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RESEARCH ARTICLE

Customer Digitalization, Supplier ESG Performance, and Supply Chain Sustainability*

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Abstract

The rapid emergence and widespread permeation of digital technologies are driving the digital transformation of supply chains, offering an opportunity to enhance their sustainability. This paper analyzes the data of Chinese A-share listed companies and their suppliers from 2013 to 2021 and explores the impact that customer enterprises' digitalization exerts on supplier enterprises' environmental, social, and governance (ESG) performance from the perspective of digital empowerment. This paper finds that customer enterprises' digitalization has an enhancement effect on supplier enterprises' ESG performance, i.e., digitalization's empowering effect on the sustainable development of supply chains, which is an asymmetric effect. This effect is more significant when customer enterprises outshine supplier enterprises in terms of digitalization. The mechanism test shows that customer digitalization enhances supplier ESG performance primarily through two empowering effects: structural (i.e., improved supply-chain collaboration) and resource (i.e., alleviated factor constraints on suppliers). Heterogeneity analysis further reveals that this positive effect is more pronounced when local governments' environmental attention is higher or when the customer-supplier relationship is closer. The effectiveness test shows that customer enterprises' digitalization boosts supplier enterprises' ESG performance and helps to enhance supply chain resilience. This paper enriches the research on the influencing factors and implementation mechanisms of sustainable supply chains, broadens the research boundaries of enterprise digitalization and supply chain resilience, and provides important enlightenment for promoting the sustainable development of supply chains in China and enhancing their resilience and security.

Keywords digitalization; environmental, social, and governance (ESG); corporate social responsibility (CSR); sustainability; supply chain resilience

1 Introduction

The report to the 20th National Congress of the Communist Party of China (CPC) points out to "make China's industrial and supply chains more resilient and secure" (Xi, 2022, p. 28). The sustainable development of supply chains, which focuses on balancing the relationships

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among economy, society, and the environment, is an inevitable requirement for promoting the modernization of supply chains, strengthening supply-chain resilience and flexibility, and ensuring supply-chain security and stability. Sustainability has become a new trend and goal for the development of supply chains. Compared with traditional ones, sustainable supply chains depend on an environment of higher visibility. This, in turn, imposes higher demands on communication, data sharing, collaboration, and cooperation among supply chain partners. Due to the limitations of traditional technical means, there are multiple challenges in the process of developing sustainable supply chains: governance difficulties caused by opportunism growing from information asymmetry; tricky problems caused by the bullwhip effect resulting from the mismatch between supply and demand; challenges in addressing responsibility bottlenecks caused by imbalanced capabilities; and the contagion effect of risks caused by high management cost, which is hard to prevent. The breakthrough development and widespread application of digital technologies have provided rare opportunities to address these challenges: They offer a new way, i.e., building digital sustainable supply chains, to achieve the sustainability, security, and stability of supply chains. We are still in the preliminary exploration stage on how to build such digital sustainable supply chains. To profoundly understand and actively build digital sustainable supply chains, it is of great practical significance to find a definite answer to this question: Does digitalization empower the sustainable development of supply chains?

The policy consensus and practical exploration of building digital sustainable supply chains have attracted the attention of the academic community to the digital empowerment for supply chain sustainability. There are two main types of relevant research. The first type mainly discusses the impact of digitalization on supply chain sustainability in the economic dimension, mainly exploring the changes brought by the application of digital technologies to traditional supply chain activities and business processes, as well as the new advantages generated by supply chain innovation (Perano et al., 2023). This type of research focuses on the impact of digitalization on the commercial activities and economic consequences of supply chains (Loske & Klumpp, 2022) and does not involve the impact of digitalization on non-commercial activities and non-economic performances of supply chains. Most existing research belongs to this type. The second line of research analyzes the impact of digitalization on supply chain sustainability, focusing on the social and environmental dimensions. It probes the effects of various digital technologies on more narrowly defined (i.e., social and environmental) sustainable supply chains. (Oguntegbe et al., 2021). This type of research focuses on the impact of digitalization on non-commercial activities and non-economic performance of supply chains (Munir et al., 2022), including direct and indirect effects. At present, although this type of research is increasing, it is still in the preliminary stage, achieving only a few research results and leaving much room for improvement.

At present, there are three shortages in the research on digitalization's impact on sustainable supply chains.

First, there is a lack of research on the supply chain corporate interaction. Different from

the sustainable development of a single enterprise, supply chain sustainability focuses on the sustainability performance of upstream and downstream enterprises. Therefore, the realization of supply chain sustainability is highly dependent on the interaction between upstream and downstream enterprises, especially customer enterprises' influence on supplier enterprises. This is also true for digitalization's impact on supply chain sustainability. Existing studies have explored digitalization's impact on supply chain sustainability performance from the perspective of customer enterprises and have almost implicitly defined "supply chain sustainability" as a part of customer enterprises' sustainable development. Correspondingly, their measurement is based on the perspective of customer enterprises and reflects the so-called sustainable supply chain firm performance (Oubrahim et al., 2023). The sustainability performances of upstream and downstream enterprises in supply chains are not fully reflected or even ignored in such studies, and there is a lack of attention to the interaction between customer enterprises' digitalization and the sustainable development of upstream and downstream enterprises in supply chains.

