Interfirm Collaboration Enhancing Twin Transition: Evidence From the Italian Fashion Industry

Alessia Zoppelletto, Erica Santini, Cecilia Rossignoli, and Francesca Ricciardi

***Abstract*—This study enters the debate on the interplay between digital technologies and the pursuit of sustainable development goals in organizations. The article investigates whether external pressures at the supply chain level push companies toward a digital and green (twin) transition, and how this effect differs according to company size and their collaborative relationships. Using a sample of fashion industry firms located in northeastern Italy, we propose and test a conceptual model by applying a moderated mediation analysis. Our proposed model suggests that collaborative partnerships between firms are essential in leveraging digital technologies for a green transition, emphasizing the importance of coordinating technological adoption across the value chain. Results confirm that adopting collaborative partnerships boosts companies' willingness and ability to leverage digital technologies toward the green transition. Moreover, we found that the positive relationship between external pressures for technology adoption and firms' collaborative behavior is moderated by firm dimension. On one hand, when external pressures for digital transformation increase, smaller firms tend to collaborate more frequently than larger ones. On the other hand, regardless of size, all firms demonstrate increased collaboration when facing the highest pressure levels. This study offers novel insights into the importance of interorganizational collaborations at the supply chain level in companies' twin transitions.**

***Managerial Relevance Statement*—The study offers guidance for practitioners and operational managers, particularly in smaller companies in the fashion industry, emphasizing the importance of integrating digital transformation and interfirm collaboration to achieve sustainable supply chains. The findings suggest that external pressures for technology adoption can boost companies. propensity to collaborate along their supply chain, using data to drive large-scale changes in industrial operations for environmental integration purposes. Managers can adopt digital technologies to optimize processes across supply chain stages. Integrating shared data across the supply chain enables significant improvements in sustainability performance. Managers should strengthen deeper, more collaborative relationships with key suppliers and partners, fostering innovation in sustainability development and technology adoption. Supply chain digital platforms can be used to enable real-time information sharing, improving collaboration, supply chain transparency, sustainability-oriented decision-making, and resilience against disruptions.**

The research highlights the need for new systematic frameworks, such as the supply chain operations reference framework, to analyze and optimize supply chain processes and performances and measure the effectiveness of twin transitions. By focusing on interorganizational partnerships in facilitating companies' (twin) transitions, this study advocates for policymakers and institutions to prioritize investments that foster a digital culture within firms and encourage interfirm cooperation.

***Index Terms*—Digital transformation, fashion industry, interfirm collaboration, sustainable supply chain, twin transition.**

I. Introduction

> *We bought new Industry 4.0 machines to employ more sustainable raw materials, reducing the impact of our product, the amount of waste, and the energy used. To be honest, this strategy originated from the needs of one of our trusted clients to become more sustainable.*
>
> *To carry out this project, we collaborated with our suppliers and found new business partners along the value chain with higher sustainability standards. Therefore, we developed new collaborations with those who could provide us with more sustainable materials and increase our knowledge to reach our new goals.*
>
> *To become more sustainable and develop our new product prototypes, we had to collect and analyze large amounts of data.*
>
> (Operations manager, Company A, textile manufacturing company)

The quotation above, which emerged during the exploratory phase of this research, underlines how adopting the most recent digital technologies (e.g., smart manufacturing tools, digital twins, blockchain, and artificial intelligence) often leads to significant and contrasting environmental externalities [1], [2], [3]. In recent years, academic literature at the crossroads between digital transformation and sustainability has highlighted the tendency of companies to employ digital technologies (commonly referred to as Industry 4.0 technologies) to achieve sustainable development goals [4], such as creating greener production processes, boosting resource use efficiency, mapping and reducing the environmental footprint, or improving social welfare [5], [6], [7], [8]. In addition to the academic literature, a large body of policy documents illustrates that digital technology advancement has important environmental implications [9] for a greener, more digital and more resilient Europe.[1]

Digital technologies are increasingly facilitating a shift in company behavior toward a sustainability transition [5], [8],

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demonstrating significant potential to shape supply chain processes toward more sustainable development [10], [11], [12]. For instance, in the fashion industry, which operates in highly fragmented and resource-intensive global supply chains [13], advancements in digital technology adoption are particularly crucial for improving resilience and environmental outcomes [14], [15]. However, especially for small and medium-sized enterprises (SMEs), the twin transition is not trivial, and uncertainty regarding the return of investments in digital technology, the integration of digital tools into the industrial organization, and the lack of resources and absorptive capacity allowing the exploitation of digital technology opportunities prevent the transition [16], [4].

The adoption of digital technologies and the shifts toward twin (digital and green) organizational behaviors are often triggered by external pressures such as stakeholder demands or competitive market forces [1], [4]. The pressure of external stakeholders, such as institutions and other economic and noneconomic actors, forces companies to adjust their strategies and behavior constantly [17], [18], [19]. Relevant stakeholders can exert pressure to orient companies' sustainable behaviors and practices, particularly in situations characterized by resource interdependence between different actors (e.g., supply chains and districts) [12], [20], [21], [22], [23]. As a result, the integration of green concerns along the value chain is becoming more relevant [24] [25], [26]. Consistent with the principles of lean and agile supply chain management, building and maintaining collaborative relationships also play a central role in this transition [27]. Collaboration, including through platforms for manufacturing service collaboration, enables the reduction of waste and the efficient use of resources while also helping firms respond to disruptions and external pressures, such as regulatory demands and market trends [28], [29], [30]. Through collaboration, companies can gain new knowledge, access more advanced technologies [31], and adopt new behaviors [32] that can encourage them to use digital technologies use for sustainability-oriented purposes.

Although the issue of the twin transition is relevant, and the literature is growing, limited research has explored when the adoption of digital technologies supports more sustainable businesses [32], [33]. In particular, it is unclear whether external pressures support companies toward twin transitions and whether this effect differs according to the company size and their collaborations. Moreover, despite its growing importance, the twin transition remains understudied in the engineering management literature, leaving critical gaps in understanding the role of external pressure and interfirm collaborations in supporting firms to integrate digital innovation with sustainable development purposes. To address this gap, this article aimed to answer the following research questions.

Do external pressures foster companies' green transitions through the adoption of digital technologies?

Do interfirm collaborations mediate this relationship?

Does firm size play a role in shaping the magnitude of this relationship?

The empirical setting to investigate these research questions was the Italian fashion industry, which is characterized by the prevalence of SMEs.[2] The research questions of the study were explored through three hypotheses tested on a sample of 189 Italian firms in the northern Italian fashion industry. Our findings, on one hand, confirm that embracing collaborative supply chain practices enables companies to leverage the potential of digital technologies to drive the (twin) transition toward more sustainable development outcomes [34]. On the other hand, company size moderates collaborative behavior, especially for smaller firms, as external pressures increase.

