, 2019), DO has been conceptualised by recent work, which also acknowledges the need for organisational elements that go beyond purely technological aspects (e.g., Quinton et al., 2018; Khin and Ho, 2019; Kindermann et al., 2021). Technology *per se* may not drive digital transformation (Kindermann et al., 2021) and an orientation may be required, which refers to a bundle of human and intangible resources that predict firm strategies, behaviours and performance (Chavez et al., 2021). Thus, we build on a conceptualisation of DO that captures behavioural traits to enter digital markets, which provide the willingness and proactiveness to identify and adopt digital technologies (Quinton et al., 2018; Khin and Ho, 2019; Kindermann et al., 2021).

2.5 Cost performance (CP)

CP is the most traditional operational performance objective, which refers to a company's ability to use resources efficiently (Chavez et al., 2017). However, CP improvement can also be derived from sustainable efficiency, the reduction of waste and CO_2 emissions, and thus CP improvement can result from sustainable operations (Graham and Potter, 2015).

2.6 The nexus between SSCM and circular economy

As an emerging paradigm, circular economy targets to minimise the consumption of resources by focusing on restorative design of materials, products and processes (Rosa et al., 2020). Researchers have also come to realise that effective sustainable solutions will result from an extended enterprise perspective, and thus the SSCM paradigm has amplified worldwide (Hussain and Malik, 2020). The SSCM extends the enterprise perspective with the premise that more environmentally sustainable solutions will result with an end-to-end focus at a supply chain level (Hussain and Malik, 2020). The circular economy also minimises the consumption of resources by advocating for a restorative and regenerative design of materials, products and processes (Batista, et al., 2018). Although there are common objectives and a nexus between circular economy and SSCM, the literature suggests that they differ in their intent: a) the SSCM unit of analysis is horizontal (internal and the upstream and downstream processes of an enterprise) whereas circular economy principles are applicable across the vertical layers of micro (enterprise), meso (industrial symbiotic networks) and macro (regional or national) (Liu et al., 2018); b) SSCM is characterised by the reverse flow of recovered material (closed loop supply chains) and the circular flows in circular economy refer to the forward flow of material to other supply chains (open loop supply chains) (Batista et al., 2018); and c) SSCM's focus is on improved environmental performance and economic performance (Liu et al., 2018), but circular economy's emphasis is on economic performance by alleviating environmental issues (Bag et al., 2022).

Despite the differences, SSCM includes representative practices such as ES and EPD, which centre on resource restoration. For example, the circular economy literature regards industrial symbioses (integration behaviour in and/or across supply chains), such as ES, as a key enabler of circular supply chains (Hussain and Malik, 2020). The circular economy literature has also characterised EPD as strong sustainability since it specifically targets the reuse and recovery of materials by design (Vanegas et al., 2018). Furthermore, circular economy contributes to economic performance by suggesting alternate flows of products and materials across supply chains for resource efficiency (Bag et al., 2022), therefore, cost efficiency is a key circular economy tenet. Circular economy centres on economic-related performance while considering the environment and the efficient utilisation of resources (Bag et al., 2022). Last, it has been suggested that the transition towards circularity requires radical technological change (Rosa et al., 2020) supported by a firm innovative orientation (Hussain and Malik, 2020). We suggest that DO could represent such posture. The above argument suggests that our constructs include main circular economy principles, and thus the associations proposed in this study provide a strong SSCM configuration that support circular economy's restorative processes (Batista et al., 2018). Furthermore, the interplay of SSCM and circular economy considered in this research is complex to the extent that the explanatory variables causing performance variations are potentially 'limitless' unless bounded by a theoretical lens (Furnari et al., 2021). The literature suggests 'theorizing with precision' (Fawcett et al., 2014) to put a bound on this complex interplay by identifying a limited set of constructs and mechanisms theorized to bring about the expected relationships. The ROT and CT theoretical underpinnings employed in our study suggests that the orchestration actions such as leveraging a specific arrangement (configuration) of complementary capabilities (ES, EPD, CP and DO in our conceptualisation) exploits the resource-based advantage. All the associations and our integrated model will be discussed in the following section.

3 Research hypotheses

3.1 The effect of ES on EPD

According to Preuss (2002), the ability to effectively capture and share relevant environmental information determines the success of environmental supply chain efforts. Integration mechanisms and external environmental information exchange on environmental goals, responsibilities, strategies and benefits drive better resource allocation for EPD (Wong et al., 2015). Specifically, ES can reduce uncertainty and increase process integration on sourcing, practice implementation and performance indicators when designing environmental products and closed-looped supply chains (Carter & Ellram, 1998; Wong et al., 2020a). ES facilitates goal-setting, product life cycle analysis, the creation of environmental knowledge, and design and manufacturing capabilities (Vachon and Klassen, 2008).

The role of environmental information exchange in the SSCM literature remains underexplored (Chavez et al., 2021), and existing studies show inconsistent results in the ES-EPD relationship (e.g., Liu et al. 2018a; Wong et al., 2020a). For example, Green et al. (2012) found support for the positive association between green information systems and EPD; however, Wong et al. (2020a) could not find support for the impact of green supplier integration, which includes ES, on EPD. While the lack of consistency in the literature demands further investigation, we anticipate a positive effect of ES on EPD, which is aligned with the first element of ROT (Chirico et al., 2011). Specifically, ES provides tactical and strategic environmental information with suppliers, which can be regarded as a key and intangible resource for the creation of capabilities, namely EPD capabilities. Thus, consistent with ROT, we attempt to complement prior work by offering the following hypothesis:

H1: ES is positively associated with EPD.

3.2 The effect of EPD on CP

Environmental product design targets environmental performance improvement; however, it can potentially have a positive influence on CP (Green et al., 2012). However, it has been suggested that the impact of EPD on cost is not straightforward (Wong et al., 2020a). While the design of environmentally friendly products may be effective to lower environmental impact, it is often expensive for product development (Hart, 1995). Furthermore, EPD may help to reduce energy consumption when using the product; however, it usually involves radical technology, which comes at higher costs (Wong et al., 2020a). The above argument offers contrasting views on the impact of EPD on CP, which demands further investigation.

