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Navigating the supply chain environmental sustainability: The moderating role of digitalization in driving supply chain efficiency on circular economy performance

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Abstract

Within the framework of supply chain sustainability, the significance of circular economy (CE) from a supply chain management (SCM) perspective has garnered increasing attention. However, it is unclear how traditional supply chain efficiency (SCE) strategies might facilitate CE development amid digitalization, nor how digital transformation (DT) moderates this link. This prompts an intriguing inquiry into these understudied areas. Our study delves into the impact of SCE on CE development through the dynamic capabilities (DC) framework. Given that DT has emerged as a crucial capability for both SCM and CE transitions, we investigate its moderating role in this context. Economic feasibility is also taken into account to evaluate the practical viability of the proposed strategies. Utilizing text analysis, we obtain DT indicators from corporate annual reports and supplementary data sourced from the Chinese Research Data Services Platform (CNRDS) and the China Stock Market and Accounting Research (CSMAR). We conduct panel data regressions on a sample of 4,248 firm-year observations. Our findings reveal a positive correlation between SCE and CE development, which is further bolstered by DT. In the economic feasibility analysis, we unexpectedly observe a negligible impact of DT on the relationship between SCE and financial performance (FP), contrasting with its notable effect in the CE context. These insights contribute to our understanding of the SCM-CE nexus in the supply chain sustainability community. For nascent CE transitions, firms can harness their existing SCM capabilities by optimizing SCE, offering a cost-effective pathway to CE development. Although the influence of DT on the link between SCE and FP awaits further validation, its unmistakable and advantageous role in the CE context provides a compelling rationale for managers to prioritize CE development in the era of supply chain digitalization and SCM advancement.

Keywords: dynamic capabilities; digital transformation; supply chain efficiency; circular economy; financial performance

Article classification: Research paper

1 Introduction

The concept of the circular economy (CE) has emerged as a pivotal strategy to tackle the pressing issues of environmental pollution and global warming, which are rooted in traditional economic growth models (Geng et al., 2019). As these environmental issues grow more acute, CE is gaining increasing attention and significance in the global discourse (Bag et al., 2022). CE embodies a robust and enduring model of production and consumption, centered on the "reduce, reuse, recycle" (3R) principles to minimize resource waste and environmental pollution throughout the supply chain life cycle (Bag et al., 2022; Geng et al., 2019). By implementing a closed-loop production framework, drawing inspiration from nature's ability to minimize waste, CE seeks to rectify the structural inefficiencies inherent in the conventional linear approach to production and consumption activities (Su et al., 2013; De Angelis et al., 2018). The integration of CE principles into corporate production and operational frameworks can significantly optimize resource efficiency, minimize waste production, and facilitate the development of innovative revenue models, thereby driving the evolution of strategic business practices (Lu et al., 2024; Yuan and Pan, 2023). In essence, CE provides enterprises with a pathway to reconcile economic performance with environmental responsibility, and is increasingly regarded as a transformative business paradigm capable of advancing the broader agenda of sustainable development (De Angelis et al., 2018; Lu et al., 2024).

The contemporary industrial environment faces complex challenges such as volatile resource prices, strict decarbonization regulations (Caiado et al., 2019), increased stakeholder demands (Schmidt et al., 2021), and global supply chain disruptions (Triguero et al., 2022). These pressures have prompted enterprises to rethink their strategies and prioritize sustainability. In light of the growing emphasis on sustainable development, enterprises are increasingly prioritizing the harmonization and enhancement of resource flows within their supply chain management (SCM) frameworks to align with CE objectives (Del et al., 2020; Lu et al., 2024). Khedr and S (2024) argued that SCM involves a variety of integrated methodologies aimed at optimizing resource distribution, cutting costs, and fulfilling customer demands. According to the dynamic capabilities (DC) theory, which suggests that a company's sustained competitive advantage hinges on its capacity to integrate, construct, and reconfigure both internal and external resources to adjust to shifts in the environment

(Teece and Pisano, 1994; Teece et al., 1997), SCM constitutes a pivotal aspect of DC, particularly in its emphasis on integrating resources to enhance corporate performance. However, the escalating frequency and intricacy of interactions among supply chain nodes may lead to heightened energy consumption and carbon emissions (Schultz et al., 2021). To support the transition toward CE, enterprises must deploy strategies that mitigate environmental impacts and promote the ecological evolution of the supply chain. Supply chain efficiency (SCE) has emerged as a fundamental metric for evaluating SCM performance (Belhadi et al., 2022). Nevertheless, it remains unclear whether enterprises that focus on improving SCE, a traditional and essential means of enhancing SCM capacity, can leverage SCE to bolster their CE performance. Clarifying this relationship is critical for managers aiming to balance operational efficiency with sustainability goals, as it can inform resource allocation, process optimization, and strategic decision-making in SCM. Therefore, our first research question is: Can enterprises' SCE enhance CE performance?

To facilitate the development of CE, enterprises must gather, process, and apply relevant information to effectively implement anticipated changes in their operations (Hasan et al., 2024). In the contemporary era, digital technologies have become key enablers of operational transformation (Bai and Sarkis, 2017; Ghobakhloo et al., 2025). The process of digital transformation (DT) necessitates enterprises leveraging the capabilities of digital technology to drive transformation and innovation in their production and service delivery processes (Fitzgerald et al., 2014). Although previous research has argued for the application of DT in SCM practices to enhance production and operational efficiency (Enrique et al., 2022; Zhao et al., 2023), empirical analysis exploring the moderating influence of DT on the relationship between SCE and CE performance remains limited. By clarifying how DT influences the link between SCE and CE, enterprises can develop more targeted strategies to balance operational efficiency with environmental responsibility, thereby improving long-term competitive advantage and resilience. Therefore, our second research question is: What is the impact of DT on the relationship between SCE and enterprises' CE performance?

While enterprises are increasingly committing to sustainable development initiatives, it is important to acknowledge that profitability remains a core strategic objective for most firms (Zopounidis and Lemonakis, 2024). As such, when adjusting strategies and operational models to align

with CE principles, firms inevitably evaluate the financial implications of such transitions. Operating in a complex ecosystem where environmental and economic objectives are often intertwined may lead to conflicts between these goals (Feng et al., 2024). Pursuing CE often entails substantial upfront investments, technological upgrades, workforce retraining, and restructuring of existing production in the short term, which places financial pressure on firms. Unilever has acknowledged that its sustainability initiatives have incurred substantial short-term costs, even though they are expected to deliver long-term value.[1] By further examining financial performance (FP), which is measured by indicators such as return on assets (ROA) to reflect a firm's ability to generate profits from its operations (Simin Chen et al., 2023), this study investigates whether DT-driven improvements in SCE can achieve a "win-win" situation of advancing environmental goals without compromising profitability, or whether there is a trade-off between these priorities. In light of economic feasibility, this study raises the following two questions as part of our third and fourth research questions: Can enterprises' SCE enhance FP? What is the impact of DT on the relationship between SCE and enterprises' FP?

To examine these potential impacts, we analyze data from Chinese A-share listed companies over the period from 2017 to 2022. To measure SCE, we adopt the inventory turnover ratio (ITR), a widely used proxy for SCE that reflects how efficiently a firm converts inventory into sales (Lin, 2023; Lo et al., 2009). Meanwhile, DT is evaluated through the text recognition function of a Python web scraper and the "search-pair-sum" methodology devised by Buehlmaier and Whited (2018). CE data and other variables are sourced from the China Stock Market and Accounting Research (CSMAR) and the Chinese Research Data Services Platform (CNRDS), both of which are esteemed research databases specializing in Chinese enterprises. Our empirical findings emphasize a strong and beneficial effect of SCE on CE. DT amplifies the positive correlation between SCE and CE. Intriguingly, when examining the impact on FP, we discover a negligible moderating role of DT in the relationship between SCE and FP. By contrast, our study underscores a clear impact of DT within the CE context.

This study contributes to the literature on DC theory and corporate sustainability in the context

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[1] https://www.supplychaindive.com/news/unilever-supplier-sustainability-costs-savings/595388/

of sustainable development reform in three key ways. First, we conceptualize SCE and DT as two distinct forms of DC: SCE reflects a firm's capacity to integrate and coordinate resources, while DT embodies its ability to sense and adapt through technological innovation and information integration. This dual-capability framework provides a novel theoretical lens for understanding how firms enhance their performance through the interaction of SCE and DT. Second, we develop an interaction-based DC framework and systematically investigate how DT moderates the relationship between SCE and related performance outcomes. Our findings reveal the synergistic mechanism through which SCE and DT jointly drive the achievement of CE goals and further extend the analysis to traditional FP, broadening and deepening the understanding of multi-dimensional performance dynamics. Third, this study advances the measurement of DT by combining firm-level textual analysis with keyword expansion based on national digital policy documents, thereby enhancing the accuracy and policy relevance of DT indicators for future research.

The remainder of this paper is organized as follows: Section 2 introduces the theoretical foundations of SCE, CE, DT, and DC, and provides a literature review of related research. Based on the findings from the literature, hypotheses are proposed in Section 3. Section 4 outlines the research design, including sample selection criteria, methodologies for variable measurement, and the specification of the analytical framework. Section 5 presents the empirical results derived from the analysis. Section 6 discusses the theoretical implications and practical insights derived from the findings. Lastly, Section 7 concludes the study with a summary and outlines directions for future research.