II. Literature Review and Theoretical Development

In recent decades, technological progress has profoundly enhanced company performance [4], but at the same time, it has raised expectations regarding its potential to positively affect business sustainability [9]. To this extent, many studies have demonstrated that the employment of digital technologies in business contexts not only increases firms' economic competitiveness but can also provide benefits for society, human health, and the environment [1], [15]. Most studies have explored how digital technologies create opportunities for more sustainable businesses focusing on environmental sustainability [6], [12]. For example, at the company level, digital technologies seem to support greener production processes by reducing resource consumption and negative environmental externalities [6], [7], [15].

According to Montresor and Vezzani [1, p. 2], "the last generation of digital technologies has been envisaged to allow for more environmentally efficient processes, confirming that the twin transition is becoming more and more a strategic priority for firms." The digital and green transition of our economy, termed the twin transition, has been identified as a priority by the European Commission.[3] In this transition, digital goals complement green agendas, and sustainability goals can be achieved through investments and learning activities related to digital technologies.

Research into the twin transition is still fragmented in the engineering management literature, and further investigation into how firms embark on twin transition initiatives by integrating technological capabilities, interorganizational networking, and environmental performance is needed.

A. Adoption of Digital Technologies and the Green Transition

De Sousa Jabbour et al. [36] argue that in contemporary manufacturing practices, digital technologies play a pivotal role by enabling firms to gather, process, and use precise consumption data effectively. This capability not only enhances operational efficiency but also facilitates strategic product development. By leveraging digital technologies, companies can implement the 5

[2]According to the permanent census of companies published by the Italian Institute for Statistics (ISTAT), SMEs represent the 97.41% of the Italian companies (ISTAT, 2023). Moreover, according to Macchion et al. [35], most companies operating the Italian fashion sector are micro and small enterprises.

[3]European Commission. https://commission.europa.eu/ Accessed: Dec. 2, 2021. [Online.] Available: https://circabc.europa.eu/ui/group/96ccdecd-11b4-4a35-a046-30e01459ea9e/library/9827b88f-cf22-43d5-9d8e-9b87dfe89b91/details

Rs strategy—reduce, repair, reuse, recycle, and remanufacture—in a more precise and targeted manner. This approach not only supports sustainability goals by minimizing waste and resource consumption but also fosters innovation in product design and manufacturing processes [15].

The integration of digital technologies also enables real-time monitoring and adaptive responses, thereby improving overall environmental performance, optimizing the usage of natural resources, and improving the carbon footprint [12], [37]. Companies facing environmental challenges are becoming capable of deploying digital technologies to collect data on environmental issues [8], [9]. Some studies suggest that companies start investing in digital technologies because of internal and external motivations [16], [38], [39]. For instance, internal motivations refer to a well-defined digital transformation strategy [40] or a digitally oriented organizational culture [41], while external motivations rely on pressures from the competitive environment [42]. Indeed, customers, supply chain partners, or policymakers might exert external pressure to favor digital transformation [20]. In addition, institutions can exert external pressure on digital transformation, boosting companies' digital knowledge and promoting digital adoption.

Policymakers and institutions are dedicating resources to support companies to understand the value of digital technologies for both efficiency and sustainability [6], [43]. Facilitating their learning processes enhances digital knowledge accumulation, enabling firms to explore opportunities to reduce negative environmental externalities [1], [44]. Therefore, by building on the previous statements, we developed our first research hypothesis:

H1: External pressures for the adoption of digital technologies exert a positive influence on the use of digital data for environmental behaviors.

B. Mediating Effect of Collaboration

Using digital technologies for sustainability-oriented purposes is not an automatic achievement for companies, especially for SMEs. Several studies indicate that the investment and adoption of digital technologies are not sufficient conditions for developing a sustainability-oriented strategy [1], [8]. Empirical evidence shows that collaboration with external stakeholders plays an important role in allowing firms to share best practices and exchange digital knowledge, thereby reducing information asymmetry regarding digital transformation [22], [45].

Despite this evidence, most research into the potential of digital transformation in boosting firm sustainability performance has used a firm-level approach (e.g., [6], [46], [47]). Conversely, sustainability challenges require adaptation and innovative interorganizational approaches with external actors [10], [12], [15]. These approaches have been shown to reduce risk and provide access to complex knowledge, new technologies, and markets [18], enabling the adoption of new behaviors [32] and green practices [12], [22], [24]. These collaborations are vital for closed-loop supply chain management, enhancing the efficiency of manufacturing and remanufacturing processes through collaboration with suppliers, collectors, and retailers. Strategic collaborations, supported by carefully designed contracts, further improve coordination among supply chain members, facilitating valuable information and knowledge acquisition and increasing digital technology adoption for sustainability-oriented purposes, which are understudied [22].

These outcomes are evident in the case of the implementation of Industry 4.0 technologies and digital supply chain platforms, which facilitated system integration and information exchange within and across supply chain partners, including in the pursuit of sustainability-related objectives [43], [48]. Digital technologies have the power to shape interfirm collaborations among different stakeholders, allowing the integration of different information systems to share relevant information and data [12], [43], [46]. Digital technologies modify the structure and behavior of organizations, building more resilient supply chains by crossing multiple organizational and community boundaries [12], [32], [49], [50]. For instance, technologies such as digital twins can enhance supply chain coordination by improving information flows, optimizing logistics, enabling just-in-time production, and bolstering supply chain resilience to shocks [14].

Therefore, to benefit from sustainability outcomes associated with digitalization, companies may approach collaborative organizational forms, such as extended supply chains, collaborative networks, digital platforms, or business ecosystems[4] [5], [51], [52]. According to Ghisetti et al. [18], companies with external collaboration agreements (formal or informal) seem to achieve better in terms of their environmental performance. These external collaboration agreements can support the adoption of digital technologies, such as supply chain platforms, which serve as the underlying mechanism linking digital technologies to sustainability performance [43]. Therefore, we tested our second research hypothesis:

H2: The positive relationship between external pressures for adopting digital technologies and using digital data for environmental behaviors is mediated by the level of interfirm collaboration along the supply chain (because of digital technologies).

C. Moderating Role of Firm Dimension

The managerial literature on digital transformation and environmental sustainability highlights the paramount importance of company size (e.g., [18], [30], [53]). For SMEs, obstacles related to resource constraints, uncertainty, and lack of skills and knowledge increase dramatically [16], [30], [39], [53]. To address these challenges, SMEs commonly rely on close geographical relationships, long-lasting interorganizational linkages, and a vibrant network of stakeholders and business partners [35]. These relationships are pivotal for enabling SMEs to navigate the digital [54] and green transition [1], allowing knowledge circulation and supporting them to access more information and resources [55], [56], [57].

The literature highlights the constraints faced by smaller firms, which are particularly evident in the early stages of their sustainability transition [58]. These constraints in sustainable

[4]"Borrowed from biology, the term ecosystem generally refers to a group of interacting firms that depend on each other's activities" [51, p. 2256].

development capability include limited internal readiness to change [19], a lack of a strategic vision and a short-term focus on environmental improvements [59], and difficulties in balancing economic and environmental performance [60]. Moreover, smaller firms experience less stakeholder pressure regarding sustainability and seem less committed to sustainable practices than their larger firms [19], [61]. To embark on this transition, SMEs need to redesign different aspects of their value-creation process [62] and, in some cases, develop new business models [19]. In a recent report by the European Commission[5] about the impact of digital technology adoption on environmental sustainability, it emerged that large enterprises are more likely to radically reduce their environmental footprint by employing information and communication technologies than micro and small companies. For this reason, the present study aimed to consider the influence of company size in the third research hypothesis:

H3: The relationship between external pressures for the adoption of digital technologies and the level of interfirm collaboration (because of digital technologies) is moderated by the company dimension.