Empirical evidence on the effect of EPD on cost show inconsistent results (e.g., Green et al., 2012; Esfahbodi et al., 2016; Liu et al., 2018a; Wong et al., 2020b). For example, internal environmental management, which contained EPD, was positively associated with economic performance (e.g., cost) (De Giovanni, 2012). Conversely, Green et al. (2012) could not find support for the association between EPD and CP. The empirical work offers ambiguous findings, which require further empirical research. Despite this, we anticipate a positive effect of EPD on CP, which is supported by the second element of the ROT (Chirico et al., 2011). Specifically, bundling resources to build capabilities (e.g., EPD as an internal and complex bundle of resources and capabilities) can offer differentiation and competitive advantage (e.g., CP). Thus, complementing the above literature and consistent with the ROT, we hypothesise the following:

H2: EPD is positively associated with CP.

While H1 and H2 were tested previously in the literature, they are essential for testing our integrated model. Further, H1 and H2 are essential for replication and extension of our results to other contexts where inconsistent results are found (Whetten, 1989; Wiengarten et al., 2013). For example, regarding the ES-EPD relationship, evidence revealed that external integration capabilities (ES) were more significantly positively related to EPD in Chinese-owned firms than in Western-owned firms operating in China (Liu et al., 2018a). Regarding the EPD-CP link, it was found a significant but negative relationship between EPD and CP when comparing two counties: Iran and China (Esfahbodi et al., 2016). We test our hypotheses in Australia, which has been regarded as advanced in supply chain practices characterised by strong supplier collaboration traits such as trust, commitment, adaptation, shared values, communication and integration technology infrastructure if compared to other countries (Collins et al., 2012). Thus, to increase the certainty of results, the Australian industry provides an interesting context to retest theory as an important part of the theory development process, and which has been an underdeveloped practice in OM research (Chavez et al., 2017).

The arguments presented in previous sections for H1 and H2 implicitly suggest that EPD can potentially act as a mediator. This argument is also complemented by the lack of consistency in the literature for the associations ES-EPD and EPD-CP, since studies have concentrated on either consequences or antecedents and thus on individual links (Paulraj et al., 2017); however, integrated models, which test mediations to further elucidate on inconsistent findings, are understudied (Wong et al., 2020a). The argument for the mediating role of EPD is that external supply chain integration efforts require internal coordination mechanisms to improve performance (Zhu et al., 2012). In the environmental field, external practices require internal key environmental systems such as eco-design to more effectively share product specifications with suppliers (Zhu et al., 2012). Firms need to be aware first of their own processes, policies and operations, and develop sustainable capabilities from within, which complement supplier integration practices (Gualandris and Kalchschmidt, 2014). ROT offers the theoretical perspective to better explain the mediation argument, which has been used to explain environmental phenomena (Asiaei et al., 2021). Specifically, the translation of ES into CP involves the acquisition, management and mastering of internal environmental capabilities concerning product design. ES affects CP through a complex mechanism, using resource leveraging mechanisms to build EPD capability. ES require an internal implementation-focus capability to leverage the information shared with suppliers, which in turn could further potentiate the effect on cost efficiencies. The mediating role of EPD is consistent with the third element of ROT: leveraging capabilities for competitive advantage (Chirico et al., 2011). Thus, we offer an integrated model rooted in the ROT to explain how ES can contribute to CP, but ES alone may not be sufficient; EPD capabilities to help identify, leverage and transform external information into efficient environmental solutions are also required.

The exploration of the mediating effect of internal mechanisms such as EPD remains unresearched in the SSCM literature, and there have been calls to formally test it empirically (Wong et al., 2020a). In response to the calls, Zhu et al. (2012) initially explored the mediating role of various internal green supply chain management practices on the relationship between external green supply chain management and economic performance; however, neither an information-sharing perspective, nor the mediating role of EPD was specifically considered. Although not formally tested, few studies implied the mediating role of internal environmental practices but with contradictory results (e.g., Liu et al., 2018a; Wong et al., 2020a). Thus, complementing the above studies, the lack of consistency in the ES-EPD and EPD-CP links in previous sections, and consistent with ROT, we provide an integrated model that investigates the potential mediation effect of EPD on the ES-CP link. The ROT fundamentally underpins the mediating role of EPD in converting ES into CP, in that EPD serves as a valuable, rare, inimitable, and non-substitutable internal capability that enables the functioning of internal resource orchestration mechanisms in the SSCM context. Further, consistent with the circular economy literature, our model answers the calls to offer a SSCM effective configuration of practices that support restorative and regenerative processes in the supply chain (Batista, et al., 2018). We thus offer the following hypothesis:

H3: EPD mediates the relationship between ES and CP.

3.3 The effect of ES on CP

Our hypotheses so far proposed the association between ES and CP being mediated by EPD; however, it has been suggested that ES can be directly associated with CP.

SSCM integration practices are considered essential for environmental solutions (Lai et al., 2015), which implies the exchange of environmental information about goals, practices and performance indicators (Wong et al., 2015). Customers and suppliers exchange information about reducing energy consumption, resource usage, carbon footprints, transportation, and solid and toxic waste (De Giovanni, 2012). In turn, the reduction of energy use, better resource and materials allocation and solid waste would naturally lead to the reduction of the associated costs (Graham and Potter, 2015; Esfahbodi et al., 2016). Despite this, it has been suggested that cost-related benefits do not always equate with environmental capabilities (Wong et al., 2020a), and the ultimate objective for most firms is to obtain potential synergies that generate both environmental and cost superiority (Graham and Potter, 2015).

The specific role of information exchange, as a key integration mechanism in SSCM, remains underexplored in the literature (Lai et al., 2015), and existing empirical work shows inconsistent results. For example, Lai et al. (2015) found support for the positive association between ES and CP; conversely, Esfahbodi et al. (2016) found that the ES was not associated with cost improvement. The above argument shows that there is a need to further explore the relationship between ES and CP. However, while still under debate, it can be suggested that ES could provide valuable, rare and inimitable information environmental resources, which could affect directly how well a firm achieves performance, namely CP (Hart, 1995). This argument is consistent with the NRBV, which could anticipate that ES can provide a complex bundle of environmental and intangible resources to enhance CP. However, as noted earlier, the NRBV is complemented by ROT and thus the direct relationship between ES and CP could be part of the overall explanation of how resources are orchestrated, together with EPD, to obtain competitive advantage. Thus, we hypothesise:

H4: ES is positively associated with CP.