Second, the conditions and mechanisms of digitalization's empowerment for supply chain sustainability have not been fully explored. While a body of research has examined the indirect effects of digitalization on supply chain sustainability performance, for example, by improving efficiency, optimizing operations, refining processes, enhancing agility (Fantazy & Tipu, 2024), and fostering knowledge development (Thöni & Tjoa, 2017). These studies are predominantly conducted from the perspective of customer enterprises. They also pay inadequate attention to corporate interactions within the chain and often rely on the implicit assumption of simultaneous digitalization across all upstream and downstream partners. What they actually reflect is how the digitalization of each enterprise in a supply chain empowers its own sustainable development rather than the enabling role of supply chain sustainability. The mechanisms and conditions for digitalization to empower the sustainable development of upstream and downstream enterprises in supply chains have not been explicitly revealed.

Third, there is a lack of large-scale empirical research. At present, research on the impact of digitalization on supply chain sustainability predominantly employs qualitative case studies (Oguntegbe et al., 2021) and questionnaire surveys (Oubrahim et al., 2023). There is a notable lack of large-scale empirical testing, which is needed to generate more accurate and reliable results.

This paper delves into the internal dynamics of supply chains by utilizing data from A-share listed companies and their suppliers from 2013 to 2021. From the perspective of interactions between customer enterprises and supplier enterprises, it investigates the enabling role of digitalization in promoting supply chain sustainability. Specifically, it examines whether customer enterprises' digitalization can enhance the environmental, social, and governance (ESG) performance of their suppliers and explores the mechanisms and conditions through which customer enterprises' digitalization influences supplier enterprises' ESG performance. The possible marginal contributions of this paper include the following. Firstly, it reveals the conditions for digitalization to empower supply chain sustainability and enriches the research

on the direct effect of digitalization on supply chain sustainability performance. The large-sample empirical test finds that customer enterprises' digitalization significantly enhances their suppliers' ESG performance, but only when the customers' level of digitalization exceeds that of their suppliers. This shows that the direct effect of digitalization on supply chain sustainability performance exists, but the occurrence of this effect is based on specific scenarios and conditions, which supports the affirmative view (Oubrahim et al., 2023) and the negative conclusion (Fantazy & Tipu, 2024) of relevant research. Secondly, it fully discusses the mechanism of digitalization's empowerment for supply chain sustainability and deepens the research on the indirect effect of digitalization on supply chain sustainability performance. This paper overcomes the limitations of existing research on the indirect effect of digitalization on supply chain sustainability performance (Karmaker et al., 2023). It does so by adopting the perspective of supply chain corporate interaction to conduct a profound analysis of supply chains. It finds that the customer enterprises' digitalization enhances supplier enterprises' ESG performance through structural empowerment and resource empowerment between supply chain enterprises and thoroughly discusses the mechanism of digitalization's empowerment for supply chain sustainability at the micro level. Thirdly, it finds more positive consequences of digitalization's empowerment for supply chain sustainability and expands the relevant research on digitalization's enhancement effect on supply chain resilience. Current research on how digitalization promotes supply chain sustainability exhibits two limitations. (1) Studies on its consequences are predominantly conducted from the customer enterprises' perspective. (2) Investigations into its mechanisms for enhancing resilience are largely confined to economic activities (Belhadi et al., 2024). Conversely, the social dimension of supply chain sustainability remains relatively neglected in this digitalization discourse. This paper finds from the perspective of supply-demand interaction that customer enterprises' digitalization enhances supplier enterprises' ESG performances, which ultimately enhances supply chain resilience. Such findings not only enrich the literature on the empowering effects of digitalization for supply chain sustainability, but also broaden perspectives and increase dimensions for examining how digitalization enhances supply chain resilience.

2 Literature Review and Research Hypothesis

2.1 Literature Review

2.1.1 Corporate Digitalization

Corporate digitalization is a fundamental transformation process underpinned by the innovative use of digital technologies and the strategic leverage of core resources and capabilities, with the purpose of fundamentally upgrading enterprises and redefining their value propositions to stakeholders. Corporate digitalization emphasizes the reshaping of corporate business modes, operation processes, and customer experience, which entails changes at the individual, organizational, and social levels and a wide range of significant effects. Currently,

there are a large number of studies discussing the impact of corporate digitalization, but they mainly focus on the effects at the organizational and the cross-organizational level. At the organizational level, many studies have studied the impact of an enterprise's digitalization on the enterprise itself. These studies can be divided into two categories. The first explores how corporate digitalization affects business performance, demonstrating its positive impacts on governance, operational efficiency, and innovation (Chi et al., 2020; Gao et al., 2023). The other mainly discusses how an enterprise's digitalization impacts its own sustainability, involving issues such as corporate social responsibility or ESG performance, carbon emission reduction, and sustainability performance (Haftor & Climent, 2021; Xiao et al., 2021).

At the cross-organizational level, an enterprise's digitalization induces not only changes within itself but also external changes, i.e., enabling the establishment of an interconnected business network for enterprises and bringing cross-border operation opportunities for enterprises in the supply chain. Some studies have discussed such an impact on the upstream and downstream of a supply chain, and they are divided into three categories. Studies in the first category contend that the impact of corporate digitalization on upstream enterprises, namely, customer enterprises' digitalization, promotes their supplier enterprises' digitalization and innovation (Li et al., 2022; Yang et al., 2022). In the second category, there are studies focusing on the impact of corporate digitalization on downstream enterprises, arguing that the supplier enterprises' digitalization can create delivery value for customer groups (Matarazzo et al., 2021) and increase the supply of business credit to customers. Studies in the third category hold that an enterprise's digitalization impacts the entire supply chain. They believe that corporate digitalization can optimize the geographical distribution of supply chains, improve the trust relationship of the supply chain financial network, and improve supply chain efficiency and performance (Tan et al., 2023).