III. Methodology

A. Fashion Industry in Italy's Northeastern Region

The digital transformation holds great potential for the fashion industry's transition toward sustainability, which is increasingly demanded by the sector [63]. The fashion industry is indeed the second-largest polluter; consequently, companies have been striving to improve their sustainability performance by employing well-known technologies, such as laser cutting, linear digital printing, and additive manufacturing, or less diffused ones, such as digital twins, artificial intelligence, or integrated digital infrastructures that leverage the Internet of Things and the Internet of People [64].

The Italian fashion industry plays an important role [65] in the country's economy, generating 8.5% of revenue (i.e., over €80 billion) from Italian industrial manufacturing.[6] The industry accounts for about one-third of the total value of the European fashion sector and supplies around 60% of the world's high-quality fashion goods.[7] Companies operating in the fashion sector are mainly microenterprises and SMEs [35]. The small size of these companies allows for high specialization and strong flexibility, fostering supply chain competitiveness in a globalized market [66]. According to the industrial district literature, the problems related to the small size of Italian companies are balanced by strong networks throughout the value chain, which develops locally and is globally anchored [67], [68], [69], [70]. Indeed, the Italian fashion chain is deeply embedded within the territory and benefits from a local network of relationships, allowing smaller firms access to economies of specialization and scale and sufficiently large markets [67].

The Italian fashion system includes several firms operating in the leather, textile, eyewear, footwear, clothing, and jewelry industries [35]. In line with this sector composition, our sample considered firms operating in these industries, thus representing the Italian fashion system.

B. Method and Data Collection

To test our hypothesis, we implemented a survey focusing on the manufacturing fashion industry in the northern regions of Italy. We identified 1262 firms from the Italian section of the Bureau van Dijk database (AIDA) as our population. Data collection was conducted using a computer-assisted web interview survey [71] designed in collaboration with SMACT [72] (Observatory 4.0. for digitalization). The survey design process lasted from September to November 2021. To test the validity of the survey and verify the content and clarity of the items, we conducted two qualitative, in-depth interviews lasting between 60 and 90 min with two companies in the fashion industry. These interviews allowed us to collect other qualitative information, such as insights into their perception of external pressures for technology adoption. This feedback encouraged us to include other relevant stakeholders in the survey options, and refine the final version of the survey.

UniCredit Bank administered the survey, which was collected from December 2021 to January 2022. With an effective response rate of 15%, we obtained a sample of 189 firms. Of the responding firms, 38.6% belonged to the leather industry, 30.7% to clothing manufacturing, 14.8% to the textile industry, and 15.9% to other manufacturing fields, including jewelry and eyewear. The sample mirrors the industrial specialization of the fashion industry in the northeastern region. Moreover, by investigating the firm size in our sample, we observed that 30.7% were micro, 40.3% were small, 23.8% were medium, and 5.3% were large firms. This distribution mirrors the Italian market structure, in which SMEs represent around 99% of all firms [66].

In the final phase of our investigation, the survey results were compared in light of the literature and the concrete managerial needs and interpretations that had emerged during the exploratory phase. In particular, we triangulated the survey results with qualitative data collected through six interviews, each lasting about 90 min. Interviewees were encouraged to share their experiences and perspectives on how technologies enable sustainability in company processes through seven questions asked during the interviews. The focus was on the strategic role of data in terms of internal impacts, external collaborations with stakeholders, the evolving relationships with the company's supply chain, and the main challenges in transitioning to integrated models of digitization and sustainability.

In both the survey and the qualitative interviews, the respondents were business executives and top-level managers with a comprehensive understanding of the company's digital and sustainability-related practices. According to the survey, most

[5]European Commission, "Survey on the contribution of ICT to the environmental sustainability of actions of EU enterprises." https://commission.europa.eu/. Accessed: Dec. 20, 2023. [Online.] Available: https://digital-strategy.ec.europa.eu/en/library/survey-contribution-ict-environmental-sustainability-actions-eu-enterprises

[6]EY. ey.com. Accessed: Dec. 12, 2021. [Online.] Available: https://www.cdp.it/resources/cms/documents/Settore%20Moda%20e%20Covid-19.pdf

[7]EY. ey.com. Accessed: Dec. 12, 2021. [Online.] Available: https://www.cdp.it/resources/cms/documents/Settore%20Moda%20e%20Covid-19.pdf

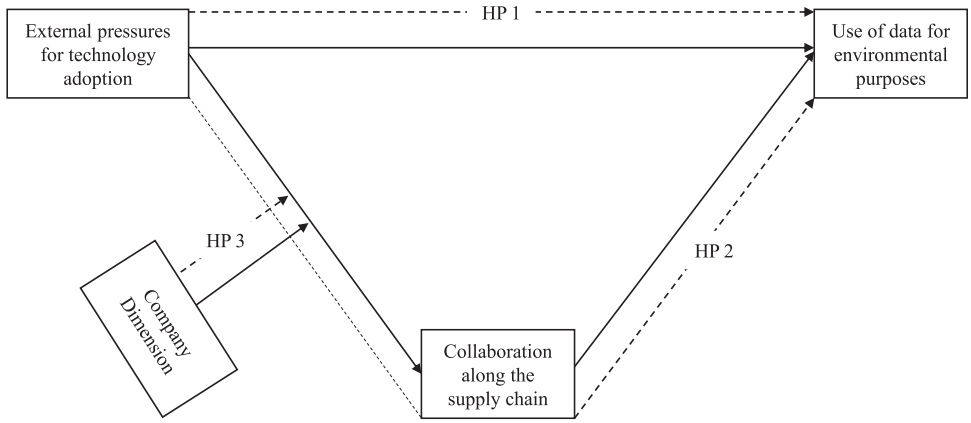

Fig. 1. Conceptual model. Notes. HP1, hypothesis 1; HP2, hypothesis 2; HP3, hypothesis 3.

participants were chief executive officers (63%), followed by chief operation officers (31%), chief information officers (4%), and chief sustainability officers (2%). Most participants were aged between 55 and 65 years (72%), and the second-largest age group was 45–54 years (18%). The researchers ensured participants' anonymity was safeguarded, and only aggregated data were used to adhere to privacy regulations.

C. Measures

Following Zhang and Li [72], the survey was developed in Italian, ensuring that the original meaning was preserved during the translation. A conceptual model was developed comprising the following four variables (see Fig. 1):

1) use of data for environmental purposes;
2) external pressures for technology adoption;
3) collaboration along the supply chain because of the adoption of digital technologies;
4) company dimension.