3.4 The moderating role of DO

As mentioned above, the exact associations between ES, EPD, and CP are still under debate in the extant literature. While our proposed hypotheses anticipate positive relationships through the lenses of ROT, CT provides an alternative and complementary explanation to ROT and the lack of consistent findings (Aragón-Correa & Sharma, 2003). CT provides a suitable theoretical framework to understand inconsistent findings in the relationship between environmental collaboration practices and performance (Zhao et al., 2018). CT suggests that organizations are continuously exposed to contingency variables, which determine how resources and capabilities affect performance (Aragón-Correa and Sharma, 2003). Contingency variables tend to focus on competitiveness, technology and integration mechanisms in the SSCM literature; however, the role of a firm orientation, as a managerial, human and organisational condition, remains unresearched (Lai et al., 2015). Consistent with CT, we propose DO as a driving force that can strengthen or weaken the relationships in our integrated theoretical model, which is discussed below.

Digital technologies such as the internet of things (IoT), big data and cloud computing enhance the flow of information between suppliers and customers, which enable collaboration for effective EPD (Dubey et al., 2019; Fisher et al., 2018). Digital technologies, through data coming from sensors (e.g., RFID) embedded in products, allow firms to capture precise consumption data; this can help to better design product recovery options, product life cycle analysis (Joshi and Gupta, 2019) and circular supply chains (Paul et al., 2022). Information about product energy efficiency and the amount of wear of components can be collected and shared between supply chain partners, which supports the redesign of products and processes, in turn helping minimise a firm's environmental impact (Li et al., 2020). The above argument suggests that sharing relevant and precise environmental information with suppliers (i.e., ES) can help organisations better design products (i.e., EPD) and processes for environmental solutions.

Moreover, information sharing and information quality (e.g., cloud computing) strengthen a firm's internal communication capabilities and process integration to reduce its environmental impact while increasing in efficiency (Li et al., 2020; Fisher et al., 2018). Digital technologies can play a pivotal role in the achievement of both objectives. For example, digital technologies such as big data and its '5Vs': data volume, velocity, variety, veracity and value (Schroeck et al., 2012) can be leveraged by manufacturing firms to create and coordinate new product design that support both environmental and CP, and thus obtain potential synergistic benefits (Li et al., 2020). For example, cloud computing helps companies to make fast internal intelligent and sustainable decisions on how by-products and waste can be converted into higher value products or used as resources for other companies (i.e., closed and open loop supply chains), thereby providing the most sustainable and cost-effective solutions (Fisher et al., 2018). Thus, it can be suggested that digital technologies could enhance the integration and synchronisation of internal processes (e.g., EPD), which then can be used by manufacturing firms to reduce environmental impact as well as increase resource efficiency, namely cost improvement (i.e., CP).

Finally, data-driven supply chains facilitate internal and external communication and thus enable the integration and coordination of processes throughout the supply chain (Sanders, 2014). Digital technologies enable the creation of superior operational and supply chain capabilities, which decrease production costs and improve overall operational performance (Li et al., 2020). Specifically, the availability of key information and IT applications allow firms to leverage the use of capabilities from strategic supply chain partnerships (Liu et al., 2018a). Similarly, sustainable supply chains can be leveraged by digital technologies, which integrate supply chain stakeholders (Li et al., 2020). For example, the collection and sharing of data can be used to evaluate the most suitable yet cost-effective solution for circular economy models such as industrial symbiosis and circular business models (Hussain and Malik, 2020). In sum, digital technologies could increase the availability and dissemination of key environmental information across the extended enterprise (e.g., ES), which can be used to generate cost efficiencies (i.e., CP).

The above arguments suggest that the associations in our integrated model (ES-EPD, EPD-CP and ES-CP) could be moderated by digital technologies. These associations are illustrated by successful business examples during the COVID-19 pandemic that used digital collaborative technologies such as blockchain to make information more transparent. Further, paired with IoT, artificial intelligence (AI) and big data predictive analytics, companies quickly identified environmental vulnerabilities and built the needed manufacturing capabilities for both effective and efficient environmental solutions (Sarkis et al., 2020).

Despite this, it has been suggested that technology *per se* may not reflect the overall opportunities presented by digital technologies (Khin and Ho, 2020). The digital technology literature has concentrated on technical issues rather than cultural and managerial views, which complement technological aspects and drive real digital transformation (Kindermann et al., 2021; Quinton et al., 2018). A firm orientation that directs human action might be necessary and complementary to sole technologies (Jones et al., 2014). Specifically, a firm orientation guides activity in organisations and generates actions aimed at transforming cultures towards SSCM practice adoption and improving performance (Mariadoss et al., 2016). In contrast, lack of a firm orientation may hinder the process of cultural and behavioral transformation required to implement innovations (Quinton et al., 2018). Specifically, the lack of values, beliefs and behavioural norms, which shape a firm orientation, may delay the shift of the existing business model to the absorption of SSCM activities and how these affects performance (Mariadoss et al., 2016). This suggest that a firm orientation (e.g., DO) naturally provides a suitable contingency factor that could strengthen or weaken the successful implementation of SSCM practices (Chavez et al., 2021). This argument is consistent with the circular economy paradigm, which initially requires facilitators (e.g., ES and EPD); however, facilitators must be supported by organisational culture and attitudes (e.g., DO) to change the way goods are produced and consumed (Hussain and Malik, 2020). We would expect that DO represents such attitude to motivate firms to engage in the use of digital technologies and make valuable environmental information available. Firms in turn will use information to better integrate its processes, externally and internally, to design environmental products that reduce environmental damage and generate cost advantage. Thus, complementing the ROT with the CT, we propose the contingency role of DO on our integrated model: the relationship between ES, EPD, and CP. Thus, we hypothesise:

H5: DO moderates the relationships between ES and EPD.

H6: DO moderates the relationship between EPD and CP.

H7: DO moderates the relationships between ES and CP.