2.1.2 Corporate ESG Performance

ESG has been a hot topic in the field of financial and corporate economics in recent years, and a large number of studies have been conducted on ESG investment and corporate ESG. ESG investment refers to the ESG concept and ESG factors considered by investors for their investment decisions and activities (Cai & Zhang, 2023; Tang & Jin, 2023), which serve as an essential driving force in the ESG value chain. Corporate ESG is a domain of corporate sustainability actions, which is used to define and describe the non-financial results that an enterprise hopes to achieve (Baid & Jayaraman, 2022). It is a core link in the ESG value chain. This paper studies corporate ESG. The current research on corporate ESG involves corporate ESG information disclosure, ESG measurement and rating, ESG certification, major ESG issues, and ESG management, among which the pre-influence factors and influence effects of corporate ESG performance are the hot spots of corporate ESG research.

From the perspective of pre-influencing factors, some studies focus on the impact of national-level factors, domestic factors, and corporate-level factors on corporate ESG

performance (Rau & Yu, 2024). At the national level, differences in economic development, culture, institutional quality, and legal sources among different countries affect corporate ESG practices and performances differently (Cai et al., 2016; Pinheiro et al., 2024). In terms of domestic factors, political affiliation and social capital are considered important factors influencing corporate ESG behaviors and performances (Jha & Cox, 2015). At the corporate level, governance and operational factors have a significant impact on corporate ESG performance. The former mainly involves executive-team characteristics and shareholding characteristics (Lei et al., 2023), while the latter is related to organizational resilience, corporate digitalization, merger and acquisition behaviors, etc. (Liang & Li, 2023; Xiao et al., 2021). In terms of influencing effects, many studies focus on the impact of corporate ESG performance on corporate performance, including financial performance, corporate value, innovation performance, and employment performance (Fang & Hu, 2023; Mao & Wang, 2023; Shi & Wang, 2023).

2.1.3 Sustainable Supply Chains

Supply chain sustainability constitutes an important part of supply chain management. It is to implement the concept of sustainable development throughout the supply-chain process and expand the traditional supply-chain management objectives: the traditional sole emphasis on economic dimension being replaced with the so-called "triple bottom lines," i.e., economic benefits, social responsibility, and environmental protection from a strategic height, or the emphasis on the social and environmental dimensions of supply chain management. The former entails a broad-sense sustainable supply chain, and the latter, a narrow-sense sustainable supply chain. This paper adopts the narrow-sense definition of sustainable supply chains.

From the perspective of the customer-supplier relationship, the existing studies on sustainable supply chains fall into two categories. The first category contains studies on the preference of customer enterprises for supplier enterprises' sustainability performances when selecting new suppliers. Existing research has found that when selecting suppliers, customer enterprises will consider their environmental/green performance and environmental standards and prefer suppliers with strong social responsibility (Tao et al., 2023). Studies in the second category mainly discuss the impact of customer enterprises on their suppliers' sustainable development. The early literature mainly adopts the method of questionnaire survey and finds that customer enterprises have a positive impact on supplier enterprises' sustainable development. For example, Zhu and Sarkis (2007) find through survey research that customer enterprises encourage supplier enterprises to implement green supply-chain management and improve environmental performance. The recent research usually uses empirical methods and also finds this relationship from the perspectives of supply-chain diffusion, spillover, or synergy. For example, Tang et al. (2023) find that customer enterprises' ESG performance has a spillover effect on supplier enterprises' ESG performance.

From the perspective of the relationship between digitalization and sustainable supply chains, existing research basically focuses on the impact of digitalization on sustainable supply chains. The main views can be summarized as follows. Firstly, digitalization is a driving factor for sustainable supply chain practice, and the application of digital technologies can provide information support for decisions on sustainable supply chain practices, which is a key driving factor for the integration of sustainable supply chains and plays a role in promoting the implementation of sustainable supply chains (Khan et al., 2022). Secondly, digitalization can directly or indirectly improve supply chain sustainability performance. From the perspective of direct impact, the use of digital technologies in supply chain management has a positive impact on environmental and social sustainability performances. Digital transformation and the application of Industry 4.0 technologies are believed to significantly improve supply chain sustainability performance (Karmaker et al., 2023; Oubrahim et al., 2023). Nevertheless, some researchers have found that digitalization has no direct impact on supply chain sustainability performance (Fantazy & Tipu, 2024). From the perspective of indirect impact, the positive impact of digitalization on supply chain sustainability performance can be achieved by increasing efficiency, optimizing operations, improving processes, and enhancing agility, traceability, transparency, accountability, and knowledge development (Fantazy & Tipu, 2024; Munir et al., 2022; Thöni & Tjoa, 2017).