All perceptual measures were rated on a five-point Likert scale. For multi-item variables, the scores were calculated by averaging the items. Table I shows the variables employed in the model, representing a good fit of the data. We used SPSS (version 28) to conduct exploratory factor analysis; Table I reports the item loadings in brackets next to each item. Reliability was assessed using Cronbach's alpha and was found to be 0.75, which was above the commonly suggested threshold of 0.7 [74].

1) Dependent Variable: The dependent variable, the *use of data for environmental purposes* (PEP), was a single-item measure adapted from [75], [76], [77]. It assessed whether data collected by the company using digital technologies were used to increase its environmental sustainability.

In line with the literature (e.g., [78]), this item assessed whether employing digital technologies through company activities fosters environmental benefits. We asked respondents to rate their use of data for environmental purposes from (1) very low to (5) very high.

2) Independent Variable: We used four items to measure the *external pressures for technology adoption* (EPT). This variable assessed whether external stakeholders influence companies' adoption of digital technologies. This scale was adapted from Sarkis et al. [79]. Consistent with the literature (e.g., [45]), this variable focused on external pressures from customers, suppliers, supply chain partners, or policymakers to adopt new technologies. We asked respondents the extent to which technology adoption was stimulated as a result of 1) client requests, 2) supplier requests, 3) fiscal benefits or governmental incentives, or 4) supply chain projects. Respondents rated each external stakeholder pressure from (1) very low to (5) very high

The average score of these four items was used as a synthetic indicator to evaluate the external pressures for technology adoption.

3) Mediator: The mediator, *collaboration along the supply chain as a result of the adoption of digital technologies* (COL), was a single-item measure that captured the intensity of collaboration enhanced by digital tools between firms and their external stakeholders within the supply chain. In line with the literature (e.g., [52]), this variable focused on digital transformation as a potential enabler of business collaborations among firms. This scale was adapted from Crick [80] and Koufteros et al. [81].

4) Moderator: The *company dimension* was measured using respondents' turnover data (CD) from 2019 (year 2). This year was selected to minimize potential bias caused by the COVID-19 pandemic's effects on business performance. The moderator variable was categorized into three classes: micro–small enterprises, medium-sized enterprises, and large enterprises.

5) Control Variables: According to the previous literature [82], we controlled for *company age* (CA) (i.e., the number of years since founding).

IV. Results

The Pearson correlation matrix is presented in Table II. Almost all correlations between variables were lower than 0.33 and are, therefore, within acceptable limits. In addition, the Pearson correlation matrix, shows a relationship between EPT (independent variable) and PEP (dependent variable). Moreover, a significant correlation was found between COL and PEP. However, the presence of a multicollinearity effect was excluded [83].

TABLE I
VARIABLES EMPLOYED IN THE MODEL

Variable	Source	Scale Item (Item Loading)
Use of data for environmental purposes (PEP)	Adapted from Gadenne et al. [74], Godos-Díez et al. [75], and Perrini et al. [76]	Data collected by the company using digital technologies is used to increase the company's environmental sustainability
External pressures for technology adoption (EPT)	Adapted from Sarkis et al. [78]	Rate the extent to which your firm adopted digital and Industry 4.0 technology in terms of the following: 1. due to the client's requests (0.90) 2. due to the suppliers' requests (0.95) 3. due to the fiscal benefits or governmental incentives (0.79) 4. as part of supply chain projects (0.90)
Collaboration along the supply chain as a result of the adoption of digital technologies (COL)	Adapted from Crick [79] and Koufteros et al. [80]	The adoption of digital technologies increased the collaboration along the supply chain
Company dimension (CD)		Please indicate the company turnover in 2019: • • revenues were less than 2 million euros • • revenues from 2 to 10 million euros • • revenues from 10 to 50 million euros • • revenues from 50 to 100 million euros • • revenues were more than 100 million euros
Control: company age (CA) α of the model = 0.75		Please indicate your company age

To test Hypothesis 1, Hypothesis 2, and Hypothesis 3, we conducted an integrated moderated mediation analysis using model 7 [84] with external pressures for technology adoption as the independent variable (EPT), the company dimension (CD) as the moderator, collaboration along the supply chain (COL) as the mediator, and the use of data for environmental purposes (PEP) as the dependent variable.

To test Hypothesis 1 in this model, we verified the presence of a direct effect, i.e., between external pressures for technology adoption and the use of data for environmental purposes. Indeed, the effect of external pressures for technology adoption on the use of data for environmental purposes was enhanced by the mediator. Additionally, we excluded multicollinearity because the variance inflation factor value was lower than 3 [74]. However, to address potential multicollinearity, we mean-centered the mediator and moderator before creating the interaction terms. To test the conditional mediation effect, we employed the bootstrapping technique (5.000 times). Thus, we verified the significance of direct and indirect effects using mediation analysis and interaction effects using moderation analysis [84]. The mediating role of collaboration along the supply chain was confirmed. The results showed that the relationship between external pressures for technology adoption and collaboration along the supply chain was also positively moderated by the firm dimension. Thus, Hypothesis 2 and Hypothesis 3 were also accepted.

TABLE II
PEARSON CORRELATION MATRIX

	EPT	COL	CD	PEP
EPT	1			
COL	0.355**	1		
CD	– 0.171*	0.036*	1	
PEP	0.130	0.155*	0.093	1

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)
Notes. CD, company dimension; COL, collaboration along the supply chain as a result of the adoption of digital technologies; EPT, external pressures for technology adoption; PEP, use of data for environmental purposes.

TABLE III
MODERATION EFFECT

Mediator	Moderator			
	Condition	Effect (a)	SE	LLCI–ULCI
Collaboration along the supply chain as a result of the adoption of digital technologies	Low	0.99	0.16	[0.67–1.31]
	Middle	0.88	0.14	[0.61–1.15]
	High	0.64	0.17	[0.30–0.99]
p-value of the moderation effect = 0.08				
F = 3.11				
DF = 1				

Notes. DF, degrees of freedom; LLCI, lower limit confidence interval; SE, standard error; ULCI, upper limit confidence interval.

Table III shows the moderating effect of the company dimension on the relationship between EPT, COL, and PEP. As the size of the company (moderator) increased, the effect between external pressures for technology adoption and collaboration along the supply chain decreased. Smaller firms were more exposed to external stakeholder pressure to digitalize, tending to collaborate more than larger companies. Indeed, the effect between EPT and the level of COL was 0.99 for small companies, 0.88 for medium-sized companies, and 0.64 for larger companies (all significant).

Tables III and IV present the regression coefficients, standard errors (SEs), and lower and upper limit confidence intervals (ULCI, LLCI). Table IV reports the direct and indirect effects according to the level of company dimension. The table shows that the moderation effect reduced the indirect effect between external pressures for technology adoption (EPT) and the use of data for environmental purposes (PEP). Therefore, larger companies tend to collaborate less and appear less prone to employ data for environmental purposes. Conversely, smaller companies tend to collaborate more and become increasingly interested in using their data for environmental purposes when external pressures to adopt technologies increase.