4 Research methodology

4.1 Data collection

For data collection, we surveyed Australian companies for two reasons. First, Australian companies are increasingly becoming involved in supply chain sustainability initiatives (Sullivan and Gouldson, 2017; Malik et al., 2021). Previous government-led initiatives, such as the introduction of carbon pricing scheme, have been instrumental in raising sustainability awareness among Australian businesses. Second, due to rapidly changing climate conditions and challenges associated with unique geographical dispersion of business activity, Australian businesses are in a favourable position to become more competitive through adoption of circular economy practices. For our sample, Ethical Trade Alliance (ETA) was engaged as the gateway organisation. ETA is an Australian industry body supporting implementation of sustainable supply chain practices across several industrial sectors. Through their extensive directory of industry contacts, ETA provided us access to a sampling frame that is likely to provide accurate assessment of research propositions. We engaged supply chain and operations managers as the target participants. The literature suggests opting for managers because they have both the breadth and depth of knowledge to objectively evaluate supply chain processes and practices under examination (Krause et al., 2018). The survey instrument was pilot tested by three academics with operations and supply chain management background and one industry contact with extensive experience in the field of supply chain sustainability and ethical trade. The pilot testing was performed to evaluate the validity and relevance of questions and to ensure the instrument is capturing the intended information. Survey was programmed and delivered in Qualtrics. A research information statement was also prepared as part of the email invitation to provide the necessary details about the questions and research background to the participants.

The email invitation was received by 1124 industry contacts from ETA's directory, which resulted in 113 survey responses, of which 13 were deleted due to missing data points. As a result, our final sample resulted in 100 responses and a participation rate of 8.9 percent (see Table 1). It is important to acknowledge that the survey is part of a multi-faceted project and part of the survey data have been used in a prior study (Chavez et al., 2021) that is different in character from this present study.

Table 1. Summary of participants and their organizations

Representing sector (%)		**Summary of participants' profile**	
Logistics and transportation	31	**Position**	
Beverage and food processing	14	Executive level	14
Plastic, rubber and chemicals	8	Directors	11
Technology and telecommunication	8	Managers	37
Automotive	5	Others	38
Electrical and electronics	5	**Annual revenue (AUD Millions) ***	
Retail and wholesale	5	<10	23
Apparel and textile	3	10-100	33
Others	16	101-800	28
		>800	15
		Number of employees	
		<50	38

	50-200	12
	201-500	11
	>500	39

4.2 Instrument design and scale development

To maximise content validity and the reliability of the theoretical construction, measurement scales were identified from the extant literature (Forza, 2002; Hulland et al., 2018). Several criteria were considered when selecting measurement scales, including the source of publication being a highly recognised journal in the field of operations and supply chain management, citations of the source, year of publications, the operationalisation of the scales in future studies and suitability to the theoretical model of this study. To measure CP, Wong et al. (2011) was employed, using a four-item scale that included questions on lowering the costs of production inventory, overheads, and price competitiveness in relation to rivals in the market. For DO, the scales were borrowed from Khin and Ho (2019), which were initially adopted from Gatignon and Xuereb (1997) and Zhou et al. (2005). The scales for DO consist of items describing an organisation's commitment to the use of digital technologies for the development of new products, solutions' superiority in terms of embedded digital technologies, acceptance, and pursuit for digital technologies across the organisation's innovation efforts. For EPD, we have employed the scales from Paulraj et al. (2017), which include items describing the use of environmentally friendly materials for product design, use of life cycle analysis, having formal guidelines for environmental design, ease of disassembly and design considerations to recycle and recover materials. Finally, Wong et al. (2015) and Wong et al. (2020) were used for ES items, comprising items related to the exchange of environmental-related information with suppliers, including goals, practices, technologies, requirements, and life cycle impacts. All indicator variables were measured using a 7-point Likert scale.

Previous studies have highlighted the likely confounding effects of firm size, mainly because large organisations are able to harmonise their supply chain processes due to their resourcefulness and integrated systems (Koufteros et al., 2007). To factor in such effects, this study controlled for firm size through measurement of natural log of annual turnover.

4.3 Data Collection Adequacy Tests

We follow Westland (2010) to determine the minimum sample size to detect effects by using the Soper (2016) calculator. The input parameter values for the Soper calculator (such as the anticipated effect size = 0.35, desired statistical power = 0.80 and probability level = 0.05) were borrowed from comparable studies such as Malik and Abdallah (2020). Based on the 22 observed variables representing four latent constructs, the Soper calculator returned 94 as the minimum sample size and our sample size exceeds this minimum requirement. In addition, (Hair et al., 2014 p. 574) also suggests that a sample size of 100 is acceptable for models with fewer than five latent constructs and if the number of observed variables for each latent construct is at least three. Our sample size also fulfils this requirement.

Next, we checked for survey non-response bias and common method variance (CMV). A non-response bias test was performed by conducting a Mann-Whitney U test to detect statistically significant differences between early respondents and late respondents as a proxy for non-responders (Malik and Abdallah, 2020). The first quarter and last quarter of respondents did not reveal any statistically valid differences for the four theoretical constructs, implying that non-response bias was not a significant concern for our data (Chavez et al., 2021; Malik and Abdallah, 2020). As an ex-ante approach to minimise common method bias, we assured the respondents of their complete anonymity and we also did not label our survey questions with the relevant theoretical constructs so that the respondents were unable to guess the underlying causal relationships, thereby minimising social desirability and acquiescence-related biases (Hulland et al., 2018). We also performed a post-hoc common latent factor (CLF) test to determine the presence of CMV in our data. A measurement model with and without the CLF was run to see the differences in the model fit parameters such as Tucker–Lewis Fit Index (TLI) and Comparative Fit Index (CFI). The differences in the model fit parameters were marginally different (ΔTLI and ΔCFI < 0.02), indicating that CMV was not a major issue with our data collection approach (Hulland et al., 2018).

4.4. Confirmatory Factor Analysis and Measures Validity

For measures validation and to check the unidimensionality, we first performed a confirmatory factor analysis (CFA) in AMOS version 27. Two absolute and two incremental fit indices were used to determine the CFA model fit (Hair et al., 2014; Malik and Abdallah, 2020). The CFA model returned the $\chi 2$/ degree of freedom ratio (CMIN/DF) = 1.69, TLI = 0.90, CFI = 0.92, with a Root Mean Square Error of Approximation (RMSEA) = 0.08 which meet the acceptable thresholds of CMIN/DF ≤ 2, TLI & CFI ≥ 0.9 and RMSEA ≤ 0.08 (Hair et al., 2014; Malik and Abdallah, 2020). The standard coefficients and the t-values for all construct variables are shown in Table 2. The CFA models also allowed the determination of measures reliability and convergent validity such as the composite reliability and average variance extracted (AVE) (see Table 3). Both composite reliability and AVE scores exceed the benchmarks of 0.70 and 0.50, respectively (Hair et al., 2014; Malik and Abdallah, 2020). The discriminate validity of measures was confirmed using the square root of the AVE which was more than the inter-constructs correlations (Hair et al., 2014; Malik and Abdallah, 2020).