In summary, while existing literature offers some support for the link between digitalization and supply chain sustainability, primarily from the perspectives of customer enterprises and the supply chain as a whole, significant gaps remain. Specifically, there is a lack of in-depth research that examines the empowering effect and underlying mechanisms through the lens of detailed supply chain analysis and corporate interactions. Furthermore, the contingent conditions and specific mechanisms of this empowerment have yet to be thoroughly explored at the micro level. Given that the customer-supplier relationship plays a vital role in promoting the practice of supply chain sustainability and that the secret of a successful sustainable supply chain lies in effective supplier relationships and appropriate cooperation, it is particularly necessary to study empowerment from the perspective of customer-supplier interaction. This paper, based on the empowerment theory, deeply examines the impact of customer enterprises' digitalization on supplier enterprises' ESG performance to clarify the conditions and mechanisms of the empowerment at the micro level and provide new support for the development of sustainable supply chains.

2.2 Research Hypothesis

Since the 1980s, empowerment theory has become an important theory in the fields of psychology, sociology, and organizational management. In the digital economy era, empowerment has been given a new meaning, and the concept of digital empowerment has emerged. Digital empowerment refers to the application of digital technologies to transform organizational structures, business processes, and management systems, as well

as to improve employees' skills, knowledge, and confidence (Leong et al., 2015). Digital empowerment exists in three situations, i.e., intra-organizational, inter-organizational, and non-organizational situations. Digital empowerment between supply chain enterprises is a typical inter-organizational empowerment. Digital empowerment includes three types: structural empowerment, psychological empowerment, and resource empowerment (Leong et al., 2015). Structural empowerment refers to the improvement of external objective conditions and the empowerment of organizations to take action so that organizations can obtain relevant information, resources, and opportunities. Psychological empowerment refers to efforts to give employees the feeling of being in control of their fate by enhancing social psychology, intrinsic motivation, or employees' subjective interpretations (such as self-awareness and self-confidence). Resource empowerment refers to the improvement in the ability of those who are not capable to obtain, control, or manage resources. In an inter-organizational context, empowerment of supply chain enterprises primarily takes two forms: structural and resource-based, as psychological empowerment is typically not involved. Customer enterprises' digitalization can promote the formation of digital empowerment between supply chain enterprises, which relies on digital technologies to achieve more effective structural empowerment and resource empowerment, promote supply chain collaboration, and alleviate the factor constraints on empowered enterprises. In view of this, this paper believes that customer enterprises' digitalization can affect supplier enterprises' ESG performance through the structural empowering effect and the resource empowering effect.

2.2.1 The Structural Empowering Effect (*i.e., Improvement in Supply-Chain Collaboration*)

The structural empowerment between supply chain enterprises is mainly to optimize the structure, process, and connection between supply chain enterprises and promote supply chain collaboration. That is, two or more supply chain functional subjects respond to customer needs through information sharing, resource integration, business collaboration, etc. The digitalization of customer enterprises can enhance the structural empowerment between supply chain enterprises and form the digital structural empowerment between supply chain enterprises. Digital technologies are utilized for the following purposes: to optimize the supply chain structure, policies, and channels and change the existing conditions (Khin & Ho, 2020); to eliminate the structural barriers and obstacles that hinder enterprises from obtaining information, opportunities, and resources; to form strong relationship embedding and structural embedding; to enhance the mutual trust, cooperation, knowledge sharing, and joint action between customer enterprises and supplier enterprises; and to promote the formation of a stable community of interests for multiple subjects of the supply chain. Further, supply chain sustainability performance is highly dependent on supply chain corporate cooperation, and the construction of a sustainable supply chain requires the establishment of a good collaborative relationship between customer enterprises and supplier enterprises. Customer enterprises' digitalization can promote the digital structural empowerment between supply chain enterprises and the supply chain collaboration in terms of risk management, operation,

and transparency, thus enhancing the ESG performance of supplier enterprises.

(1) *Risk management collaboration.* The digitalization of customer enterprises enhances joint management and collaborative control of supply chain risks, thereby reducing the social and environmental risks inherent in supplier operations. This, in turn, contributes to the improved ESG performance of supplier enterprises. The contagion effect of risks in supply-chain networks determines that customer enterprises and supplier enterprises form a community of common destiny. Preventing supply chain ESG risks and enhancing supply chain legitimacy are important aspects of supply chain management for customer enterprises. In the traditional supply chain networks, customer enterprises and supplier enterprises manage their ESG risks separately due to information asymmetry. Customer enterprises often lack the information and capability to effectively oversee their suppliers' ESG risks. Furthermore, a coordinated risk management mechanism to address systemic ESG risks across the supply chain is absent. The digitalization of customer enterprises usually incorporates supply chain risk management into supply chain digitalization: It integrates the management of suppliers' ESG risks into the bottom architecture of supply chain risk management through the deep embedding of digital technologies; realizes the real-time identification, monitoring, tracking, and management of supply chain ESG risks; promotes the digital management of ESG risks of upstream and downstream enterprises in the supply chain; and forms a linkage management mechanism targeting ESG risks based on massive unstructured data sharing. In this way, the problem that upstream and downstream enterprises of a supply chain are forced to manage ESG risks separately can be solved, and the ESG risk management collaboration between customer enterprises and supplier enterprises can be strengthened.