Furthermore, Fig. 2 highlights that when external pressures for technology adoption is lower (between 1 and 1.5), larger enterprises have a higher collaboration along the supply chain than smaller firms. Conversely, when external pressures for technology adoption (EPT) is higher (between 2.5 and 3), company dimension has no effect because all companies converge to approximately the same (and very high) level of collaboration. Therefore, collaboration aimed at achieving greater environmental outcomes is important; regardless of company size, a high level of external pressure to adopt technologies increases the likelihood that companies employ data for environmental purposes. Eventually, we can also note that larger companies have a flatter growth than their smaller counterparts.

V. DISCUSSION

This study sheds light on the critical interplay between external pressures for technology adoption, interfirm collaboration, and company size in influencing the use of digital data

TABLE IV
MEDIATION EFFECT

Effect	Mediation			
	Moderation Effect	Effect	SE	LLCI–ULCI
Direct effect	0.35	0.06	0.18	[−0.01–0.71]
Indirect effects	Low	0.16	0.08	[−0.05–0.28]
	Middle	0.10	0.08	[−0.05–0.25]
	High	0.08	0.06	[−0.04–0.21]

Notes. LLCI, lower limit confidence interval; UCLI, upper limit confidence interval.

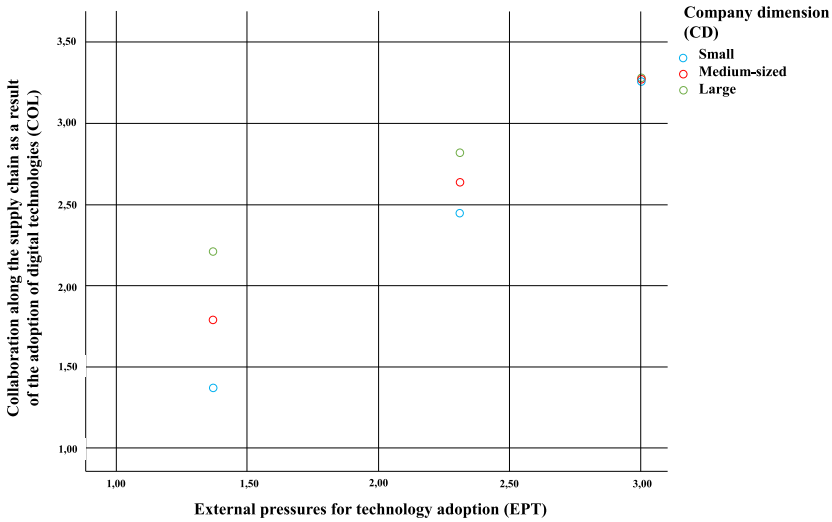

Fig. 2. Relationship between external pressures for the adoption of digital technologies and the use of digital data for environmental purposes is mediated by the level of interfirm collaboration—the moderating role of the company dimension.

for environmentally sustainable purposes. By focusing on the mediating role of collaboration and the moderating effect of firm size, the findings contribute to ongoing discussions on the sustainable development of our economy and its implications for the introduction of sustainable business practices.

The findings confirm that external pressures for technology adoption positively influence firms' propensity to use data for environmental purposes [6], [9], [44], [46], [47]. This finding reinforces the importance of regulatory frameworks, stakeholder expectations, and market competition as key drivers of sustainability-oriented digital transformation.

External pressures help firms recognize the value of digital technologies in reducing negative environmental externalities [14], aligning with prior studies emphasizing the importance of institutional and competitive pressures in fostering organizational change (e.g., [1]). Our findings specifically investigated the role of the value chain's external pressures over twin transitions [1], [43], [48]. These results, triangulated in light of the empirical managerial evidence gathered through qualitative interviews, suggest that regulatory bodies and policymakers should intensify efforts to create external incentives for the twin transition, such as sustainability mandates or financial support for digitalization, to ensure broader adoption across industries.

Even more interesting, our results underline the central role of collaboration along the supply chain in fostering the so-called twin transition. When external pressures increase, all companies demonstrate an elevated level of collaboration along the supply chain when they embark on sustainability-related practices. This evidence suggests that strong external pressures, such as regulatory mandates or market-driven incentives, can effectively override size-based differences in collaboration behavior, creating a unified push toward sustainability goals.

Interfirm collaboration emerged as a significant mediator in the relationship between external pressures and the use of digital data for environmental purposes. Collaboration allows firms to share resources, expertise, and best practices, addressing critical knowledge and resource gaps, particularly for SMEs. This finding aligns with previous research emphasizing the role of collaboration in sustainability outcomes, particularly in closed-loop supply chain management and resource optimization [18].

Notably, collaboration is essential for overcoming informational asymmetry and building collective knowledge, which is especially relevant for SMEs facing resource constraints. These findings suggest that fostering collaborative networks—both formal and informal—can enhance firms' ability to leverage digital data for sustainability goals. Policymakers and industry leaders should support initiatives that promote cross-sector collaboration, such as business ecosystems, consortia, and public–private partnerships, to accelerate the adoption of sustainability-focused digital practices.

The study provides new insights into the role of firm size in twin transitions, showing that as external pressures for technology adoption rise, smaller firms tend to increase their levels of collaboration along the supply chain more than larger ones to use data for environmental purposes [8]. Firm size significantly moderates the relationship between external pressures for technology adoption and interfirm collaboration. Smaller firms, which are also exposed to external stakeholder pressures, tend to collaborate more than larger firms when adopting digital technologies for sustainability-related purposes. This higher collaboration tendency reflects the critical role of external networks in helping SMEs overcome resource constraints, uncertainty, and knowledge gaps in their twin transition journey. These findings align with previous literature indicating the reliance of SMEs on geographic proximity, long-term partnerships, and vibrant stakeholder networks to navigate digital and green transitions [86].

Larger companies exhibit a flatter growth in collaboration than their smaller counterparts, suggesting that their established systems and hierarchical structures may limit the agility needed for deeper integration with external partners. This dynamic highlights the need for targeted policies and support mechanisms for SMEs to ensure they are not left behind in the twin transition.

From a managerial point of view, this work highlights the importance of interorganizational collaborations for companies aiming at entering a twin transition. In other words, companies need to collaborate with key value chain partners to optimize processes across different supply chain stages, driving large-scale twin transitions toward a more sustainable future.

By collaborating with their business partners and leveraging data and digital tools, companies can learn to collect and manage sustainable data along the supply chain. This will enable supply chain companies to answer external pressures by increasing their sustainability-related disclosure, improving compliance, and end-to-end tracking throughout the value chain.

In addition, and interestingly, this study supports the hypothesis that such need is stronger for SMEs. In this regard, this study encourages policymakers and institutions to invest in developing firms' digital culture and creating the conditions to favor companies' cooperation.

VI. Conclusion

There is growing interest in the potential support that digital solutions may provide to develop environmentally oriented behaviors and sustainability development outcomes in firms. By adopting an interorganizational perspective, which has been less investigated in the sustainable development literature [85], [86], this study paves the way for a comprehensive understanding of the twin transition, in which digital adoption combines with network (interorganizational) structures, transcending organizational boundaries to support sustainable businesses [32]. Like previous studies on the relationship between digital transformation and environmental sustainability, our findings show that increased supply chain collaborations, supported by adopting digital technologies, can promote a green transition of companies.