2   Literature review

2.1 Supply chain efficiency

SCE refers to the seamless operation of the entire product lifecycle from design, procurement, production, warehousing, and logistics to transaction and after-sales within a network of division of labor and collaboration (Liao et al., 2024; Lo et al., 2009). Centered on customer demand, it is achieved by optimizing information flow, resource allocation, and business coordination among enterprises. It manifests as increased dialogue frequency and closer trade ties between enterprises (Li et al., 2025;

Zhong et al., 2024), by reducing information asymmetry, breaking down process barriers, and minimizing redundant consumption to ensure the continuous and smooth circulation of products and services (Liao et al., 2024). This enables precise alignment with market demand and rapid response to demand fluctuations with minimal time, cost, and resource investment (Li et al., 2025).

This efficiency relies on dynamic coordination between supply and demand, in which upstream enterprises flexibly adjust production capacity and supply rhythms based on real-time demand signals, while downstream enterprises must accurately convey market feedback to guide production and inventory decisions (Liao et al., 2024; Wei et al., 2024). Through collaborative optimization, they avoid discrepancies between pre-production capacity planning and post-production actual market demand and operational levels (Khedr and S, 2024). This approach effectively reduces inventory backlogs, waiting times, and resource wastage, safeguarding operational efficiency for individual enterprises while enhancing the risk resilience and market competitiveness of the entire industrial chain (Dalal et al., 2024). Ultimately, it enables value co-creation and sustainable operations across all supply chain segments.

2.2 Circular economy

Emerging as a pivotal business model, CE holds the potential to significantly propel sustainable development and foster a harmonious society (Su et al., 2013). CE is primarily articulated through three key principles outlined in the literature: reduction, reuse, and recycling (Geng et al., 2019). These principles constitute an economic growth model characterized by efficient resource utilization and recycling (Lu et al., 2024). The reduction principle underscores the importance of minimizing resource use and waste generation by optimizing the efficiency of production and consumption processes (Ghisellini et al., 2016). The reuse principle suggests that any product or component not deemed waste should be repurposed for its original intended use, thereby conserving resources (Castellani et al., 2015). The recycling principle converts discarded materials into new products or substances, thereby promoting CE practices (Ghisellini et al., 2016). These renewable resources can be reintroduced into the market, either maintaining their original use or or repurposed for new applications.

By incorporating CE principles, enterprises can refine their operational strategies and advance

sustainable practices (De Angelis, 2021; Geng et al., 2019). The implementation of CE through SCE strategies can effectively address resource wastage and environmental contamination, strengthen corporate competitiveness, and fulfill social responsibilities (De Angelis, 2021; Lu et al., 2024). CE has been explored from various perspectives and, in some cases, has been used to investigate the sustainability of firms (Ghisellini et al., 2016).

2.3 **Digital transformation**

The definition of DT proposed by Fitzgerald et al. (2014) has been widely recognized. It refers to a dynamic reform process that carries out systematic reconstruction and iterative upgrading of an organization's operation mode, management system, value creation mechanism, and industrial collaboration relationships against the backdrop of digital technology innovation and the reconstruction of global industrial value networks (Zhai et al., 2022). This process goes beyond the scope of superficial optimization in traditional technology application, takes data-driven as its core, and achieves the efficient flow of information resources, precise allocation of value elements, and in-depth collaboration in business links by breaking down internal and external data silos of the organization, thereby promoting the organization to transform from the traditional linear operation mode to an agile, intelligent, and ecological digital operation mode (Warner and Wäger, 2019).

Through the systematic integration of technologies and reconstruction of modes, DT effectively addresses issues in the traditional operation of organizations (Zhong et al., 2024). It realizes the precise control of operating costs, the innovative upgrading of businesses, and the significant improvement of market response capabilities (Vial, 2019). Ultimately, it enables organizations to build sustainable competitive advantages in the digital economy environment (Zhai et al., 2022), while promoting the optimization of the industrial division of labor system and the leapfrog development of the overall industrial digitalization level, thus providing support for the high-quality development of industries in the digital economy era.

2.4 **Dynamic Capabilities theory**

The resource-based view (RBV) posits that firms can achieve sustainable competitive advantage and

generate economic returns by acquiring and developing valuable, rare, imperfectly imitable, and non-substitutable assets (Barney, 1986; Dierickx and Cool, 1989). However, RBV has been criticized for its static nature and limited ability to explain how firms respond to rapid change and environmental uncertainty. This static limitation is particularly prominent in the context of CE and SCE research, where dynamic adjustments to resource loops and inter-organizational coordination are critical. In response to these limitations, Teece and Pisano (1994) introduced the concept of DC theory derived from RBV to explain how firms acquire and sustain competitive advantage. DC theory emphasizes product innovation and organizational adaptation through resource renewal and capability reconfiguration. Teece et al. (1997) proposed the ideas of internal replicability and external inimitability as responses to environmental change. Eisenhardt and Martin (2000) argued that while DC can bring competitive advantage, it may not be sustainable in fast-paced markets, emphasizing the role of learning mechanisms and resource reconfiguration. Zollo and Winter (2002) highlighted that DC involves enhancing existing value-generating activities through standardization and investment. Teece (2007) refined the framework by dividing DC into three key components: sensing opportunities, seizing them, and managing threats and transformations. According to the measurement model of DC proposed by Pavlou and El Sawy (2011), DC encompasses four key capabilities: sensing the environment, learning, coordinating, and integrating. In today's highly competitive environment, firms must develop strong adaptability by effectively deploying DC to sustain competitive advantages (Komkowski et al., 2023).

2.5 Literature analysis and research gaps

Existing studies mainly verified the independent impacts of supply chain-related capabilities or DT on corporate performance while neglecting the synergistic interaction between the two as dual capabilities. Wong et al. (2021) and Liu (2023) respectively analyzed the impact of supply chain-related capabilities and DT on operational and environmental performance, yet they did not link SCE with DT as interactive DC capabilities. Yuan and Pan (2023) and Meng et al. (2023) explored the mediating role of SCM in the impact of DT on CE, but only discussed the sequential transmission relationship between the two rather than their mutual interaction and joint effect. This study differs from previous

research by clearly categorizing SCE and DT into two functional dimensions of DC and constructing an interaction framework, filling the gap of insufficient systematic classification and interactive analysis of dual DC capabilities in existing literature.

Most prior research either focused on the impact of supply chain-related or DT on FP alone examining how DT reduces costs and improves operational efficiency to boost corporate performance (e.g., Wong et al., 2021; Yuan and Pan, 2023; Zhai et al., 2022) or centered on environmental performance (e.g., Bai et al., 2022; De Angelis et al., 2018; Govindan, 2023; Song et al., 2024). Even though Wong et al. (2021) mentioned that strong SCI can simultaneously reduce costs, increase revenue, and reduce greenhouse gas emissions, it only provided preliminary observational findings without systematically constructing a theoretical framework to analyze the joint driving mechanism of relevant capabilities on dual performance. This lack of research on the joint impact of relevant capabilities on dual performance leaves a gap in understanding the synergistic improvement path of corporate financial and environmental performance.

This study fills the above gaps by defining SCE and DT as two functional dimensions of DC with distinct attributes, constructing a two-dimensional DC interaction framework to analyze their synergy, and examining the joint impact of the two capabilities on CE and FP, which complements the limitations of previous research focusing on independent effects or single-dimensional DC analysis. **Table 1** summarizes the key differences between this study and prior related studies to highlight the research gaps and our contributions.

3 Hypotheses development

3.1 Supply chain efficiency and circular economy performance

The performance benefits of SCE are realized through mechanisms of DC development, particularly those related to integration and collaboration capabilities, as outlined in the framework of Pavlou and El Sawy (2011). Internal resource integration capability has a core impact on CE, mainly in promoting closed-loop resource utilization and minimizing environmental footprint (Velenturf and Purnell, 2021). Through improved production processes, inventory management, and resource allocation, firms can optimize material and energy efficiency, lower excess inventory, minimize waste, and reduce carbon

emissions—thus mitigating the environmental impact of their operations (Zhao et al., 2023). External coordination refers to the extent to which an organization establishes strategic partnerships with its suppliers and customers, integrating interorganizational strategies and operations into a cohesive and mutually reinforcing process (Chen et al., 2017; Chen and Yu, 2022). By deepening strategic collaboration with suppliers and customers, firms can jointly develop reuse, remanufacturing, and material recovery processes across organizational boundaries, thus establishing resource circulation networks that significantly advance CE outcomes (Bai et al., 2020). The core mechanism lies in facilitating resource flows across product life cycles while systematically mitigating environmental impacts. Integrated upstream–downstream collaboration fosters the formation of closed-loop supply chains, ensuring the effective reintegration of discarded materials into production processes and reducing resource intensity and waste generation through the value chain (Chen et al., 2017). Together, these DC-based mechanisms demonstrate that SCE exerts a positive influence on CE performance by activating internal resource integration and external coordination capabilities. In light of these insights, this study proposes the following hypothesis:

H1: SCE is positively associated with CE performance.

3.2 The moderating effect of digital transformation

Rooted in the DC theoretical framework proposed by Teece et al. (1997), DC serves as a crucial transformational mechanism linking a firm's resource base to performance outcomes, moderating the conversion of resources into sustainable competitive advantages (Efrat et al., 2018) and playing a key moderating role between operational capability and firm performance (Barreto, 2010; Teece et al., 1997) which is particularly prominent in the context of DT (Wu, 2007). DC is strengthened by digital technologies enabling companies to optimize resource allocation and more effectively seize market opportunities (Ghobakhloo et al., 2025). DT capabilities enhance the sensing and learning dimensions of DC, thereby reconfiguring the pathways through which enterprises achieve competitive advantage via technological empowerment (Komkowski et al., 2023; Matarazzo et al., 2021; Yuan and Pan, 2023). Specifically, through digitization, enterprises can achieve continuous surveillance of supply chain processes through instantaneous data acquisition at each node of the supply chain, and identify

resource wastage, production pollution, or other environmental problems in the supply chain promptly (Alkaraan et al., 2022). This fine-grained sensing capability enables enterprises to dynamically adapt to evolving market conditions and environmental fluctuations, and optimize resource allocation based on data-driven decision-making to improve production and logistics efficiency and promote the goal of a CE (Nascimento et al., 2019). By continuously acquiring technological knowledge and advancements, enterprises can reconfigure their operational strategies to support green innovations, thereby fostering long-term enhancement of the CE (Nascimento et al., 2019). DT acts as an amplifier that strengthens the sensing and reconfiguration capabilities underlying SCE's impact on CE, thereby magnifying the positive relationship between SCE and CE performance. Accordingly, we propose the following hypothesis:

H2: DT positively moderates the relationship between SCE and CE.