(2) *Operational collaboration.* The digitalization of customer enterprises can enhance supply chain collaboration in terms of business, resources, and management; maximize the efficiency of supply chain enterprises and supply chain activities to create comprehensive value; and improve the ESG performance of supplier enterprises. Firstly, customer enterprises' digitalization usually involves the reorganization and digital reconstruction of supply-chain processes. Customer enterprises use digital technologies to promote the integration of production, sales, and distribution; ensure more accurate and immediate supply-demand matching between customer enterprises and supplier enterprises; and actualize closer and more efficient upstream-downstream business collaboration, thus strengthening the ESG-behavior synergy entailed by business collaboration. Secondly, through digitalization, customer enterprises optimize both their internal and external resource management. This, in turn, promotes the integration and optimal allocation of supply chain resources, ultimately achieving resource sharing and capability complementarity between customers and suppliers. Through the supply chain knowledge sharing and technological support enabled by their digitalization, customer enterprises can help suppliers improve their ESG practices (Pimenta et al., 2021), which in turn elevates the level of social value co-creation across the supply chain. Finally, customer enterprises' digitalization can realize real-time information sharing in the supply chain, greatly improve the decision-making efficiency of enterprises, and facilitate

the upstream-downstream management connection and matching. This helps to avoid the internal frictions in customer-supplier management activities, realizes better operational collaboration, and improves supplier enterprises' governance ability and management efficiency, including ESG management ability.

(3) *Transparency collaboration.* Customer enterprises' digitalization can enhance the information sharing and visibility of supply chains, enhance the governance of supply chain enterprises' and supply chain activities' responsibilities for stakeholders and the general public, and improve the ESG performance of supplier enterprises. Supply chain transparency is essential for the effective implementation of environmental and social policies and constitutes an important part of supply chain sustainability management. In a traditional supply chain relationship network, supply chain transparency is a challenge. There are two main reasons: the lack of information disclosure by supply chain members, which is caused by information asymmetry and conflicts of interest, and the fact that the supply chain is too long for the tracking, measurement, and monitoring of relevant environmental and social information of suppliers at different levels. Customer enterprises' digitalization can largely solve these challenges, mainly by enhancing supply chain traceability and information-disclosure collaboration of supply chain enterprises. When applied, digital technologies enable the recording, tracing, and sharing of all kinds of information. This allows product or service data to be effectively tracked and linked to every stage of the supply chain. This way is more convenient to track the history, source, and movement of products or services in the supply chain, which significantly enhances the traceability of the supply chain. The application of digital technologies also facilitates information disclosure (Xiao et al., 2021), especially supply chain information disclosure, which entails higher requirements for supplier enterprises' information disclosure. To obtain legitimacy in the supply chain and in society, supplier enterprises often engage in information-disclosure collaboration with customer enterprises through institutional isomorphism mechanisms for better social and environmental information disclosure.

2.2.2 The Resource Empowering Effect (*i.e., Alleviation in Factor Constraints on Suppliers*)

The resource empowerment between supply chain enterprises mainly enhances the ability of empowered enterprises to acquire, integrate, and release resources, such as capital, technologies, and professional knowledge and skills. Customer enterprises' digitalization is conducive to promoting resource empowerment and forming digital resource empowerment on supplier enterprises. That is, digital technologies are used as a means to connect resources and promote the innovation and optimization of resource acquisition methods: enhancing supplier enterprises' abilities to acquire, control, and manage resources and effectively improving their ability to cope with uncertainty (Chi et al., 2020). According to the resource orchestration theory, enterprises facing resource constraints can gain competitive advantages through network relationships with their supply chain partners, and

the resource constraints on supplier enterprises can be alleviated or even solved through resource orchestration between supply chain partners. The digitalization of customer enterprises is conducive to the resource orchestration between supply chain partners, including resource sharing, transformation, and coordination. Further, resources are the basis and guarantee for enterprises to implement ESG, and higher resource redundancy, especially non-sedimentary redundant resources, is conducive to enhancing the willingness and action of enterprises to implement ESG (Chiu & Sharfman, 2011). The digital resource empowerment enabled by customer enterprises' digitalization within supply chains can alleviate suppliers' financing constraints and promote their green innovation, thereby addressing key capital and green technology bottlenecks. This effect is particularly pronounced for small and medium-sized enterprises and ultimately improve their ESG performance.

(1) *Mitigating financing constraints.* Customer enterprises' digitalization can reduce the financing costs and the information asymmetry between financial institutions and supply chain enterprises, increase supplier enterprises' capital redundancy and capital resources that can be invested in environmental and social actions, and improve the ESG performance of supplier enterprises. The digitalization of a customer enterprise facilitates the information flow of the supply chain, enhances the supply-chain information sharing and transparency, boosts the information interaction between financial institutions and supplier enterprises, and strengthens their information connection, which enables financial institutions to grasp diversified information of supplier enterprises, reduces the information asymmetry between them, solves the problem of weak trust, and increases financial institutions' willingness to lend. In particular, the application of blockchain technology in supply-chain management by customer enterprises can ensure the immutability of supplier enterprises' information, improve the credibility of the information, solve the problem of adverse selection in financing, reduce the cost of financing, and alleviate the financing constraints. In addition, customer enterprises' digitalization is conducive to building a digital supply chain financial platform and improving customer enterprises' ability to implement supply chain finance. Supply chain finance will grant credit to the supply chain as a whole and realize credit binding between customer enterprises and supplier enterprises (Ling et al., 2023), which can solve a series of problems for supplier enterprises, especially small and medium-sized supplier enterprises, such as high operational uncertainties, information asymmetry, and weak mortgage guarantee ability; alleviate financing constraints on them; and enhance the support for their sustainable development.