Table 2: Confirmatory Factor Analysis Results

	Latent Construct and Indicators	Std. Coeff.	t- Values***
Exchange environmental information with suppliers (ES)			
1	We exchange information about our environmental goals with our suppliers	0.88	6.52
2	We exchange information about our environmental responsibilities with our suppliers	0.85	6.39
3	We exchange information about our environmental strategies with our suppliers	0.85	6.41
4	We exchange information about our environmental benefits with our suppliers	0.91	6.67
5	We exchange information about our environmental best practices with our suppliers	0.91	6.66
6	We exchange information about our performance standards related to environmental issues with our suppliers using an integrated environmental information system	0.60	8.44
7	We exchange information with our suppliers about environmental issues using an integrated environmental information system	0.59	_a
Environmental Product Design (EPD)			
8	When designing products, we pay attention to reduced consumption of material/energy	0.63	6.65
9	When designing products, we pay attention to reuse, recycle, and/or recover material	0.70	6.93
10	We design our products to use environmentally friendly materials	0.76	7.68
11	We design our products with standardised components to facilitate reuse	0.63	6.89
12	We design our products for easy disassembly	0.52	5.47
13	We use life cycle analysis to evaluate the environmental impacts of our products	0.88	9.64
14	We have formal guidelines for environmental product design	0.81	_a
Digital Orientation (DO)			
15	We are committed to use digital technologies (e.g., IoT, artificial intelligence, advanced robotics, machine learning, big data) in developing our new products and services	0.96	_a
16	Our products and services benefit from advanced digital technologies	0.73	5.11
17	New digital technologies are readily accepted in our organisation	0.77	5.24
18	We continuously search for opportunities to use digital technology to remain innovative	0.81	5.40
Cost performance (CP)			
19	Produce products with low costs	0.88	_a
20	Produce products with low inventory costs	0.79	9.71
21	Produce products with low overhead costs	0.89	11.62
22	Offer price as low or lower than our competitors	0.67	7.64

_a indicates a parameter that was fixed at 1.0, CMIN/DF = 1.69, CFI = 0.92, TLI=0.90, RMSEA=0.08
*** $p < 0.005$ for all t-values

Table 3. Measurement Validity

Construct	Composite Reliability	Average Variance Extracted	ES	EPD	CP	DO
Exchange environmental information with suppliers (ES)	0.93	0.66	**0.81**			
Environmental Product Design (EPD)	0.88	0.51	0.55	**0.71**		
Cost performance (CP)	0.89	0.66	0.24	0.48	**0.81**	
Digital Orientation (DO)	0.89	0.68	0.32	0.31	0.26	**0.82**

Average Variance Extracted' s square root is shown as bold along the diagonal.

4.5 Mediated Moderation Analysis

The hypothesised relationships warrant a moderated-mediation analysis (Calantone et al., 2017), i.e., how the indirect relationship of ES with CP is affected by DO. Specifically, the moderated mediation model in Figure 1 is represented by the following two equations:

$$M = \alpha_0 + \alpha_1 X + \alpha_2 W + \alpha_3 (X \text{ x } W) + Error \qquad (1)$$

$$Y = \beta_0 + \beta_1 X + \beta_2 M + \beta_3 W + \beta_4 (X \text{ x } W) + \beta_5 (M \text{ x } W) + Error \qquad (2)$$

Where $M = EPD,\ X = ES,\ W = DO,\ Y = CP$

To operationalise this moderated mediation analysis, we converted the latent theoretical constructs to observed measures by obtaining the factor scores through Amos 27's impute function (Calantone et al., 2017 ; Chavez et al., 2021). We also standardised the observed measures to avoid multicollinearity and for the ease of visualisation of moderation effects (Chavez et al., 2021). Then, we used the Model 59 of PROCESS macro for SPSS (Hayes, 2018 p. 597) to run the moderated-mediation analysis. Firm size was used as a control variable and added to the PROCESS macro as a covariate. The statistical significance of the conditional direct and indirect effects of ES on CP was determined using 10,000 bootstrap samples (Hayes, 2018). A summary of the moderated mediation results is presented in Figure 2 and the hypothesis test results are reported in Tables 4 and 5.