3.3 Economic feasibility

In the pursuit of sustainable development goals, a firm's financial performance plays a pivotal role in determining the scope and longevity of its environmental strategies. When sustainability initiatives substantially increase operating costs, management often faces pressure to reassess or adjust their strategic priorities (Eccles et al., 2014). This practical challenge highlights the critical need to assess the economic viability of sustainability measures. Ensuring that sustainable practices are not only environmentally responsible but also economically viable is crucial for enterprises striving to achieve balanced operational models (Omer et al., 2025). Therefore, understanding the relationship between SCE and FP is essential for effectively aligning sustainability initiatives with broader financial and strategic objectives.

Improvements in SCE, achieved through the integration of internal resources, positively affect multiple dimensions of FP (Wong et al., 2021). By optimizing the utilization of equipment, raw materials, and labor, firms can enhance production efficiency and quality, accelerate inventory turnover, improve cash flow, reduce working capital requirements, and enhance overall financial health Wong et al. (2021). Furthermore, the external collaboration dimension of SCE substantially influences FP through collaborative cost savings, risk sharing, and enhanced revenue opportunities

(Chen and Yu, 2022). Joint investments with suppliers and customers foster shared costs, enhance market responsiveness, optimize resource use, and ultimately improve profit margins.

Through DT, firms can obtain accurate operational insights across all supply chain segments to monitor and assess the operational status of each link in the supply chain. For example, through the Internet of Things devices, firms can monitor inventory levels, transportation conditions, and production efficiency in real time, enabling firms to identify bottlenecks early and implement corrective actions (Unhelkar et al., 2022). This sensing capability empowers organizations to make agile and informed decisions in dynamic environments, reducing waste and avoiding supply chain disruptions, which ultimately enhances FP (Lin and Fan, 2024). Furthermore, through enhanced organizational learning capabilities, firms can leverage accumulated knowledge and digital insights to develop innovative technologies, thereby improving production efficiency. As a moderating variable, DT reinforces the relationship between SCE and FP by continuously fostering technological innovation. Thus, we propose the following hypothesis. The research framework is detailed in **Figure 1**:

H3: SCE is positively associated with FP.

H4: DT positively moderates the relationship between SCE and FP.

4 Methodology

4.1 Sample selection and data collection

The research sample includes all Chinese enterprises listed on the A-share markets of the Shanghai and Shenzhen Stock Exchanges, covering a six-year observation period from 2017 to 2022. The primary rationale for selecting A-share listed companies is twofold: first, these enterprises are governed by rigorous regulatory frameworks and transparency mandates, facilitating reliable and convenient access to relevant data (Gligor et al., 2021). Second, Chinese A-share listed firms actively adhere to governmental directives promoting environmental conservation, and thereby enhance their environmental management strategies and performance (Li et al., 2020). The observation period was selected because it aligns with the inception of most Chinese government initiatives promoting DT, which began in 2017.

To minimize the adverse effects of outliers on empirical analysis results, we implemented a series of data preprocessing steps: (1) excluding financial institutions such as banks; (2) omitting delisted companies and those under special treatment; and (3) eliminating observations with missing values. This process resulted in a final sample of 4,248 firm-year observations, encompassing 1,219 enterprises across the 2017-2022 period. To further mitigate the potential negative influence of individual extreme values on empirical outcomes, we winsorized continuous variables at the 1% and 99%. In terms of data sources, we drew upon annual reports and employed natural language processing to construct a firm-level DT indicator. Additionally, all supplementary data were sourced from two authoritative databases: CSMAR and CNRDS, both of which are frequently utilized in Chinese economy research.

4.2 Variable construction

4.2.1 Independent variables

To assess the CE performance, our methodology builds upon prior research (Xiao and Shen, 2022; Yang et al., 2021). Data pertaining to CE outcomes were sourced from the CNRDS database. Utilizing the information contained within CNRDS, CE outcomes were evaluated across two dimensions: positive and negative environmental actions. To quantify the positive environmental impacts of CE, we selected eight pivotal indicators: eco-design, waste minimization, energy efficiency, green office initiatives, recycling activities, environmental accolades, environmental certifications, and other positive environmental actions. Conversely, to gauge environmental drawbacks, we employed indicators such as environmental penalties, pollutant emissions, and other relevant factors extracted from the environmental terminology, serving as proxies for adverse environmental performance. Each indicator was coded as 1 if met by the enterprise during the statistical year, and 0 otherwise, following Yang et al. (2021). The comprehensive CE score was calculated as the total number of positive indicators minus the total number of negative indicators. A higher score indicates superior CE performance.

In previous studies, the FP of enterprises is measured based on accounting and market methods (Wang and Sarkis, 2017). Chen *et al.* (2023) indicated that return on assets (ROA) is more commonly

employed by scholars than other financial indicators and is prevalently used as a metric to quantify the FP. ROA is a metric that indicates an enterprise's profitability concerning its total assets (Wang and Sarkis, 2017). ROA takes into account the current costs and related income disclosed in the financial statements, providing a timely measure of the return on investment, which can serve as a valuable tool for management, analysts, and investors alike, enabling them to assess how efficiently enterprises utilize their assets to generate profit (Delmas et al., 2015). ROA involves dividing the earnings prior to exceptional items by the aggregate assets of a firm, reflecting the profitability relative to its total asset base. A higher ROA indicates better FP and allows cross-sectional comparisons among enterprises of different sizes. Therefore, we use ROA to measure the FP of enterprises and obtain the listed enterprises' ROA from the CSMAR database.

4.2.2 Dependent variable

SCE focuses on enhancing information and material flows between upstream and downstream enterprises, facilitating seamless coordination among supply chain partners. The Inventory Turnover Rate (ITR) is a frequently employed metric to assess SCE and has been widely recognized as a reliable and practical indicator (Lin, 2023; Lo et al., 2009). According to Ageron et al. (2012) and Lin (2023), ITR effectively captures a firm's inventory management performance by reflecting the level of inventory control achieved during a given period. ITR assesses the efficiency of enterprise management in inventory procurement, reflecting the level of inventory control achieved within a given period. It is calculated by dividing the sales cost by the average inventory. In line with the existing literature, this metric is adopted in this study. ITR data were obtained from the CSMAR database and serve as a key proxy for evaluating firms' SCE, which in turn is an essential component of industrial competitiveness.

4.2.3 Moderating variable

Due to the inherent limitations of secondary data sources, it is challenging to establish an objective measure for DT. Therefore, we leveraged unstructured textual data and applied a natural language processing technique to develop a suitable metric. The raw textual data were sourced from the annual

reports of various enterprises. Adhering to the methodology outlined by Buehlmaier and Whited (2018), we employed a frequency-based measure and subsequent analytical methods to rigorously examine the textual data.

Step 1: Utilizing Python's sophisticated web scraping capabilities, we systematically acquired the annual reports of publicly traded firms listed on the Shenzhen Stock Exchange (SZSE) and the Shanghai Stock Exchange (SHSE). These annual reports, as official and periodic disclosure documents, provide comprehensive information, including fundamentals, operational summaries, and financial performance, all of which are highly credible and reliable, serving as a pivotal source for our analysis.

Step 2: We identified a set of key terms related to DT from recent filing documents. In this study, we classified the structural dimensions of enterprise DT into two levels: (1) foundational technology, encompassing digital technologies, and (2) technology application, involving digital technology applications. Artificial intelligence, blockchain, cloud computing, and big data constitute the bedrock of enterprises' digital technology frameworks, emphasizing the integration of digital technologies primarily within the domains of digitization and the digitalization of internal production processes, operational methodologies, management systems, and supporting technologies. To quantify the overall scope of DT, we utilized these two dimensions: digital technologies and their applications.

Step 3: We extracted all textual content using Adobe Acrobat as the basis for filtering keywords related to DT. DT represents a strategic approach adopted by enterprises in the digital era, with its manifestations discernible within their annual reports (Correani et al., 2020). Hence, it is plausible to measure the degree of DT among listed enterprises based on the frequency of DT-related terms in their annual reports. Buehlmaier and Whited (2018) developed a metric to assess financial constraints through textual analysis of annual reports, providing a foundational framework that underpins the current research.

Step 4: To quantify the extent of enterprise DT, we employed the dataset compiled through Python-based extraction of annual reports. We then conducted searches, matching, and statistical analyses. Given that this type of data typically exhibits right-skewed characteristics and that some listed enterprises may not have undergone DT, this study adds 1 to the word frequency (Buehlmaier and Whited, 2018) and applies a logarithmic transformation to obtain a comprehensive measure of DT.

4.2.4 Control variables

To precisely assess the potential influence of SCE on CE, it is imperative to incorporate several control variables, each supported by a clear rationale. Initially, we introduce firm size, designated as SIZE and measured by the natural logarithm of total enterprise assets, because it significantly influences an enterprise's sustainable development strategies (Liu et al., 2017). Secondly, given that CE may not be prioritized by firms with elevated financial risks (Bhattacharya et al., 2021), we utilize the leverage ratio (LEV), calculated as long-term debt divided by total assets, as a proxy to account for financial risk (Yang et al., 2021). Furthermore, we adhere to the existing literature by including firm age (AGE) (Yang et al., 2021) and ownership status (whether the firm is state-owned) among our control variables. Following Gu (2024), we also include CEO duality (DUAL) as a control variable, given its relevance to corporate social responsibility. Additionally, drawing from the DT paper by Liang and Zhao (2024), we incorporate the book-to-market ratio (BM). All data pertaining to these control variables were sourced from the CSMAR database. **Table 2** provides a comprehensive list of the defined variables.