(2) *Promoting green innovation.* The digitalization of customer enterprises can enhance the willingness, ability, and efficiency of supplier enterprises to carry out green innovation, reduce negative environmental externalities for them, increase positive social externalities, and improve their ESG performances. Digitalization is an important driving force for green activities. Customer enterprises' digitalization is conducive to promoting the integration of green supply chains (Benzidia et al., 2021), involving green information sharing, green

process coordination, and green strategic alliances. Firstly, the application of digital technologies significantly improves the green transparency and visibility of supply chains and actualizes the instant sharing of environmental information and green technology information between customer enterprises and supplier enterprises, thereby enhancing supplier enterprises' willingness, ability, and efficiency to carry out green innovation. Secondly, customer enterprises' digitalization can promote whole-process green management of supply chains, propel supplier enterprises to adopt a clearer vision and formulate relevant strategies for green innovation, and enhance their green innovation procedural capability and resource allocation efficiency in the regard. Finally, the application of digital technologies reduces environmental information asymmetry among supply chain enterprises and fosters green cooperation between customers and suppliers (Benzidia et al., 2021). This, in turn, promotes the formation of green strategic alliances. Through the sharing of resources, costs, and benefits, it enhances supplier enterprises' motivation, capability, and efficiency in pursuing green innovation. Through green innovation, supplier enterprises can upgrade their green production technologies and clean-production processes and give better environmental performance. With green production environments, green products, and green technology diffusion, they also create positive values for their employees, customers, and other stakeholders and offer benefits for the general public. Given all of the above, this paper puts forward the following research hypothesis.

H1: Customer enterprises' digitalization improves supplier enterprises' ESG performance.

3 Research Design

3.1 Samples and Data

This paper draws on the research done by Yang et al. (2022) and obtains from the China Stock Market & Accounting Research Database (CSMAR) the data on China's A-share listed companies and their top five suppliers from 2013 to 2021. We manually sorted out the data and did the following processing: (1) excluding the samples involving companies whose top five supplier enterprises were listed companies in the financial and insurance sectors; (2) eliminating the samples where customer enterprises or supplier enterprises were labeled ST or *ST; and (3) eliminating the samples with missing data for the variables of customer enterprises or supplier enterprises. A total of 2,503 "customer-supplier-year" observations were ultimately obtained, which is basically consistent with the existing relevant study (Yang et al. 2022).

Other data sources for this paper include ESG rating data from Sino-Securities Index Information Service (Shanghai) Co., Ltd. (Sino-Securities Index); corporate digitalization data obtained through text analyses and word frequency statistics of the annual reports of listed companies; and all the other corporate financial data acquired from CSMAR. To avoid the influence of extreme values, we winsorized all continuous variables at the upper and lower 1%.

3.2 Model Construction and Variable Definitions

To examine the impact of customer enterprises' digitalization on supplier enterprises' ESG performance, this paper constructs the following econometric model:

$$ESG_supplier_{i,t} = \alpha + \beta Digital_customer_{j,t-1} + \gamma Controls + Industry_i + Year_t + \varepsilon, \quad (1)$$

where i represents a supplier enterprise, j represents a customer enterprise, t represents a year, ε represents the residual term, and *Controls* represent the control variables that simultaneously control both the customer enterprise and the supplier enterprise.

ESG_supplier is the explained variable, representing a supplier enterprise's sustainability. This paper draws on the research of Xie and Lü (2022) and measures corporate sustainability by the ESG scores given by the Sino-Securities Index. Sino-Securities Index's ESG rating data covers all A-share listed companies, and the rating is carried out quarterly for each of the companies. The rating results are divided into nine grades. We took the following steps to process the ESG scores obtained by these companies. Firstly, according to the rating grades from low to high, the quarterly ESG rating results were assigned 1 to 9. Secondly, we calculated the yearly average ESG scores of the companies.

Digital_customer is the explanatory variable, which represents the digitalization of a customer enterprise. This paper draws on the research done by Yang et al. (2022) and creates indicators for corporate digitalization through text analyses and word frequency statistics. Firstly, based on the expressions related to "digitalization" in relevant national policy documents, we extracted keywords related to "digitalization" and built a digitalized semantic feature word bank. Secondly, based on the word library, we conducted text analyses and word frequency statistics on the annual reports of listed companies. Thirdly, the word frequencies of keywords related to corporate digitalization are summed up to obtain the total digitalization word frequency, and the frequency is logarithmically processed. The semantic feature word library of corporate digitalization adopted in the main regression of this paper consists of 75 keywords related to digitalization, which were replaced with 127 related keywords in the robustness test.

Controls represent control variables. This paper draws on the approach adopted by Tang et al. (2023) and adopts the following control variables: supplier-enterprise-trait variables, supplier-enterprise-governance variables, and customer-enterprise-trait variables. Supplier-enterprise-trait variables include asset size (*Size_supplier*), liabilities (*Lev_supplier*), years on the market (*Age_supplier*), return on assets (*ROA_supplier*), corporate growth potential (*Growth_supplier*), state ownership (*SOE_supplier*), book-to-market ratio (*BM_supplier*), and corporate digitalization (*Digital_supplier*). Supplier-enterprise-governance variables include the shareholding ratio of the largest shareholder (*Top_supplier*) and CEO duality (*Duality_supplier*). Customer-enterprise-trait variables include asset size (*Size_customer*), liabilities (*Lev_customer*), years on the market (*Age_customer*), return on assets (*ROA_customer*), corporate growth (*Growth_customer*), state ownership (*SOE_customer*), and book-to-market

ratio (*BM_customer*). Descriptive statistics for all variables are listed in Table 1.[1] Besides, this paper draws on the research done by Li et al. (2022) and controls for year (*Year*) and industry (*Industry*) fixed effects.