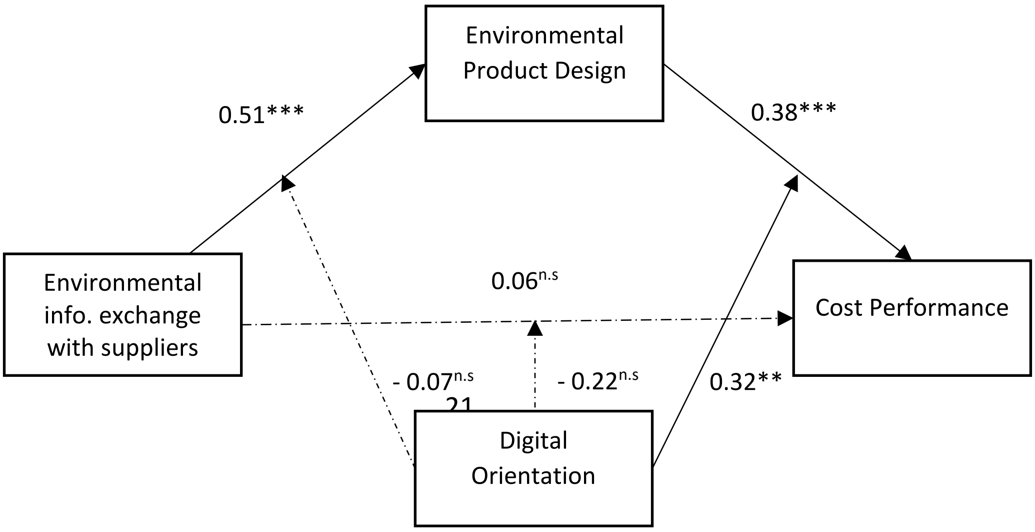

Table 4. Hypothesis Test Results and Details of Moderated Mediation Analysis

	Dependent Variables			
	M = Environmental Product Design (EPD)	***Hypothesis***	***Y = Cost performance (CP)***	***Hypothesis***
Intercept	- 0.06 (0.22)		0.01 (0.23)	
Covariate = Firm size	0.06 (0.13) $^{n.s}$		- 0.02 (0.14) $^{n.s}$	
X = Exchange environmental information with customers (ES)	0.51 (0.09) ***	***H1 - Supported***	0.06 (0.12) $^{n.s}$	***H4 - Not supported***
M = Environmental Product Design (EPD)			0.38 (0.12) ***	***H2 - Supported***
W = Digital Orientation (DO)	0.11 (0.10) $^{n.s}$		0.12 (0.10) $^{n.s}$	
Interaction X x W	- 0.07 (0.07) $^{n.s}$			***H5 - Not supported***
Interaction X x W			- 0.22 (0.11) $^{n.s}$	***H7 - Not supported***
Interaction M x W			0.32 (0.12)**	***H6 - Supported***
Model Summary				
F-Value	12.29		37.811	
R^2	0.34		0.33	
p-value	***		***	

****** < 0.005, **< 0.05, $^{n.s}$=not significant, Standardised Coefficients are reported. SE = Standard Errors are reported in ().***

Table 5. Hypothesis 3 - Conditional Direct & Indirect Effects

Conditional Direct effect of ES on CP					
DO	**Effect**	**SE**	**p-value**	**LLCI**	**ULCI**
-1 SD	0.28	0.19	0.15	-0.10	0.66
0	0.06	0.12	0.61	-0.17	0.29
+1 SD	-0.16	0.13	0.23	-0.42	0.10

Conditional Indirect Effect through EPD on CP				
DO	**Effect**	**SE**	**LLCI**	**ULCI**
-1 SD	0.03	0.10	0.18	0.22
0	0.19	0.07	0.08	0.34
+1 SD	0.31	0.13	0.08	0.59

The results reported in Figure 2 and Table 4 provide support for hypotheses 1, 2 and 6 whereas hypotheses 4, 5 and 7 were not supported. Hypothesis 3 suggested a mediation for the relationship between ES and CP through EPD. Meanwhile, the results for conditional direct and indirect tests reported in Table 5 indicate that ES is not statistically significant at three separate standardised values of mean and ±1 standard deviations (SD) of DO. This shows hypothesis 4 was not supported and the relationship between ES and CP is fully mediated by EPD. Thus, hypothesis 3 is fully supported. Table 5 also describes the conditional indirect effects of ES on CP at three separate standardised DO values of mean, +1 SD and –1 SD. This conditional indirect effect reflects the moderating effect of DO on the relationship between EPD and CP which is plotted in Figure 3. Specifically, Figure 3 shows that all three slopes are positive but the maximum increase for the effect of EPD on CP is at higher levels (+1 SD) of DO, confirming a positive and significant moderating effect of DO.

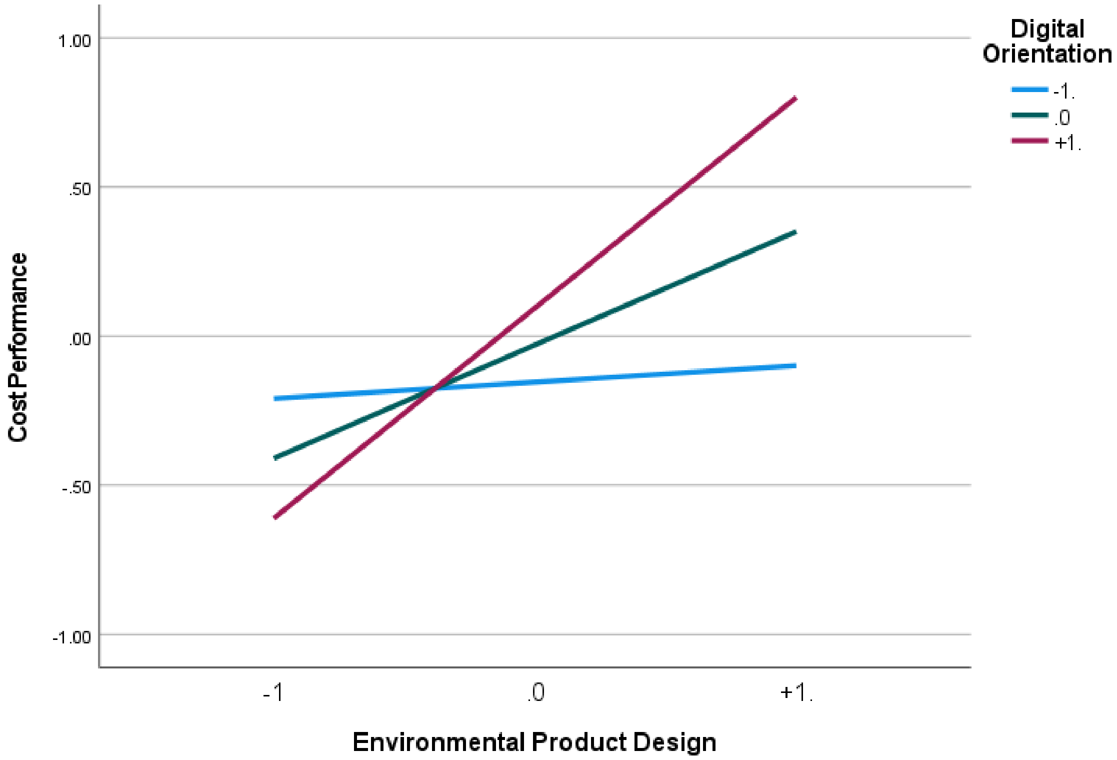

Figure 3: Moderating effect of Digital Orientation on the relationship between Environmental Product Design & Cost Performance.