4.3 Model specification

Utilizing a dataset comprising 4,248 samples from 1,219 listed companies, we constructed four models to verify our hypotheses. In alignment with prior research (Yang et al., 2023; Yuan and Pan, 2023), we employed panel data estimation techniques to substantiate our theoretical assumptions. Model 1 examines the correlation between SCE and CE. Model 2 explores the moderating influence of DT and its interaction with SCE. Models 3 and 4 are designed to investigate the economic feasibility of these practices, specifically analyzing the impact of SCE on FP and the moderating effect of DT in this context. Our panel data regression models incorporate industry and year fixed effects as dummy variables to address the potential biases arising from industry heterogeneity and temporal variations in the time-varying variables. Additionally, to alleviate concerns regarding potential heteroskedasticity, we applied firm-clustered robust standard errors within our regression models. To further account for time-invariant industry differences and temporal trends, we included industry and year-fixed effects in our models. Below is a detailed description of Models 1 to 4:

where CE and ROA are the dependent variables, representing the CE performance and FP of i

enterprise in *t* year; The independent variable SCE of *i* enterprise in *t* year is measured by ITR, calculated as the ratio of *i* enterprise's cost of goods sold to its average inventory over *t* year; The control variables encompass SIZE, LEV, AGE, SOE, DUAL, and BM, and $\varepsilon_{i,t}$ is a random error term. To ensure robustness, standard errors are clustered at the firm level in the regression analysis.

5 Results

5.1 Descriptive statistics and correlation analysis

Table 3 provides descriptive statistics and correlation metrics for all variables included in the regression models. To reduce the potential bias caused by outliers, we winsorized all continuous variables by 1%. All variance Inflation Factor (VIF) values are below 4, indicating minimal concern about multicollinearity in our analysis.

5.2 Empirical results

Table 4 presents the results of the fixed-effects regression model analysis. Model 1 includes a comprehensive set of relevant control variables to rigorously evaluate the direct effect of SCE on CE performance. Model 2 extends this framework by incorporating an interaction term between SCE and DT to examine their potential moderating influence on CE. Models 3 and 4 follow a similar structure, but shift the focus to FP, measuring the impact of SCE and its interaction with DT on FP. The coefficient of SCE remains significantly positive ($p < 0.05$) in Models 1 to 4, firmly establishing that SCE is positively correlated with CE and FP. H1 and H3 are supported. The interaction term SCE*DT is positive and significant at the 10% level in Model 2. It provides marginal evidence to support H2. However, SCE*DT in Model 4 is not statistically significant, which is inconsistent with H4.

Figure 2 provides a graphical illustration of the interaction effect of SCE*DT on CE with the low (mean -S.D.) and high (mean + S.D.) values of DT. ITR is a proxy measure for SCE. At a high level of DT, CE clearly increases with a higher level of ITR, highlighting the effect of DT on moderating the relationship between SCE and CE.

5.3 Robustness tests

5.3.1 Instrumental variables method

Enhancing SCE is recognized as a pivotal factor driving the growth of CE and FP, while improvements in CE and FP may, in turn, positively influence SCE. During the model construction process, some key variables may have been omitted. To effectively mitigate or address this endogeneity problem, this study introduces the instrumental variable method.

To address the potential endogeneity problem mentioned above, we choose the geographic distance between the enterprise and its suppliers and customers as the instrumental variable. The closer distance facilitates more efficient information transmission, reduces logistics costs, and improves market response speed and customer satisfaction. Therefore, there is a close relationship between the enterprise's distance to suppliers and customers and the efficiency of the supply chain. At the same time, the distance is not directly controlled by the enterprise, and there is no direct relationship between

CE and FP, thereby satisfying the exogenous requirements.

We replace SCE with the DISTANCE values to conduct a two-stage least-squares (2SLS) analysis. We employ the average annual distance between a company and its suppliers or customers to measure DISTANCE. The original data are sourced from CSMAR and are calculated by first adding 1 to the spatial distance between a listed company and each of its suppliers or customers, then taking the natural logarithm of this sum and multiplying by -1. Finally, the average distance across all suppliers or customers for each company in a given year is computed to derive the DISTANCE value. A higher value indicates closer spatial proximity. We first obtain the predicted value of SCE through the first stage and use this predicted value in place of SCE in the second-stage regression. **Table 5** reports the results of the second stage.

The outcomes of the instrumental variable method are presented in **Table 5**. After addressing the potential endogeneity issue, it is affirmed that the positive and significant coefficients for the primary explanatory variable SCE remain consistent, thereby reinforcing the reliability and robustness of the baseline regression results. Furthermore, the Cragg-Donald Wald F statistic 13.33 surpasses the threshold at the 15% significance level. The Kleibergen-Paap rk LM statistic is significant at the 1% level. The weak instrument test indicates that the chosen instrumental variables are both valid and effective.

5.3.2 Alternative measurement of the dependent variable

We used an alternative measurement of our dependent variable CE. We followed Wang and Sarkis (2017) and used the environment score of the Bloomberg ESG index to measure the CE of enterprises. The sample size comprises 2,832 observations, which is smaller than the 4,248 observations in the main tests. As **Table 6** shows, the coefficients of SCE are significantly positive. Regarding the moderating role of DT, the interaction term SCE*DT remains significant in Model 2, whereas the interaction term SCE*DT does not reach statistical significance in Model 4. These results further corroborate the robustness of our main findings.

5.4 Heterogeneity analysis

For the purpose of heterogeneity analysis, we categorize the samples into three distinct groups: (1) Given the varying nature of enterprises' property rights, enterprises are classified into two distinct categories: state-owned enterprises and non-state-owned enterprises; (2) The enterprises are further categorized based on their size, into large-scale enterprises and small- and medium-sized enterprises; (3) Additionally, the enterprises are grouped into manufacturing and non-manufacturing sectors.

State-owned enterprises ought to play a pivotal role in driving substantial economic advancement and preventing the economy from shifting excessively from the real sector to the virtual realm. In contrast to non-state-owned enterprises, state-owned enterprises frequently shoulder heavier responsibilities stemming from their inherent political affiliations. State-owned enterprises are more inclined to embrace environmental responsibility by adopting digital technologies aimed at enhancing CE. To further explore the influence of SCE on CE and the moderating role of DT, our research divides the samples into state-owned and non-state-owned enterprises, conducting regression analyses on these subgroups. As shown in **Table 7,** Group 1 shows that, in comparison to non-state-owned enterprises, the SCE of state-owned enterprises exerts a more pronounced influence on CE, and the implementation of digital technology by state-owned enterprises significantly reinforces the positive relationship between SCE and CE.

In addition, to further investigate whether the firm size influences the research results, our study also examines the heterogeneity by considering the size of enterprises, segmenting the sample into large-scale enterprises and small- and medium-sized enterprises to conduct group regression analyses. The results in **Table 7,** Group 2 show that both the direct effect of SCE and the moderating effect of DT are more significant in large enterprises.

Finally, we delve into the influence of the industry characteristics of enterprises. The findings in **Table 7**, Group 3 reveal that compared to the non-manufacturing industriesy, SCE has a more pronounced impact on CE in the manufacturing sector. This is primarily due to the more intricate supply chain in manufacturing, which involves a larger number of stakeholders and amplifies the influence of SCE on enterprise performance. Nevertheless, the moderating effect of DT is more pronounced in non-manufacturing industries. Non-manufacturing industries usually involve more

complex supply chain networks, more suppliers and customers, and with more information and logistics flows. DT can help non-manufacturing industries manage these complex supply chain networks more effectively, improve efficiency and transparency, and reduce errors and delays.

6 Discussion

SCE serves as a key facilitator for enterprises to enhance resource allocation efficiency, strengthen organizational coordination, and drive the transition to CE. Exploring whether and how traditional SCE frameworks can contribute to CE development is an intriguing research question. Drawing on DC theory, we examine how firms improve CE performance through the integration and coordination of resources, moderated by dynamic processes of learning and sensing environmental changes. We investigate the influence of SCE on CE performance and the moderating effect of DT. Additionally; we assess the economic feasibility of implementing such improvements in SCE and CE performance in practice. We use a dataset of 4,248 Chinese firm-year observations spanning from 2017 to 2022. Our findings reveal a positive and statistically significant relationship between SCE and CE performance. Furthermore, enterprises' DT capability is identified as a significant factor in strengthening the link between SCE and CE. The insignificant moderating impact of DT on FP, compared to its stronger effect on CE, indicates that DT may be more effective when aligned with long-term sustainability transitions rather than short-term financial gains.

6.1 Theoretical implications

The core theoretical advancements of this research can be summarized as follows: Firstly, we conceptualize SCE as an essential operational capability and analyze its function as DC that influences CE outcomes. It provides theoretical support for examining how firms can integrate internal resources and coordinate external resources to enhance environmental performance amid the sustainability transition. Previous studies on DC theory have primarily focused on how firms reconfigure resources to gain competitive advantages under highly uncertain environments, such as market volatility and technological disruptions (Efrat et al., 2018; Lin and Wu, 2014). However, limited attention has been given to SCE as a form of DC, particularly in relation to environmental sustainability and within the context of the CE. Our empirical results confirm that SCE has a significant positive impact on CE, reinforcing its role as a DC that enables firms to adapt to sustainability-driven transformations. This expands the boundaries of existing DC research, which has traditionally emphasized product innovation and market responsiveness, by highlighting its applicability and adaptability in green and sustainable strategies. Unlike prior studies that primarily examine green performance from the perspectives of external drivers such as institutional pressure or supply chain network cohesion (Omer et al., 2025; Wang et al., 2023), our research establishes a logical framework linking DC and CE performance from

an operational capability perspective. Specifically, it uncovers how firms can leverage existing external and internal operation resources to develop reconfigurable capabilities suited to the closed-loop processes and feedback mechanisms required by the CE.