Table 1 Descriptive Statistics of Variable

Variable	*n*	*AVE*	*SD*	*Min*	25% quantile	*Mdn*	75% quantile	*Max*
ESG_supplier	2,503	4.489	1.206	1	4	5	5	7
Digital_customer	2,503	2.838	1.307	0	1.946	2.773	3.584	6.178
Size_supplier	2,503	24.303	2.051	20.356	22.827	23.957	25.721	28.543
Lev_supplier	2,503	0.532	0.181	0.103	0.422	0.536	0.666	0.890
Age_supplier	2,503	2.584	0.667	0	2.303	2.773	3.045	3.332
ROA_supplier	2,503	0.040	0.046	–0.133	0.017	0.035	0.058	0.182
Growth_supplier	2,503	0.190	0.428	–0.557	–0.024	0.089	0.294	2.574
SOE_supplier	2,503	0.642	0.48	0	0	1	1	1
BM_supplier	2,503	0.800	0.278	0.148	0.602	0.836	1.020	1.270
Digital_supplier	2,503	3.245	1.177	0	2.485	3.178	3.85	6.304
Top_supplier	2,503	0.425	0.184	0.102	0.274	0.405	0.572	0.802
Duality_supplier	2,503	0.206	0.405	0	0	0	0	1
Size_customer	2,503	22.433	1.285	19.986	21.565	22.28	23.107	25.949
Lev_customer	2,503	0.463	0.199	0.072	0.301	0.458	0.612	0.884
Age_customer	2,503	2.390	0.775	0	1.946	2.485	3.045	3.367
ROA_customer	2,503	0.027	0.062	–0.292	0.011	0.030	0.053	0.164
Growth_customer	2,503	0.488	1.358	–0.610	–0.022	0.149	0.505	8.701
SOE_customer	2,503	0.456	0.498	0	0	0	1	1
BM_customer	2,503	0.663	0.269	0.126	0.453	0.674	0.878	1.195

4 Empirical Analysis

4.1 Benchmark Regression

Table 2 reports the regression results on the impact of customer enterprises' digitalization on supplier enterprises' ESG performance. Among them, column (1) of Table 2 shows the univariate regression results on the impact of customer enterprises' digitalization on supplier enterprises' ESG performance; column (2) shows the results after controlling for industry and year fixed effects based on the results shown in column (1); column (3) shows the results after involving the control variables of supplier enterprises based on the results in column (2);

[1] Due to page limitations, for specific variable definitions, please refer to Appendix 1 published on the website of *Economic Research Journal*.

and column (4) shows the results after involving the control variables of customer enterprises based on the results in column (3). All results show that the coefficient of *Digital_customer* is at least significant at the 5% level, indicating that customer enterprises' digitalization can empower supplier enterprises' sustainability. This verifies *H1*.

Table 2 Benchmark Regression: Customer Enterprises' Digitalization and Supplier Enterprises' ESG Performance

Variable	(1)	(2)	(3)	(4)
	ESG_supplier	*ESG_supplier*	*ESG_supplier*	*ESG_supplier*
Digital_customer	0.038**	0.059***	0.051***	0.060**
	(2.281)	(3.661)	(2.696)	(2.996)
Size_supplier			0.349***	0.349***
			(18.117)	(13.643)
Lev_supplier			–0.919***	–0.832***
			(–5.775)	(–4.788)
Age_supplier			–0.231***	–0.214***
			(–6.294)	(–3.115)
ROA_supplier			2.504***	2.510***
			(4.499)	(6.150)
Growth_supplier			0.025	0.058
			(0.505)	(1.048)
SOE_supplier			0.240***	0.250***
			(4.279)	(4.343)
BM_supplier			–0.089	–0.084
			(–0.738)	(–0.324)
Digital_supplier			0.051**	0.058**
			(2.172)	(2.794)
Top_supplier			–0.178	–0.194
			(–1.192)	(–1.013)
Duality_supplier			0.006	0.018
			(0.118)	(0.254)
Size_customer				–0.035
				(–0.808)
Lev_customer				–0.327
				(–1.294)
Age_customer				0.018
				(0.335)

(*To be continued*)

(*Continued*)

Variable	(1) *ESG_supplier*	(2) *ESG_supplier*	(3) *ESG_supplier*	(4) *ESG_supplier*
ROA_customer				–0.041 (–0.104)
Growth_customer				–0.031** (–2.832)
SOE_customer				0.066 (0.924)
BM_customer				0.165 (1.340)
_cons	4.418*** (87.074)	4.554*** (76.520)	–3.279*** (–9.043)	–2.672** (–2.363)
Year fixed effects	No	Yes	Yes	Yes
Industry fixed effects	No	Yes	Yes	Yes
n	3,013	3,013	2,600	2,503
Adj. R^2	0.001	0.086	0.282	0.290

Note. *** $p < 0.01$ and ** $p < 0.05$. *t*-values are provided in parentheses. The results are clustered at the industry level.