5 Discussion

5.1 Theoretical implications

This study contributes to the SSCM and circular economy literature by providing an integrated theoretical model that includes both mediation and moderation effects. Prior work in the SSCM literature has concentrated on research models focused on consequences or antecedents, and thus on individual links (Paulraj et al., 2017). Using mediation and moderation effects, our integrated model provides a more comprehensive explanation for inconsistent results in previous work (Chavez et al., 2021) and offers a more holistic and practical understanding of the relationship between SSCM and circular economy. Furthermore, the SSCM literature has called for a transition towards the use of circular economy principles and provide relevant SSCM practice configurations that support this objective (Batista et al., 2018). The circular economy literature has characterised environmental practices as weak and strong; strong being environmental practices that overlap with circular supply chains (Hussain and Malik, 2020). Our model combines strong sustainability practices (i.e., ES, EPD) according to the circular economy notion (Vanegas et al., 2018; Hussain and Malik, 2020) and offers an effective SSCM practice configuration to target economic benefits – a core objective of the firms targeting circular economy (Bag et al., 2022). Additionally, our model reveals how a digital business environment supports SSCM practices and circular economy principles. Overall, circular economy aims to close, slow and dematerialise loops (Hazen et al., 2021) by, at least, the '3Rs': reduce, reuse, and recycle; however, these initial strategies have been expanded by recovery, redesign and remanufacture ('6Rs') (Batista et al., 2019), and even by rethink, repair, refurbish and repurpose to achieve the '10Rs' (Cerqueira-Streit et al., 2021). Our integrated model provides a specific configuration of SSCM-circular economy practices, performance and DO that aims to contribute to the achievement of the '10Rs' of circular economy. These novel contributions are discussed below.

One finding underlines the importance of environmental information exchange in the SSCM and the circular economy literature, which remains underresearched (Chavez et al., 2021; Hazen et al., 2021). Specifically, our finding supports the view that ES (e.g., environmental information on goals, strategies, responsibilities, benefits and standards) helps support and coordinate internal environmental systems such as EPD (Batista et al., 2019; Hazen et al., 2021). ES thus works as a facilitator of principles that centre on product design processes that consider product life cycle analysis, recovery options and the use of environmentally friendly materials (Wong et al., 2020a). Specifically, as our EPD construct includes measurement items on the circular economy practices of reduce, reuse, recycle, recovery of materials, and redesign of products (Batista et al., 2019) our finding shows how ES does not only encourages the achievement of the basic '3Rs' principles but also beyond. In addition, our EPD conceptualisation and measurement includes 'ease of disassembly' and 'standardised components' – both these design principles support product modularity which is a key enabler of circularity in supply chains (Hazen et al., 2021; Zhu et al., 2022). Our finding supports how supply chain eco systems, through information sharing on materials, energy and waste, can promote the transition towards the achievement of more added-value circularity options such as recovery and redesign (Castiglione and Alfieri, 2019). Another finding is that EPD has a significant positive effect on CP. Although this association is described as not straightforward in the SSCM literature (Wong et al., 2020a), our result shows that environmentally friendly product design that targets lower environmental impact, in the process, also generates cost efficiencies through recycling and reduced consumption of materials/energy. In other words, our finding offers evidence of potential synergistic benefits between environmental and cost-efficient capabilities (Li et al., 2020), which supports the circular economy's emphasis on economic performance by reducing environmental burden (Bag et al., 2022). Prior work showed inconsistent results in the above ES-EPD and EPD-CP relationships (e.g., Wong et al., 2020a; Liu et al., 2018a), which may also be partially explained due to differences in country, industry, and other unknown factors in the samples. Regarding the ES-EPD relationship, evidence from Thailand for example shows that environmental efforts could be more customer-driven with ES playing a secondary role (Wong et al., 2018). Evidence from China shows that cultural and social differences are relevant, and without the use of Guanxi at the time of negotiating and accessing external resources, no trustful supplier relationship could be built (Liu et al., 2018a). Similarly, regarding the EPD-CP link, evidence from a Chinese sample shows that firms may lack knowledge and capabilities for EPD innovation that translates into cost improvement (Wong et al., 2020a). EPD may be too resource-intensive and cost-demanding, and customers may not be willing to pay for the extra cost (Wong et al., 2020a). As noted in previous sections, we test our hypotheses using an Australian sample of firm, which, compared to other countries, show sophisticated supply chain collaboration and integration capabilities (Collins et al., 2012). This could help to explain in part why H1 and H2 were supported in our study. Alternatively, if compared to previous work (e.g., Wong et al., 2020a; Liu et al., 2018a), the scales for ES, EPD and CP included a comprehensive and detailed group of measurement items, which could have captured more information, and thus it is likely than our item scales reflect more facets of the construct of interest (Bergkvist and Rossiter, 2007).

Conversely, our study shows that the association between ES and CP is not significant. This result is consistent with prior work (Wong, 2013; Chavez et al., 2020). For example, although suppliers provide key information for environmental product development and the use of materials, they hardly play a central role in innovating internal environmental processes and the associated resource efficiencies (Wong, 2013). Alternatively, it has been suggested that the development of integration systems with suppliers would require considerable investment in infrastructure, which often comes at a high cost (Chavez et al., 2020). In sum, taken individually, our findings show that ES provides important input for EPD, and EPD shows to be a critical to improve CP; not so ES directly on CP. These relationships as an integrated model will be further elucidated in the next paragraph.

A novel contribution of this research is the mediation effect of EPD. Our findings suggest a full mediation effect of EPD, which suggest that ES may not be enough when environmental efforts concentrate also on achieving cost benefits. Regarding circularity, it has been suggested that not only closed- but also open-loop relationships are required, which assume external collaboration with firms and industries (Montag, 2022); however, our finding suggests that collaboration (i.e., ES) necessitates internal implementation-focused capabilities such as EPD to translate the ES benefits into cost advantage. This can be explained by the example of eco-industrial parks, which target industrial ecology models and rely on collaboration and information sharing; however, basic internal capabilities that centre on reduce, reuse, and recycle ('3Rs') must be respected before other higher-level circularity practices ('6Rs') and external collaboration are implemented (Castiglione and Alfieri, 2019). In other words, firms need to be aware of and develop first their sustainable capabilities from within, which later complement supplier integration practices (Gualandris and Kalchschmidt, 2014). This finding supports both the SSCM (Zhu et al., 2012; Liu et al., 2018a; Wong et al. 2020a) and the circular economy literature assertion (Batista et al., 2019; Hazen et al., 2021; Zhu et al., 2022) that EPD is a necessary intervening step between the supplier integration and CP link. Drawing upon ROT, our finding suggests EPD acts as a resource leveraging, mobilising, and coordinating mechanism for implementing ES. This result also shows how the NRBV is extended by ROT (Asiaei et al., 2021) in that ES does not provide key valuable natural resources that directly translate into cost advantage; EPD is the key leveraging environmental mechanism.