Secondly, we find that DT significantly influences the association between SCE and CE, revealing the potential of technological enablement to enhance the functioning of DC. While prior studies have acknowledged DT as a driver of supply chain performance (Enrique et al., 2022; Yuan and Pan, 2023), our research takes a step further by demonstrating how DT amplifies the operational impact of SCE in circular processes. Specifically, we observe that DT, when strategically aligned, enhances SCE ability to support closed-loop operations, improve reverse logistics coordination, and accelerate resource reutilization which are critical in CE implementation. This finding contributes to DC theory by positioning DT not merely as a technological enhancement, but as a contextual enhancer that enables existing operational resources to evolve into reconfigurable capabilities suitable for CE transformation. As such, our study offers novel insights into how firms can strategically leverage DT to unlock the full potential of supply chain–based DC in driving sustainable innovation. We further advance the application of DC, addressing key gaps in existing DC-related research, which has often treated enterprise capabilities as undifferentiated single dimensions or explored DC's role in isolation from the synergy between SCE and DT. We integrate DC theory by conceptualizing SCE as a coordinating and integrating DC capability, emphasizing its central role in resource allocation and process optimization, and defines DT as a DC capability that highlights its unique role in sensing and learning. This dual conceptualization clarifies the distinct yet complementary functions and mechanisms of SCE and DT within the DC framework, advancing DC theory from single to multi dimensional capability synergy and offering a novel theoretical lens for applying DC to the intersection of SCE, DT, and CE goals.

Finally, our study advances the theoretical understanding of the economic feasibility of CE. While existing literature often focuses on the environmental benefits of CE practices (De Angelis et al., 2018; Nascimento et al., 2019; Yang et al., 2021), systematic research on whether and how such initiatives are economically viable for firms remains limited. By incorporating SCE as a DC and evaluating its impact on both CE performance and financial outcomes, we provide evidence that CE strategies can generate tangible operational benefits when effectively supported by internal capabilities. Although the moderating effect of DT on the relationship between SCE and FP is not statistically significant, this finding contributes to the theoretical discourse by identifying boundary conditions that may limit the immediate performance benefits of DT. It suggests that the positive impact of DT may be contingent upon contextual factors such as cost

structures or implementation maturity, thus enriching the theoretical integration of DT within the DC and CE frameworks.

6.2 Managerial implications

The results of this empirical study offer meaningful insights into the strategic adaptations firms must undertake regarding the strategic roles of SCE and DT. Our findings position SCE as a critical DC that enables firms to respond to market volatility and support the transition to a CE. In the early stages of CE implementation, the continuous enhancement of SCE hinges on the firm's ability to effectively integrate and coordinate resources. Internally, this involves optimizing procurement processes, inventory systems, and logistics management to ensure alignment across functional departments. Externally, collaboration with supply chain partners becomes critical to improving information flow, reducing redundancies, and fostering responsive, demand-driven operations (Chen et al., 2017). Such integrated efforts not only enhance resource utilization and operational agility but also reduce expenditures related to surplus stock, warehousing, logistics, and transportation, thereby improving cost efficiency and sustainable competitiveness.

Simultaneously, DT should be strategically integrated to support and elevate the functioning of DC. DT enables real-time environmental data collection, enhances transparency across the product lifecycle, and facilitates proactive risk identification as well as resource optimization (Shang et al., 2023). Advanced technologies such as big data analytics and AI further improve demand forecasting accuracy, helping to prevent overproduction and minimize resource waste (Bai and Sarkis, 2017). However, the absence of a significant moderating effect of DT on the relationship between SCE and FP suggests that the initial investment and operational costs of DT may dampen short-term financial returns. Therefore, enterprises are advised to adopt cost-mitigation strategies to balance short-term financial constraints with long-term environmental and operational benefits.

7 Conclusions and limitations

Amidst intense market competition, enterprises can leverage SCE as a strategic capability to address economic and environmental uncertainties. DT, as a central enabler in the digital era, significantly influences enterprise performance. This study investigates the impact of SCE on corporate CE from the perspective of DC theory, utilizing the CSMAR and CNRDS databases to quantify SCE, CE, and financial performance. The results indicate a positive influence of SCE on CE. To explore the moderating effect of DT, we identify two levels of

DT-related keywords in the annual reports of listed Chinese companies. The empirical results indicate that DT strengthens the positive relationship between SCE and CE, while its moderating effect on the relationship between SCE and financial performance is not statistically significant.

While this study contributes to the understanding of DT's role within the CE domain, it acknowledges two notable limitations. Firstly, prior research has employed various methods to measure SCE (Lo et al., 2009; Yeung et al., 2008), whereas our study opts for the ITR. Therefore, future research could adopt alternative measurement approaches for SCE. Secondly, our investigation focuses on the voluntary environmental information disclosure, where companies tend to disclose environmentally favorable information while omitting negative aspects. Consequently, future endeavors may consider the moderating influence of additional factors, such as mandatory regulatory frameworks and normative directives, on the complex interaction between supply chain network structures and the development of environmentally sustainable innovations.

Reference

Ageron, B., Gunasekaran, A., Spalanzani, A., 2012. Sustainable supply management: An empirical study. International Journal of Production Economics 140, 168–182. https://doi.org/10.1016/j.ijpe.2011.04.007

Alkaraan, F., Albitar, K., Hussainey, K., Venkatesh, V., 2022. Corporate transformation toward Industry 4.0 and financial performance: The influence of environmental, social, and governance (ESG). Technological Forecasting and Social Change 175, 121423. https://doi.org/10.1016/j.techfore.2021.121423

Bag, S., Dhamija, P., Bryde, D.J., Singh, R.K., 2022. Effect of eco-innovation on green supply chain management, circular economy capability, and performance of small and medium enterprises. Journal of Business Research 141, 60–72. https://doi.org/10.1016/j.jbusres.2021.12.011

Bai, C., Orzes, G., Sarkis, J., 2022. Exploring the impact of Industry 4.0 technologies on social sustainability through a circular economy approach. Industrial Marketing Management 101, 176–190. https://doi.org/10.1016/j.indmarman.2021.12.004

Bai, C., Sarkis, J., 2017. Improving green flexibility through advanced manufacturing technology investment: Modeling the decision process. International Journal of Production Economics 188, 86–104. https://doi.org/10.1016/j.ijpe.2017.03.013

Bai, C., Sarkis, J., Yin, F., Dou, Y., 2020. Sustainable supply chain flexibility and its relationship to circular economy-target performance. International Journal of Production Research 58, 5893–5910. https://doi.org/10.1080/00207543.2019.1661532

Barney, J.B., 1986. Strategic factor markets: expectations, luck, and business strategy. Management Science 32, 1231–1241. https://doi.org/10.1287/mnsc.32.10.1231

Barreto, I., 2010. Dynamic capabilities: A review of past research and an agenda for the future. Journal of Management 36, 256–280. https://doi.org/10.1177/0149206309350776

Belhadi, A., Kamble, S.S., Venkatesh, M., Chiappetta Jabbour, C.J., Benkhati, I., 2022. Building supply chain resilience and efficiency through additive manufacturing: An ambidextrous perspective on the dynamic capability view. International Journal of Production Economics 249, 108516. https://doi.org/10.1016/j.ijpe.2022.108516

Bhattacharya, A., Good, V., Sardashti, H., Peloza, J., 2021. Beyond warm glow: the risk-mitigating effect of corporate social responsibility (CSR). Journal of Business Ethics 171, 317–336. https://doi.org/10.1007/s10551-020-04445-0

Buehlmaier, M.M.M., Whited, T.M., 2018. Are financial constraints priced? Evidence from textual analysis. The Review of Financial Studies 31, 2693–2728. https://doi.org/10.1093/rfs/hhy007

Caiado, R.G.G., Quelhas, O.L.G., Nascimento, D.L.D.M., Anholon, R., Leal Filho, W., 2019. Towards sustainability by aligning operational programmes and sustainable performance measures. Production Planning & Control 30, 413–425. https://doi.org/10.1080/09537287.2018.1501817

Castellani, V., Sala, S., Mirabella, N., 2015. Beyond the throwaway society: A life cycle-based assessment of the environmental benefit of reuse. Integrated Environmental Assessment and Management 11, 373–382. https://doi.org/10.1002/ieam.1614

Chen, L., Zhao, X., Tang, O., Price, L., Zhang, S., Zhu, W., 2017. Supply chain collaboration for sustainability: A literature review and future research agenda. International Journal of Production Economics, Special Issue: Innovations in Production Economics 194, 73–87. https://doi.org/10.1016/j.ijpe.2017.04.005

Chen, Su, Shen, W., Qiu, Z., Liu, R., Mardani, A., 2023. Who are the green entrepreneurs in China? The relationship between entrepreneurs' characteristics, green entrepreneurship orientation, and corporate financial performance. Journal of Business Research 165, 113960. https://doi.org/10.1016/j.jbusres.2023.113960

Chen, Simin, Song, Y., Gao, P., 2023. Environmental, social, and governance (ESG) performance and financial outcomes: Analyzing the impact of ESG on financial performance. Journal of Environmental Management 345, 118829. https://doi.org/10.1016/j.jenvman.2023.118829