The present study enters this debate by testing three hypotheses. The first hypothesis aimed to investigate the role of external pressures on twin transitions. The second delved into the role of collaborative relationships along firms' value chains, and the third hypothesis explored the role of firm size. Our findings provide evidence of the moderating effect of firm size and the mediating role of collaborative relationships. This study also contributes research on the twin transition in the fashion industry, a high-polluting sector that demands more sustainable business practices [48].

The analyses did not account for the specific complex dynamics that may arise from the relationships between these two transitions. This limitation presents an opportunity for further in-depth investigations into the collaborative dynamics involved. Future research can also consider alternative research settings because testing our results in different national contexts characterized by different sociocultural elements and place-based specificities would be valuable. Moreover, this study could be further expanded by exploring whether different categories of stakeholders may be able to exert more pressure on companies' twin transitions. Finally, another relevant limitation is related to data; although we can claim correlation, we cannot detect causality.

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References

[1] S. Montresor and A. Vezzani, "Digital technologies and eco-innovation. Evidence of the twin transition from Italian firms," *Ind. Innov.*, vol. 30, no. 7, pp. 766–800, 2023.

[2] J. M. Müller et al., "Barriers and enablers for industry 4.0 in SMEs: A combined integration framework," *IEEE Trans. Eng. Manage.*, to be published.

[3] D. Ivanov, "Conceptualisation of a 7-element digital twin framework in supply chain and operations management," *Int. J. Prod. Res.*, vol. 62, no. 6, pp. 2220–2232, 2024.

[4] P. C. Kandarkar and V. Ravi, "Investigating the impact of smart manufacturing and interconnected emerging technologies in building smarter supply chains," *J. Manuf. Technol. Manage.*, vol. 35, no. 5, pp. 984–1009, 2024.

[5] A. Kuntsman and I. Rattle, "Towards a paradigmatic shift in sustainability studies: A systematic review of peer reviewed literature and future agenda setting to consider environmental (un)sustainability of digital communication," *Environ. Commun.*, vol. 13, no. 5, pp. 567–581, 2019.