Another significant contribution of this study is the contingency role of DO. Our results show that DO positively moderates the relationship between EPD and CP. Specifically, the higher the firm orientation towards the use of digital technologies, the stronger the impact of EPD on CP. It seems that digital technologies can be used by firms to better integrate internal environmental design processes and, as a result, obtain cost superiority (Li et al., 2020). However, a proactive behaviour that continuously challenges innovation processes and organisational culture is also a strong determinant in the adoption of digital technologies (Jones et al., 2014). This argument seems to align with the circular economy literature, which suggests that to reach higher levels of circularity such as the '10Rs' not only technological innovation is necessary but also socio-institutional innovation 10Rs' (Cerqueira-Streit et al., 2021). Recent literature has suggested the role of digitally enabled developments such as IoT, big data and cloud computing as key to potentiate circularity (Montag, 2021). For example, cloud computing has been used to 'Repurpose' ('10Rs') or to make fast intelligent decisions on how to give new functions to by-products and waste (Fisher et al., 2018); however, technologies *per se* may not be enough, which require the support of organizational cultures that drive digital innovation (Chavez et al., 2021). DO seems to reconcile both technological and organisational views and clearly potentiates how EPD generates high cost efficiencies. Our finding is congruent with the CT, which complements ROT perspective by providing an explanation to the conditions under which resources are more valuable (Aragón-Correa & Sharma, 2003).

Conversely, our study shows that DO does not moderate the ES-EPD and ES-CP links. An interpretation of this finding lies in the excess of information that can be produced by digital technologies and strong digital-driven firms. Companies may not be able to capitalise on the full benefits offered by the 5Vs of big data (e.g., value) (Schroeck et al., 2012) when information is very abundant. Specifically, information coming from suppliers could become excessive and less relevant, and thus complicate decision-making (Chavez et al., 2020) and the development or implementation of internal operations such as EPD. Similarly, in order to obtain the full benefits of digital technologies and business cultures, important and often expensive integration infrastructure with external partners is required. Therefore, if there is high digital drive and organisational support to implement digital technologies, a digital infrastructure between suppliers and customers may be required, which is often costly and can influence cost negatively, at least in the short and medium run. These findings and interpretations seem to be consistent with the leveraging mechanism of EPD to translate ES into CP, and how CT could complement the ROT. The contingency argument complements

ROT by offering an explanation to the conditions under which the leveraging capabilities and resources are more valuable (Aragón-Correa & Sharma, 2003). Our findings revealed that EPD is the leveraging capability, which serves in our integrated model as a valuable, rare, inimitable, and non-substitutable internal capability that enables the functioning of internal resource orchestration mechanisms. Thus, DO seems to be interacting more with EPD, which is the key internal capability to generate cost superiority from external information sharing capability (i.e., ES); not so ES by itself.

5.2 Managerial implications

The present study has important managerial insights. First, our findings suggest that ES enables the design of environmental products that centre on eco-design practices and material recovery options, and thus ES can promote the development of closed-looped supply chains practices. In other words, companies aiming to support and coordinate EPD can do so by encouraging ES in terms of practices, strategies, goals and mutual benefits. Second, our findings also suggest that EPD positively affects CP. Thus, managers aiming to obtain cost benefits should build internal EPD capabilities, which indicates compatibility and possibly synergy between environmental and operational objectives. Taken individually, this informs managers that external integration efforts can help developing internal environmental capabilities such as EPD, and that EPD can be competitive in terms of cost and price.

However, our integrated model indicates the focal and leveraging role of EPD. Firms that work closely with suppliers on environmental issues need to recognise that EPD orchestrates ES and translates it into cost efficiency. Although ES represents a source of information for EPD, EPD represents the actual key internal capability conducive to cost advantage. Thus, companies targeting environmental operations but also cost benefits should develop external and internal SSCM practice configurations that promote ES yet centre on building effective internal EPD capabilities. Our integrated model provides managers with an effective and efficient configuration of SSCM practices consistent with circular economy principles.

Our empirical findings further indicate that the effect of EPD on CP is enhanced by the level of DO. In the era of big data, digital technologies (such as IoT, artificial intelligence, and advanced robotics) help in processing and analysing large amounts of data generated in the often iterative EPD processes and from intelligent manufacturing. However, technological aspects alone may not fully reflect the opportunities presented by digital technologies. Instead, integrating both a firm orientation and digital perspective could drive real digital transformation and environmental and economic benefits. Our finding demonstrates that DO strengthens the effect of EPD on CP. Thus, managers wanting to explore or implement digital technologies in their environmental efforts should stimulate DO and a culture around it to develop effective EPD capabilities, which leads to improved CP.

Overall, our integrated model and findings are timely because of increasing interest in understanding the links between SSCM, circular economy and digital technologies. Our proposed SSCM practice configuration provides a bridge between SSCM and circular economy, and a foundation for companies wanting to target more advanced circular business models such as industrial symbiosis in the digital age.

6 Conclusion and limitations

This study offers insights into the interplay between SSCM and circular economy by establishing the important roles of EPD for SSCM and the contingency role of DO in the digital age. Specifically, our study supports the ROT and CT by explaining how EPD acts as a resource-orchestrating mechanism and how DO strengthens the effect of EPD on CP. These contributions respond to recent research calls highlighting the need for moderated-mediation effects to clarify inconsistent findings in the SSCM literature but also to provide a more holistic and practical understanding of SSCM in the era of Industry 4.0 (Chavez et al., 2021). This study offers further insight into the interface of SSCM and circular economy, providing a SSCM practice configuration that supports circular economy principles and circular supply chains.

Despite these contributions, this study has some limitations that could provide potential directions for further research. Firstly, this study suffers from the limitations inherent in cross-sectional research. Future research could explore the use of longitudinal data. Secondly, this study focuses on a small sample of organisations in Australia. Future research should confirm the empirical results obtained in our study with a larger sample size and in different industries and countries. Thirdly, this study focuses on examining the environmental dimension of SSCM and its effect on cost-related performance; however, a social dimension could also be incorporated to more fully address the sustainability concept.

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