Chen, S., Yu, D., 2022. Exploring the impact of external collaboration on firm growth capability: the mediating roles of R&D efforts. Humanities and Social Sciences Communications 9, 404. https://doi.org/10.1057/s41599-022-01429-5

Correani, A., De Massis, A., Frattini, F., Petruzzelli, A.M., Natalicchio, A., 2020. Implementing a digital strategy: Learning from the experience of three digital transformation projects. California Management Review 62, 37–56. https://doi.org/10.1177/0008125620934864

Dalal, S., Lilhore, U.K., Simaiya, S., Radulescu, M., Belascu, L., 2024. Improving efficiency and sustainability via supply chain optimization through CNNs and BiLSTM. Technological Forecasting and Social Change 209, 123841. https://doi.org/10.1016/j.techfore.2024.123841

De Angelis, R., 2021. Circular economy and paradox theory: A business model perspective. Journal of Cleaner Production 285, 124823. https://doi.org/10.1016/j.jclepro.2020.124823

De Angelis, R., Howard, M., Miemczyk, J., 2018. Supply chain management and the circular economy: towards the circular supply chain. Production Planning & Control 29, 425–437. https://doi.org/10.1080/09537287.2018.1449244

Del, G.M., Chierici, R., Mazzucchelli, A., Fiano, F., 2020. Supply chain management in the era of circular economy: the moderating effect of big data. The International Journal of Logistics Management 32, 337–356. https://doi.org/10.1108/IJLM-03-2020-0119

Delmas, M.A., Nairn-Birch, N., Lim, J., 2015. Dynamics of environmental and financial performance: The case of greenhouse gas emissions. Organization & Environment 28, 374–393. https://doi.org/10.1177/1086026615620238

Dierickx, I., Cool, K., 1989. Asset stock accumulation and sustainability of competitive advantage. Management Science 35, 1504–1511. https://doi.org/10.1287/mnsc.35.12.1504

Eccles, R.G., Ioannou, I., Serafeim, G., 2014. The impact of corporate sustainability on organizational processes and performance. Management Science 60, 2835–2857. https://doi.org/10.1287/mnsc.2014.1984

Efrat, K., Hughes, P., Nemkova, E., Souchon, A.L., Sy-Changco, J., 2018. Leveraging of dynamic export capabilities for competitive advantage and performance consequences: Evidence from China. Journal of Business Research 84, 114–124. https://doi.org/10.1016/j.jbusres.2017.11.018

Eisenhardt, K.M., Martin, J.A., 2000. Dynamic capabilities: what are they? Strategic Management Journal 21, 1105–1121. https://doi.org/10.1002/1097-0266(200010/11)21:10/113.0.CO;2-E

Enrique, D.V., Lerman, L.V., Sousa, P.R. de, Benitez, G.B., Bigares Charrua Santos, F.M., Frank, A.G., 2022. Being digital and flexible to navigate the storm: How digital transformation enhances supply chain flexibility in turbulent environments. International Journal of Production Economics 250, 108668. https://doi.org/10.1016/j.ijpe.2022.108668

Feng, S., Mohd Shafiei, M.W., Ng, T.F., Ren, J., Jiang, Y., 2024. The intersection of economic growth and environmental sustainability in China: Pathways to achieving SDG. Energy Strategy Reviews 55, 101530. https://doi.org/10.1016/j.esr.2024.101530

Fitzgerald, M., Kruschwitz, N., Bonnet, D., Welch, M., 2014. Embracing digital technology: A new strategic imperative. MIT sloan management review 55, 1.

Geng, Y., Sarkis, J., Bleischwitz, R., 2019. How to globalize the circular economy. Nature 565, 153–155. https://doi.org/10.1038/d41586-019-00017-z

Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production 114, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Ghobakhloo, M., Iranmanesh, M., Foroughi, B., Tseng, M.-L., Nikbin, D., Khanfar, A.A.A., 2025. Industry 4.0 digital transformation and opportunities for supply chain resilience: a comprehensive review and a strategic roadmap. Production Planning & Control 36, 61–91. https://doi.org/10.1080/09537287.2023.2252376

Gligor, D.M., Gölgeci, I., Newman, C., Bozkurt, S., 2021. Performance implications of the buyer-supplier market orientation fit. Industrial Marketing Management 93, 161–173. https://doi.org/10.1016/j.indmarman.2021.01.010

Govindan, K., 2023. How digitalization transforms the traditional circular economy to a smart circular economy for achieving SDGs and net zero. Transportation Research Part E: Logistics and Transportation Review 177, 103147. https://doi.org/10.1016/j.tre.2023.103147

Gu, J., 2024. Investor attention and ESG performance: Lessons from China's manufacturing industry. Journal of Environmental Management 355, 120483. https://doi.org/10.1016/j.jenvman.2024.120483

Hasan, R., Kamal, M.M., Daowd, A., Eldabi, T., Koliousis, I., Papadopoulos, T., 2024. Critical analysis of the impact of big data analytics on supply chain operations. Production Planning & Control 35, 46–70. https://doi.org/10.1080/09537287.2022.2047237

Khedr, A.M., S, S.R., 2024. Enhancing supply chain management with deep learning and machine learning techniques: A review. Journal of Open Innovation: Technology, Market, and Complexity 10, 100379. https://doi.org/10.1016/j.joitmc.2024.100379

Komkowski, T., Antony, J., Garza-Reyes, J.A., Tortorella, G.L., Pongboonchai-Empl, T., 2023. Integrating lean management with industry 4.0: an explorative dynamic capabilities theory perspective. Production Planning & Control 1–19. https://doi.org/10.1080/09537287.2023.2294297

Li, J., Yi, M., Sun, Q., 2025. Artificial intelligence and supply chain risk: Mediating effects of supply chain efficiency and resilience. International Review of Financial Analysis 108, 104700. https://doi.org/10.1016/j.irfa.2025.104700

Li, Y., Dai, J., Cui, L., 2020. The impact of digital technologies on economic and environmental performance in the context of industry 4.0: A moderated mediation model. International Journal of Production Economics 229, 107777. https://doi.org/10.1016/j.ijpe.2020.107777

Liang, Z., Zhao, Y., 2024. Enterprise digital transformation and stock price crash risk. Finance Research Letters 59, 104802. https://doi.org/10.1016/j.frl.2023.104802

Liao, F., Hu, Y., Chen, M., Xu, S., 2024. Digital transformation and corporate green supply chain efficiency: Evidence from China. Economic Analysis and Policy 81, 195–207. https://doi.org/10.1016/j.eap.2023.11.033

Lin, J., Fan, Y., 2024. Seeking sustainable performance through organizational resilience: Examining the role of supply chain integration and digital technology usage. Technological Forecasting and Social Change 198, 123026. https://doi.org/10.1016/j.techfore.2023.123026

Lin, W.L., 2023. Corporate social responsibility and irresponsibility: Effects on supply chain performance in the automotive industry under environmental turbulence. Journal of Cleaner

Production 428, 139033. https://doi.org/10.1016/j.jclepro.2023.139033

Lin, Y., Wu, L.-Y., 2014. Exploring the role of dynamic capabilities in firm performance under the resource-based view framework. Journal of Business Research 67, 407–413. https://doi.org/10.1016/j.jbusres.2012.12.019

Liu, J., Zhou, K., Zhang, Y., Tang, F., 2023. The effect of financial digital transformation on financial performance: The intermediary effect of information symmetry and operating costs. Sustainability 15, 5059. https://doi.org/10.3390/su15065059

Liu, Y., 2023. Antecedents of circular manufacturing and its effect on environmental and financial performance: A practice-based view. International Journal of Production Economics.

Liu, Y., Zhu, Q., Seuring, S., 2017. Linking capabilities to green operations strategies: The moderating role of corporate environmental proactivity. International Journal of Production Economics 187, 182–195. https://doi.org/10.1016/j.ijpe.2017.03.007

Lo, C.K.Y., Yeung, A.C.L., Cheng, T.C.E., 2009. ISO 9000 and supply chain efficiency: Empirical evidence on inventory and account receivable days. International Journal of Production Economics 118, 367–374. https://doi.org/10.1016/j.ijpe.2008.11.010

Lu, H., Zhao, G., Liu, S., 2024. Integrating circular economy and Industry 4.0 for sustainable supply chain management: a dynamic capability view. Production Planning & Control 35, 170–186. https://doi.org/10.1080/09537287.2022.2063198

Matarazzo, M., Penco, L., Profumo, G., Quaglia, R., 2021. Digital transformation and customer value creation in Made in Italy SMEs: A dynamic capabilities perspective. Journal of Business Research 123, 642–656. https://doi.org/10.1016/j.jbusres.2020.10.033

Meng, J., Hao, Z., Yang, J., Hong, Y., 2023. How does digital transformation affect organisational sustainable performance: the mediating roles of supply chain agility and integration. International Journal of Logistics Research and Applications 1–26. https://doi.org/10.1080/13675567.2023.2257139

Nascimento, D.L.M., Alencastro, V., Quelhas, O.L.G., Caiado, R.G.G., Garza-Reyes, J.A., Rocha-Lona, L., Tortorella, G., 2019. Exploring industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. Journal of Manufacturing Technology Management 30, 607–627. https://doi.org/10.1108/JMTM-03-2018-0071

Omer, M.A.E., Mahmoud Ibrahim, A.M., Elsheikh, A.H., Hegab, H., 2025. A framework for integrating sustainable production practices along the product life cycle. Environmental and Sustainability Indicators 26, 100606. https://doi.org/10.1016/j.indic.2025.100606

Pavlou, P.A., El Sawy, O.A., 2011. Understanding the elusive black box of dynamic capabilities. Decision Sciences 42, 239–273. https://doi.org/10.1111/j.1540-5915.2010.00287.x