[6] M. Ghobakhloo, M. Iranmanesh A. Grybauskas, M. Vilkas, and M. Petraitė, "Industry 4.0, innovation, and sustainable development: A systematic review and a roadmap to sustainable innovation," *Bus. Strat. Environ.*, vol. 30, no. 8, pp. 4237–4257, 2021.
[7] R. Sarc, A. Curtis, L. Kandlbauer, K. Khodier, K. E. Lorber, and R. Pomberger, "Digitalisation and intelligent robotics in value chain of circular economy oriented waste management—A review," *Waste Manage.*, vol. 95, pp. 476–492, 2019.
[8] D. M. Haftor, R. C. Climent, and J. E. Lundström, "How machine learning activates data network effects in business models: Theory advancement through an industrial case of promoting ecological sustainability," *J. Bus. Res.*, vol. 131, pp. 196–205, 2021.
[9] D. Antonioli, G. Cecere, and M. Mazzanti, "Information communication technologies and environmental innovations in firms: Joint adoptions and productivity effects," *J. Environ. Plan. Manage.*, vol. 61, no. 11, pp. 1905–1933, 2018.
[10] D. R. Krause, S. Vachon, and R. D. Klassen, "Special topic forum on sustainable supply chain management: Introduction and reflections on the role of purchasing management," *J. Supply Chain Manage.*, vol. 45, no. 4, pp. 18–25, 2009.
[11] L. Jraisat, A. Upadhyay, T. Ghalia, M. Jresseit, V. Kumar, and D. Sarpong, "Triads in sustainable supply-chain perspective: Why is a collaboration mechanism needed?," *Int. J. Prod. Res.*, vol. 61, no. 14, pp. 4725–4741, 2023.
[12] S. V. Matos, M. C. Schleper, J. K. Hall, C. M. Baum, S. Low, and B. K. Sovacool, "Beyond the new normal for sustainability: Transformative operations and supply chain management for negative emissions," *Int. J. Oper. Prod. Manage.*, vol. 44, no. 13, pp. 263–295, 2024.
[13] S. Guo and T. M. Choi, "Risk management for second-hand clothing imports in least developed countries: Legislations and perception of public-sector corruption," *Risk Anal.*, vol. 44, no. 1, pp. 108–125, 2024.
[14] D. Guo and S. Mantravadi, "The role of digital twins in lean supply chain management: Review and research directions," *Int. J. Prod. Res.*, 2024, pp. 1–22.
[15] J. Reyes, J. Mula, and M. Díaz-Madroñero, "Development of a conceptual model for lean supply chain planning in industry 4.0: Multidimensional analysis for operations management," *Prod. Plan. Control*, vol. 34, no. 12, pp. 1209–1224, 2023.
[16] A. Messeni Petruzzelli, G. Murgia, and A. Parmentola, "How can open innovation support SMEs in the adoption of I4.0 technologies? An empirical analysis," *R&D Manage.*, vol. 52, no. 4, pp. 615–632, 2022.
[17] L. M. Camarinha-Matos, H. Afsarmanesh, and X. Boucher, "The role of collaborative networks in sustainability," in *Proc. Work. Conf. Virtual Enterprises*, 2010, vol. 336, pp. 1–16.
[18] C. Ghisetti, A. Marzucchi, and S. Montresor, "The open eco-innovation mode. An empirical investigation of eleven European countries," *Res. Policy*, vol. 44, no. 5, pp. 1080–1093, 2015.
[19] A. Shevchenko, M. Lévesque, and M. Pagell, "Why firms delay reaching true sustainability," *J. Manage. Stud.*, vol. 53, no. 5, pp. 911–935, 2016.
[20] J. Frooman, "Stakeholder influence strategies," *Acad. Manage. Rev.*, vol. 24, no. 2, pp. 191–205, 1999.
[21] H. Hofmann, M. C. Schleper, and C. Blome, "Conflict minerals and supply chain due diligence: An exploratory study of multi-tier supply chains," *J. Bus. Ethics*, vol. 147, no. 1, pp. 115–141, 2018.
[22] T. M. Choi, Y. Li, and L. Xu, "Channel leadership, performance and coordination in closed loop supply chains," *Int. J. Prod. Econ.*, vol. 146, no. 1, pp. 371–380, 2013.
[23] J. E. Haddock-Fraser and M. Tourelle, "Corporate motivations for environmental sustainable development: Exploring the role of consumers in stakeholder engagement," *Bus. Strategic Environ.*, vol. 19, no. 8, pp. 527–542, 2010.
[24] G. C., K. F. Schmidt, and B. Schaltenbrand, "The supply chain position paradox: Green practices and firm performance," *J. Supply Chain Manage.*, vol. 53, no. 2, pp. 3–25, 2017.
[25] M. Pagell and Z. Wu, "Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars," *J. Supply Chain Manage.*, vol. 45, no. 2, pp. 37–56, 2009.
[26] P. Beske and S. Seuring, "Putting sustainability into supply chain management," *Supply Chain Manage.*, vol. 19, no. 3, pp. 322–331, 2014.
[27] J. Wolf, "The relationship between sustainable supply chain management, stakeholder pressure and corporate sustainability performance," *J. Bus. Ethics*, vol. 119, pp. 317–328, 2014.
[28] F. T. S. Chan and K. Ding, "Industrial intelligence-driven production and operations management," *Int. J. Prod. Res.*, vol. 61, no. 13, pp. 4215–4219, 2023.
[29] P. Kouvelis, C. Chambers, and H. Wang, "Supply chain management research and production and operations management: Review, trends, and opportunities," *Prod. Oper. Manage.*, vol. 15, no. 3, pp. 449–469, 2006.
[30] A. A. Tsay, J. V. Gray, I. J. Noh, and J. T. Mahoney, "A review of production and operations management research on outsourcing in supply chains: Implications for the theory of the firm," *Prod. Oper. Manage.*, vol. 27, no. 7, pp. 1177–1220, 2018.
[31] Ø. D. Fjeldstad, C. C. Snow, R. E. Miles, and C. Lettl, "The architecture of collaboration," *Strategic Manage. J.*, vol. 33, no. 6, pp. 734–750, 2012.
[32] K. Lyytinen, Y. Yoo, and R. J. Boland Jr., "Digital product innovation within four classes of innovation networks," *Inf. Syst. J.*, vol. 26, no. 1, pp. 47–75, 2016.
[33] J. Ukko, M. Nasiri, M. Saunila, and T. Rantala, "Sustainability strategy as a moderator in the relationship between digital business strategy and financial performance," *J. Cleaner Prod.*, vol. 236, 2019, Art. no. 117626.
[34] B. Chae, H. J. R. Yen, and C. Sheu, "Information technology and supply chain collaboration: Moderating effects of existing relationships between partners," *IEEE Trans. Eng. Manage.*, vol. 52, no. 4, pp. 440–448, Nov. 2005.
[35] L. Macchion, A. Moretto, F. Caniato, M. Caridi, P. Danese, and A. Vinelli, "Production and supply network strategies within the fashion industry," *Int. J. Prod. Econ.*, vol. 163, no. C, pp. 173–188, 2015.
[36] A. B. L. De Sousa Jabbour, C. J. C. Jabbour, C. Foropon, and M. Godinho Filho, "When titans meet—Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors," *Technol. Forecasting Social Change*, vol. 132, no. C, pp. 18–25, 2018.
[37] W. Steffen et al., "Planetary boundaries: Guiding human development on a changing planet," *Science*, vol. 347, 2015, Art. no. 1259855.
[38] M. Bellandi and E. Santini, "Place leadership in emerging product-service systems," *Int. J. Bus. Environ.*, vol. 11, no. 3, pp. 321–335, 2020.
[39] E. Cassetta, U. Monarca, I. Dileo, C. Di Berardino, and M. Pini, "The relationship between digital technologies and internationalization. Evidence from Italian SMEs," *Ind. Innov.*, vol. 27, no. 4, pp. 311–339, 2020.
[40] A. Bharadwaj, O. A. El Sawy, P. A. Pavlou, and N. Venkatraman, "Digital business strategy: Toward a next generation of insights," *MIS Quart.*, vol. 37, no. 2, pp. 471–482, 2013.
[41] J. Karimi and Z. Walter, "The role of dynamic capabilities in responding to digital disruption: A factor-based study of the newspaper industry," *J. Manag. Inf. Syst.*, vol. 32, no. 1, pp. 39–81, 2015.
[42] G. Vial, "Understanding digital transformation: A review and a research agenda," *J. Strat. Inf. Syst.*, vol. 28, no. 2, pp. 118–144, 2019.
[43] Y. Li, J. Dai, and L. Cui, "The impact of digital technologies on economic and environmental performance in the context of industry 4.0: A moderated mediation model," *Int. J. Prod. Econ.*, vol. 229, 2020, Art. no. 107777.
[44] I. Guandalini, "Sustainability through digital transformation: A systematic literature review for research guidance," *J. Bus. Res.*, vol. 148, pp. 456–471, 2022.
[45] C. Martinez-Fernandez and P. Braun, "Regional connectivity & virtual clustering: Networking SMEs for competitive advantage," in *Proc. Conf. Lett. 5th Glob. Competitiveness Inst. Conf.*, Oct. 2002, pp. 18–22.
[46] S. Gupta, R. Meissonier, V. A. Drave, and D. Roubaud, "Examining the impact of Cloud ERP on sustainable performance: A dynamic capability view," *Int. J. Inf. Manage.*, vol. 51, 2020, Art. no. 102028.
[47] W. El Hilali, A. El Manouar, and M. A. Janati Idrissi, "Reaching sustainability during a digital transformation: A PLS approach," *Int. J. Innov. Sci.*, vol. 12, no. 1, pp. 52–79, 2020.
[48] R. Ferlito, "Industry 4.0 and sustainability: The case of the Italian textile district of Prato," *Compet. Rev.*, vol. 34, no. 5, pp. 995–1016, 2024.
[49] D. T. Wong and E. W. Ngai, "An empirical analysis of the effect of supply chain innovation on supply chain resilience," *IEEE Trans. Eng. Manage.*, vol. 71, pp. 8562–8576, 2024.
[50] S. Nambisan, "Information technology and product/service innovation: A brief assessment and some suggestions for future research," *J. Assoc. Inf. Syst.*, vol. 14, no. 4, pp. 215–226, 2013.
[51] M. G. Jacobides, C. Cennamo, and A. Gawer, "Towards a theory of ecosystems," *Strategic Manage. J.*, vol. 39, no. 8, pp. 2255–2276, 2018.
[52] J. Ramezani and L. M. Camarinha-Matos, "Approaches for resilience and antifragility in collaborative business ecosystems," *Technol. Forecasting Soc. Change*, vol. 151, 2020, Art. no. 119846.
[53] G. Cainelli, M. Mazzanti, and R. Zoboli, "Environmental innovations, complementarity and local/global cooperation: Evidence from North-East Italian industry," *Int. J. Technol. Policy Manage.*, vol. 11, no. 3/4, pp. 328–368, 2011.