Schmidt, C.V.H., Kindermann, B., Behlau, C.F., Flatten, T.C., 2021. Understanding the effect of market orientation on circular economy practices: The mediating role of closed-loop orientation in German SMEs. Business Strategy and the Environment 30, 4171–4187. https://doi.org/10.1002/bse.2863

Schultz, F.C., Everding, S., Pies, I., 2021. Circular supply chain governance: A qualitative-empirical study of the European polyurethane industry to facilitate functional circular supply chain management. Journal of Cleaner Production 317, 128445. https://doi.org/10.1016/j.jclepro.2021.128445

Shang, Y., Raza, S.A., Huo, Z., Shahzad, U., Zhao, X., 2023. Does enterprise digital transformation contribute to the carbon emission reduction? Micro-level evidence from China. International Review of Economics & Finance 86, 1–13. https://doi.org/10.1016/j.iref.2023.02.019

Song, Y., Du, C., Du, P., Liu, R., Lu, Z., 2024. Digital transformation and corporate environmental performance: Evidence from Chinese listed companies. Technological Forecasting and Social Change 201, 123159. https://doi.org/10.1016/j.techfore.2023.123159

Su, B., Heshmati, A., Geng, Y., Yu, X., 2013. A review of the circular economy in China: moving from rhetoric to implementation. Journal of Cleaner Production 42, 215–227. https://doi.org/10.1016/j.jclepro.2012.11.020

Teece, D., Pisano, G., 1994. The dynamic capabilities of firms: an introduction. Industrial and Corporate Change 3, 537–556. https://doi.org/10.1093/icc/3.3.537-a

Teece, D.J., 2007. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. Strategic Management Journal 28, 1319–1350. https://doi.org/10.1002/smj.640

Teece, D.J., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Strategic Management Journal 18, 509–533. https://doi.org/10.1002/(SICI)1097-0266(199708)18:7%253C509::AID-SMJ882%253E3.0.CO;2-Z

Triguero, Á., Cuerva, M.C., Sáez-Martínez, F.J., 2022. Closing the loop through eco-innovation by European firms: Circular economy for sustainable development. Business Strategy and the Environment 31, 2337–2350. https://doi.org/10.1002/bse.3024

Unhelkar, B., Joshi, S., Sharma, M., Prakash, S., Mani, A.K., Prasad, M., 2022. Enhancing supply chain performance using RFID technology and decision support systems in the industry 4.0–A systematic literature review. International Journal of Information Management Data Insights 2, 100084. https://doi.org/10.1016/j.jjimei.2022.100084

Velenturf, A.P.M., Purnell, P., 2021. Principles for a sustainable circular economy. Sustainable Production and Consumption 27, 1437–1457. https://doi.org/10.1016/j.spc.2021.02.018

Vial, G., 2019. Understanding digital transformation: A review and a research agenda. The Journal of Strategic Information Systems 28, 118–144. https://doi.org/10.1016/j.jsis.2019.01.003

Wang, Z., Doren, C., Cai, S., Ren, S., 2023. Enterprise level responses to environmental institutional pressure: Focus on legitimization strategies. Journal of Cleaner Production 382, 135148. https://doi.org/10.1016/j.jclepro.2022.135148

Wang, Z., Sarkis, J., 2017. Corporate social responsibility governance, outcomes, and financial performance. Journal of Cleaner Production 162, 1607–1616. https://doi.org/10.1016/j.jclepro.2017.06.142

Warner, K.S.R., Wäger, M., 2019. Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. Long Range Planning 52, 326–349. https://doi.org/10.1016/j.lrp.2018.12.001

Wei, J., Zhang, X., Tamamine, T., 2024. Digital transformation in supply chains: Assessing the spillover effects on midstream firm innovation. Journal of Innovation & Knowledge 9, 100483. https://doi.org/10.1016/j.jik.2024.100483

Wong, W.P., Sinnandavar, C.M., Soh, K.-L., 2021. The relationship between supply environment, supply chain integration and operational performance: The role of business process in curbing opportunistic behaviour. International Journal of Production Economics 232, 107966. https://doi.org/10.1016/j.ijpe.2020.107966

Wu, L.-Y., 2007. Entrepreneurial resources, dynamic capabilities and start-up performance of Taiwan's high-tech firms. Journal of Business Research 60, 549–555. https://doi.org/10.1016/j.jbusres.2007.01.007

Xiao, G., Shen, S., 2022. To pollute or not to pollute: Political connections and corporate

environmental performance. Journal of Corporate Finance 74, 102214. https://doi.org/10.1016/j.jcorpfin.2022.102214

Yang, Y., Jiang, Y., Chen, X., 2021. Does buyers' financial slack promote or inhibit suppliers' circular economy performance? Industrial Marketing Management 99, 111–122. https://doi.org/10.1016/j.indmarman.2021.10.004

Yang, Z., Hu, W., Shao, J., Shou, Y., He, Q., 2023. How does digitalization alter the paradox of supply base concentration? The effects of digitalization intensity and breadth. IJOPM 43, 1690–1722. https://doi.org/10.1108/IJOPM-10-2022-0685

Yeung, A.H.W., Lo, V.H.Y., Yeung, A.C.L., Cheng, T.C.E., 2008. Specific customer knowledge and operational performance in apparel manufacturing. International Journal of Production Economics 114, 520–533. https://doi.org/10.1016/j.ijpe.2007.06.011

Yuan, S., Pan, X., 2023. The effects of digital technology application and supply chain management on corporate circular economy: A dynamic capability view. Journal of Environmental Management 341, 118082. https://doi.org/10.1016/j.jenvman.2023.118082

Zhai, H., Yang, M., Chan, K.C., 2022. Does digital transformation enhance a firm's performance? Evidence from China. Technology in Society 68, 101841. https://doi.org/10.1016/j.techsoc.2021.101841

Zhao, N., Hong, J., Lau, K.H., 2023. Impact of supply chain digitalization on supply chain resilience and performance: A multi-mediation model. International Journal of Production Economics 259, 108817. https://doi.org/10.1016/j.ijpe.2023.108817

Zhong, Y., Chen, X., Wang, Z., Lin, R.F.-Y., 2024. The nexus among artificial intelligence, supply chain and energy sustainability: A time-varying analysis. Energy Economics 132, 107479. https://doi.org/10.1016/j.eneco.2024.107479

Zollo, M., Winter, S.G., 2002. Deliberate learning and the evolution of dynamic capabilities. Organization Science 13, 339–351. https://doi.org/10.1287/orsc.13.3.339.2780

Zopounidis, C., Lemonakis, C., 2024. The company of the future: Integrating sustainability, growth, and profitability in contemporary business models. Development and Sustainability in Economics and Finance 1, 100003. https://doi.org/10.1016/j.dsef.2024.100003

Table 1 The differences between previous related studies and our research

Papers	Supply chain management	Digital transformation	Environmental performance	Financial performance
De Angelis et al., 2018	√		√	
Bai et al., 2022		√	√	
Govindan, 2023		√	√	
Zhai et al., 2022		√		√
Song et al., 2024		√	√	
Wong et al., 2021	√		√	√
Liu et al., 2023		√	√	√
Yuan and Pan, 2023	√	√	√	
Our paper	√	√	√	√
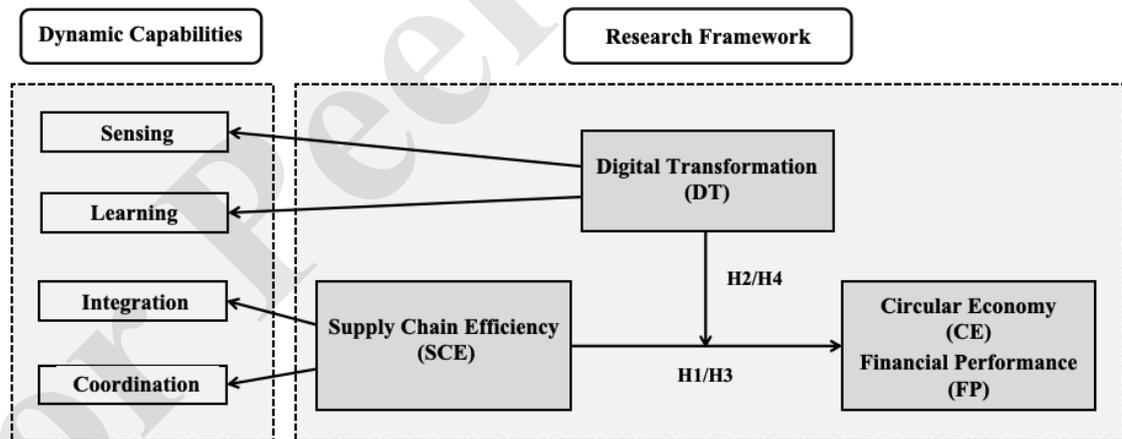
Figure 1 Research Framework

Table 2 Variable definition

Type	Symbol	Definition	Method
Dependent variable	CE	Circular economy performance	Eight environmental advantage items (Eco-design, waste reduction, energy saving, green office, recycling, environmental recognition, environmental certification and other advantages) minus three environmental concern items (environmental penalties, pollutant emissions, and other issues)
Dependent variable	ROA	Return on assets	Net Income / Total Assets.
Independent variable	ITR	Inventory turnover rate (Supply Chain efficiency)	Cost of Goods Sold / ((Beginning Inventory + Ending Inventory) / 2)
Moderating variable	DT	Degree of DT	Total frequency of five digital technology words frequency in public enterprise reports
	SIZE	Enterprise scale	Natural logarithm of a firm's total assets
	LEV	Enterprise debt scale	Long-term debt scaled by total assets
	AGE	Enterprise age	Natural logarithm of firm age
	SOE	Enterprise's nature	If the enterprise is a state-owned enterprise, then 1, otherwise 0
Control variables	DUAL	CEO duality	When the chairman of the board is also the general manager, the dummy variable is assigned a value of 1 and 0 otherwise
	BM	Book-market ratio	The ratio of the total owner's equity to the market value