[54] N. Omrani, N. Rejeb, A. Maalaoui, M. Dabić, and S. Kraus, "Drivers of digital transformation in SMEs," *IEEE Trans. Eng. Manage.*, vol. 71, pp. 5030–5043, 2024.
[55] G. Berlingieri, S. Calligaris, C. Criscuolo, and R. Verlhac, "Laggard firms, technology diffusion and its structural and policy determinants," *OECD STI Policy*, Mar. 2020, Paper 86.
[56] V. Scuotto, M. Del Giudice, S. Bresciani, and D. Meissner, "Knowledge-driven preferences in informal inbound open innovation modes. An explorative view on small to medium enterprises," *J. Knowl. Manage.*, vol. 21, no. 3, pp. 640–655, 2017.
[57] R. Eller, P. Alford, A. Kallmünzer, and M. Peters, "Antecedents, consequences, and challenges of small and medium-sized enterprise digitalization," *J. Bus. Res.*, vol. 112, no. C, pp. 119–127, 2020.
[58] S. Sharma and I. Henriques, "Stakeholder influences on sustainability practices in the Canadian forest products industry," *Strat. Manage. J.*, vol. 26, no. 2, pp. 159–180, 2005.
[59] L. Oxborrow and C. Brindley, "Adoption of 'eco-advantage' by SMEs: Emerging opportunities and constraints," *Eur. J. Innov. Manage.*, vol. 16, no. 3, pp. 355–375, 2013.
[60] G. Valenza, A. Zoppelletto, and G. Fazio, "Family SMEs and managerial approaches to sustainability in the blue economy," *J. Manage. Org.*, vol. 30, no. 3, pp. 1–24, 2023.
[61] F. Bartolacci, A. Caputo, and M. Soverchia, "Sustainability and financial performance of small and medium sized enterprises: A bibliometric and systematic literature review," *Bus. Strategy Environ.*, vol. 29, no. 3, pp. 1297–1309, 2020.
[62] L. Eon-Kyung, H. Sungdo, and K. Sheung-Kow, "Supplier selection and management system considering relationships in supply chain management," *IEEE Trans. Eng. Manage.*, vol. 48, no. 3, pp. 307–318, Aug. 2001.
[63] S. Guo, X. Sun, and H. K. S. Lam, "Applications of blockchain technology in sustainable fashion supply chains: Operational transparency and environmental efforts," *IEEE Trans. Eng. Manage.*, vol. 70, no. 4, pp. 1312–1328, Apr. 2023.
[64] P. Bertola and J. Teunissen, "Fashion 4.0. Innovating fashion industry through digital transformation," *Res. J. Text. Appar.*, vol. 22, no. 4, pp. 352–369, 2018.
[65] L. Berra, L. Piatti, and G. Vitali, "The internationalization process in the small and medium sized firms: A case study on the Italian clothing industry," *Small Bus. Econ.*, vol. 7, no. 1, pp. 67–75, 1995.
[66] M. J. Piore and C. F. Sabel, *The Second Industrial Divide: Possibilities for Prosperity*. New York, NY, USA: Basic Books, 1986.
[67] G. Becattini, M. Bellandi, and L. De Propris, Eds., *A Handbook of Industrial Districts*. Cheltenham, U.K.: Edward Elgar Publishing, 2014.
[68] I. De Noni, L. Orsi, and F. Belussi, "The role of collaborative networks in supporting the innovation performances of lagging-behind European regions," *Res. Policy*, vol. 47, no. 1, pp. 1–13, 2018.
[69] E. Giuliani and M. Bell, "The micro-determinants of meso-level learning and innovation: Evidence from a Chilean wine cluster," *Res. Policy*, vol. 34, no. 1, pp. 47–68, 2005.
[70] A. Venkatraman, "Digital business strategy: Toward a next generation of insights," *MIS Quart.*, vol. 37, no. 1, pp. 47–68, 2005.
[71] K. Braunsberger, H. Wybenga, and R. Gates, "A comparison of reliability between telephone and web-based surveys," *J. Bus. Res.*, vol. 60, no. 7, pp. 758–764, 2007.
[72] SMACT, "Osservatorio 4.0," 2020. [Online]. Available: https://www.smact.cc/. [Online]. Available: https://www.smact.cc/osservatorio
[73] Y. Zhang and H. Li, "Innovation search of new ventures in a technology cluster: The role of ties with service intermediaries," *Strat. Manage. J.*, vol. 31, no. 1, pp. 88–109, 2010.
[74] J. F. Hair, W. C. Black, B. J. Babin, and R. E. Anderson, *Multivariate Data Analysis*, 7th ed. London, U.K.: Pearson Educ., 2010.
[75] D. L. Gadenne, J. Kennedy, and C. McKeiver, "An empirical study of environmental awareness and practices in SMEs," *J. Bus. Ethics*, vol. 84, no. 1, pp. 45–63, 2009.
[76] J. L. Godos-Díez, R. Fernández-Gago, and A. Martínez-Campillo, "How important are CEOs to CSR practices? An analysis of the mediating effect of the perceived role of ethics and social responsibility," *J. Bus. Ethics*, vol. 98, no. 4, pp. 531–548, 2011.
[77] F. Perrini, S. Castaldo, N. Misani, and A. Tencati, "The impact of corporate social responsibility associations on trust in organic products marketed by mainstream retailers: A study of Italian consumers," *Bus. Strategy Environ.*, vol. 19, no. 8, pp. 512–526, 2010.
[78] A. Chiarini, V. Belvedere, and A. Grando, "Industry 4.0 strategies and technological developments. An exploratory research from Italian manufacturing companies," *Prod. Plan. Control*, vol. 31, no. 16, 2020.
[79] J. Sarkis, P. Gonzalez-Torre, and B. Adenso-Diaz, "Stakeholder pressure and the adoption of environmental practices: The mediating effect of training," *J. Oper. Manage.*, vol. 28, no. 2, pp. 163–176, 2010.
[80] M. J. Crick, "The dark side of coopetition: When collaborating with competitors is harmful for company performance," *J. Bus. Ind. Market.*, vol. 35, no. 2, pp. 318–337, 2020.
[81] X. Koufteros, M. Vonderembse, and J. Jayaram, "Internal and external integration for product development: The contingency effects of uncertainty, equivocality, and platform strategy," *Decis. Sci.*, vol. 36, no. 1, pp. 97–133, 2005.
[82] S. H. Hanks, C. J. Watson, E. Jansen, and G. N. Chandler, "Tightening the life cycle construct: A taxonomic study of growth stage configurations," *Entrepreneurship Theory Pract.*, vol. 18, no. 2, pp. 5–29, 1994.
[83] R. Grewal, J. A. Cote, and H. Baumgartner, "Multicollinearity and measurement error in structural equation models: Implications for theory testing," *Market. Sci.*, vol. 23, no. 4, pp. 519–529, 2004.
[84] A. F. Hayes, *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*, 2nd ed. New York, NY, USA: Guilford Press, 2017.
[85] T. Dyllick and K. Muff, "Clarifying the meaning of sustainable business: Introducing a typology from business-as-usual to true business sustainability," *Org. Environ.*, vol. 29, no. 2, pp. 156–174, 2016.
[86] P. Cooke, M. G. Uranga, and G. Etxebarria, "Regional innovation systems: Institutional and organisational dimensions," *Res. Policy*, vol. 26, no. 4/5, pp. 475–491, 1997.
[87] S. G. Azevedo, H. Carvalho, S. Duarte, and V. Cruz-Machado, "Influence of green and lean upstream supply chain management practices on business sustainability," *IEEE Trans. Eng. Manage.*, vol. 59, no. 4, pp. 753–765, Nov. 2012.
[88] A. Zoppelletto, "Digital transformation and organizational sustainability: A multi-level analysis," Univ. Trento, 2024. [Online]. Available: https://dx.doi.org/10.15168/11572_407590

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