Models 1 to 4

$$CE^{it} = \beta_0 + \beta_1 ITR^{it} + \sum_{=2}^{7} \beta^k \, Controls^{it} + \sum Year + \sum IND + \varepsilon^{it} \tag{1}$$

$$CE^{it} = \beta_0 + \beta_1 ITR^{it} + \beta_2 DT^{it} + \beta_3 ITR^{it} \times DT^{it} + \sum_{=4}^{9} \beta^k \, Controls^{it} + \sum Year + \sum IND + \varepsilon^{it} \tag{2}$$

$$ROA^{it} = \beta_0 + \beta_1 ITR^{it} + \sum_{=2}^{7} \beta^k \, Controls^{it} + \sum Year + \sum IND + \varepsilon^{it} \tag{3}$$

$$ROA^{it} = \beta_0 + \beta_1 ITR^{it} + \beta_2 DT^{it} + \beta_3 ITR^{it} \times DT^{it} + \sum_{=4}^{9} \beta^k \, Controls^{it} + \sum Year + \sum IND + \varepsilon^{it} \tag{4}$$

Table 3 Descriptive statistics and correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
CE	1									
ROA	0.075***	1								
ITR	0.027*	0.025*	1							
DT	0.092***	-0.016	0.015	1						
SIZE	0.318***	-0.031**	0.081***	0.016	1					
LEV	0.132***	-0.384***	-0.027*	-0.010	0.525***	1				
AGE	0.049***	-0.080***	-0.053***	-0.089***	0.130***	0.151***	1			
SOE	0.015	-0.108***	0.136***	-0.172***	0.326***	0.214***	0.165***	1		
DUAL	-0.006	0.045***	-0.074***	0.108***	-0.131***	-0.089***	-0.074***	-0.317***	1	
BM	0.113***	-0.190***	-0.068***	-0.133***	0.586***	0.553***	0.160***	0.293***	-0.115***	1
Mean	3.311	0.042	1.789	4.092	23.335	0.474	3.059	0.514	0.218	1.796
S.D.	1.767	0.077	0.963	0.792	1.452	0.199	0.273	0.500	0.413	2.264
Minimum	0	-2.071	0.019	2.773	18.875	0.014	1.792	0	0	0
Maximum	7	0.604	5.474	6.435	28.509	2.290	4.159	1	1	27.005

Note: *p<0.1, **p<0.05, ***p<0.01.

Table 4 Regression results

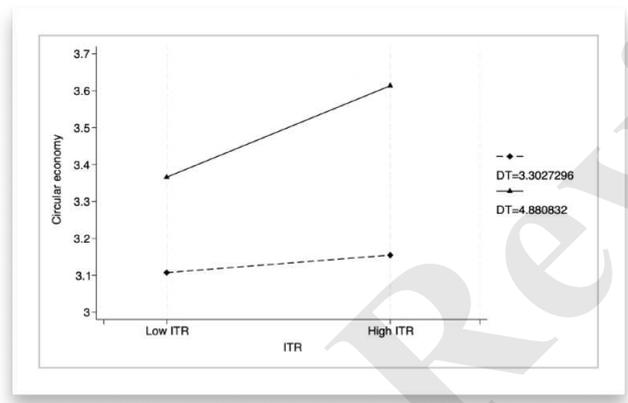|	(1)	(2)	(3)	(4)
	CE	CE	ROA	ROA
ITR	0.083**	0.078**	0.004***	0.004***
	(2.22)	(2.09)	(3.47)	(3.55)
SIZE	0.516***	0.483***	0.013***	0.014***
	(20.94)	(18.99)	(11.68)	(12.63)
LEV	0.028	-0.008	-0.134***	-0.134***
	(0.14)	(-0.04)	(-11.01)	(-10.97)
AGE	0.077	0.099	-0.010***	-0.010***
	(0.84)	(1.08)	(-3.00)	(-3.05)
SOE	-0.207***	-0.171***	-0.007***	-0.007***
	(-3.47)	(-2.85)	(-3.57)	(-3.83)
DUAL	-0.041	-0.052	0.001	0.001
	(-0.66)	(-0.84)	(0.51)	(0.56)
BM	-0.085***	-0.078***	-0.005***	-0.005***
	(-4.88)	(-4.43)	(-9.50)	(-9.48)
DT		0.227***		-0.004**
		(5.11)		(-2.49)
ITR*DT		0.067*		0.001
		(1.85)		(0.49)
Cons	-9.450***	-9.559***	-0.181***	-0.180***
	(-14.00)	(-14.06)	(-6.65)	(-6.62)
N	4248	4248	4248	4248
YEAR	Yes	Yes	Yes	Yes
IND	Yes	Yes	Yes	Yes

Note: *p<0.1, **p<0.05, ***p<0.01.

Figure 2 Moderating effect of DT on the relationship between SCE (as measured by ITR) and CE

Table 5 Instrumental variables method

	(1)	(2)	(3)	(4)
	CE	CE	ROA	ROA
ITR	1.246*	1.380*	0.096***	0.094***
	(1.67)	(1.87)	(3.49)	(3.52)
LEV	0.326	0.178	-0.138***	-0.138***
	(0.61)	(0.33)	(-5.73)	(-5.65)
SIZE	0.311***	0.294***	0.005	0.005*
	(2.98)	(2.69)	(1.50)	(1.70)
DUAL	-0.702***	-0.772***	-0.002	-0.002
	(-3.29)	(-3.73)	(-0.30)	(-0.26)
BM	0.034	0.041	-0.001	-0.002
	(0.55)	(0.66)	(-0.69)	(-0.80)
AGE	-1.136*	-1.269**	-0.037*	-0.037*
	(-1.95)	(-2.18)	(-1.71)	(-1.74)
SOE	-0.907***	0.043	-0.019	0.027**
	(-2.67)	(0.12)	(-1.48)	(2.03)
DT		0.336**		-0.007
		(2.29)		(-1.51)
ITR*DT		0.530***		-0.003
		(2.70)		(-0.40)
_cons	-2.498	-3.132	-0.005	0.012
	(-0.85)	(-1.05)	(-0.05)	(0.11)
N	531	531	531	531
YEAR	Yes	Yes	Yes	Yes
IND	Yes	Yes	Yes	Yes

Note: *$p<0.1$, **$p<0.05$, ***$p<0.01$.

Table 6 Alternative measurement of the dependent variable

	(1)	(2)	(3)	(4)
	CE	CE	ROA	ROA
ITR	0.100***	0.100***	0.004***	0.005***
	(3.62)	(3.68)	(3.61)	(3.65)
SIZE	0.376***	0.360***	0.012***	0.012***
	(23.36)	(21.23)	(14.10)	(13.83)
LEV	-0.501***	-0.511***	-0.148***	-0.148***
	(-4.24)	(-4.32)	(-20.55)	(-20.48)
AGE	-0.129*	-0.115	-0.015***	-0.015***
	(-1.76)	(-1.56)	(-3.43)	(-3.38)
SOE	-0.063	-0.049	-0.007***	-0.007***
	(-1.52)	(-1.18)	(-3.28)	(-3.28)
DUAL	0.148***	0.143***	0.005*	0.005*
	(3.45)	(3.33)	(1.73)	(1.76)
BM	-0.028**	-0.026**	-0.006***	-0.006***
	(-2.53)	(-2.29)	(-9.33)	(-9.28)
DT		0.111***		-0.001
		(3.37)		(-0.57)
ITR*DT		0.049*		0.002
		(1.94)		(1.30)
Cons	-6.959***	-7.035***	-0.143***	-0.145***
	(-15.07)	(-15.17)	(-5.13)	(-5.17)
N	2832	2832	2832	2832
YEAR	Yes	Yes	Yes	Yes
IND	Yes	Yes	Yes	Yes

Note: *p<0.1, **p<0.05, ***p<0.01.

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Table 7 Heterogeneity analysis

Variable	Group 1				Group 2				Group 3			
	state-owned		non-state-owned		large-scale		small and medium-scale		manufacturing industry		non-manufacturing industry	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
	CE	CE	CE	CE	CE	CE	CE	CE	CE	CE	CE	CE
ITR	0.074	0.094*	0.081	0.079	0.181***	0.150**	0.076	0.070	0.186***	0.183***	0.027	0.007
	(1.39)	(1.80)	(1.44)	(1.38)	(2.89)	(2.54)	(1.53)	(1.40)	(2.93)	(2.88)	(0.58)	(0.14)
DT		0.196***		0.197***		0.346***		0.304***		0.110*		0.411***
		(2.94)		(3.22)		(5.15)		(5.12)		(1.91)		(5.36)
ITR*DT		0.182***		-0.005		0.210***		-0.014		-0.061		0.098**
		(3.70)		(-0.09)		(3.84)		(-0.27)		(-0.81)		(2.34)
Cons	-10.777***	-10.771***	-8.618***	-8.635***	4.411***	3.202***	0.502	-0.498	-7.905***	-8.023***	-10.888***	-11.151***
	(-11.09)	(-11.00)	(-10.50)	(-10.42)	(8.28)	(5.59)	(1.10)	(-0.99)	(-6.97)	(-7.09)	(-10.45)	(-10.70)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2185	2185	2063	2063	2124	2124	2124	2124	2557	2557	1691	1691
YEAR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IND	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: *p<0.1, **p<0.05, ***p<0.01