4.2 Asymmetry Test on Digital Empowerment

The benchmark regression results provoke such a thought: Do the results exist symmetrically in the two scenarios, i.e., the scenario of customer enterprises outshining supplier enterprises in terms of digitalization and that of supplier enterprises outshining customer enterprises in terms of digitalization? To solve this problem, this paper draws on the research done by Houston and Shan (2022) and breaks the sample into two groups. One group involves customer enterprises outshining supplier enterprises in digitalization; the other group, supplier enterprises outshining customer enterprises in digitalization. The regression test is carried out according to model (1). Results in column (1) of Table 3 show that when customer enterprises outshine supplier enterprises in digitalization, customer enterprises' digitalization has a significant promoting effect on supplier enterprises' ESG performance. On the contrary, when supplier enterprises outshine customer enterprises in digitalization, the promoting effect of customer enterprises' digitalization on supplier enterprises' ESG performance is not significant. That is, the promoting effect of customer enterprises' digitalization on supplier enterprises' ESG performance is asymmetric: Only when customer enterprises surpass supplier enterprises in their level of digitalization can they effectively empower suppliers' sustainability through digitalization.

Table 3 Asymmetry Test on Customer Enterprises' Digital Empowerment

Variable	(1) Customers outshining suppliers in digitalization	(2) Suppliers outshining customers in digitalization
Digital_customer	0.124***	0.049
	(3.835)	(1.516)
Controls	Yes	Yes
_cons	–1.127	–3.921***
	(–0.462)	(–5.544)
Year fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes
n	939	1,548
Adj. R^2	0.262	0.313

Note. *** $p < 0.01$. *t*-values are provided in parentheses. The results are clustered at the industry level.

4.3 Robustness Test

4.3.1 Treatment of the Endogeneity Issue

(1) *Instrumental variable method.* There may be a problem of mutual causality in this paper; that is, supplier enterprises with better ESG performance may be more attractive to customer enterprises boasting a higher level of digitalization. To solve this problem, the two-stage least squares (2SLS) method is used. The digital industry talent input is selected as the instrumental variable, and the construction of this instrumental variable is as follows. Firstly, the ratios of the numbers of employees in the information transmission, computer service, and software industries in the cities where customer enterprises are located to the total numbers of employees in the information transmission, computer service, and software industries in the province where customer enterprises are located, with the numbers lagging one period, are obtained. Secondly, the ratios are divided into five equal parts according to the time and location. Thirdly, assigned values. If the ratio belongs to the first two parts, the instrumental variable (*IV*) takes the value of 1; otherwise, it is 0. In addition, considering that some supplier enterprises and customer enterprises are in the same city in the sample, customer enterprises' ESG performance may be affected by the instrumental variable. That is, it does not meet the exclusivity requirements of the instrumental variable. To solve this problem, we removed from the sample the data relating to this situation. After completing the above processing, it is reasonable to contend that the instrumental variable meets the scientific requirements. First of all, the digitalization of a customer enterprise is inseparable from the talent support of the digital industry in the city where it is located, so the instrumental variable meets the correlation requirements. Secondly, the digital industry talent input in the city where the customer enterprise is located is unlikely to affect the ESG performance of its supplier enterprises in a different city. That is, the instrumental variable meets the exclusivity

requirements. In addition, we also tested the validity of the instrumental variable. The Cragg-Donald Wald *F* value is 11.828, which is greater than 10, so the weak instrumental variable hypothesis is rejected. This indicates that the instrumental variable meets the relevant requirements.

The retesting results obtained through the 2SLS method are shown in columns (1) and (2) of Table 4. The first-stage results indicate that the coefficient of the instrumental variable (*IV*) is significantly positive at the 5% level, satisfying the relevance condition. Furthermore, the second-stage results show that the coefficient of *Digital_customer* remains significantly positive at the same level after controlling for endogeneity, which confirms the robustness of the positive effect of customer digitalization on supplier ESG performance.

(2) *Propensity score matching (PSM) method.* To overcome the endogenous problems caused by systematic differences in control variables between supply chain samples with high-level digitalization and those with low-level digitalization. This paper draws on the research done by Li et al. (2022) and uses the PSM method for testing. Firstly, the sample was divided into two groups, i.e., customer enterprises with high-level digitalization and those with low-level digitalization, according to their year and industry medians. Secondly, we selected the control variables of the benchmark regression as the concomitant variables and used the 1∶1 replaceable nearest-neighbor caliper matching method (caliper: 0.01) for matching. After the matching, the mean values of the concomitant variables in the two groups are not significantly different, so the balance hypothesis is met.[2]

Finally, the matched samples were re-regressed. The results are shown in column (3) of Table 4. The coefficient of *Digital_customer* is significantly positive at the 5% level, indicating that after the PSM, customer enterprises' digitalization still has a significant promoting effect on supplier enterprises' ESG performance.

(3) *Difference-in-Differences (DID) method.* We involved the policy impact of state-owned enterprises' digital transformation to further solve the endogeneity issue. In 2020, the General Office of the State-Owned Assets Supervision and Administration Commission of the PRC State Council issued the *Notice on Accelerating the Digital Transformation of State-Owned Enterprises*,[3] requiring state-owned enterprises to accelerate their digital transformation. According to this, we constructed a DID model to examine the impact of customer enterprises' digitalization on supplier enterprises' ESG performance. According to whether the customer enterprises are affected by the policy, the customer enterprises are divided into two groups: Those affected by the policy in the sample are taken as the experimental group, and the unaffected ones are taken as the control group. *Treat* is a virtual variable to distinguish the experimental group and the control group. *Post* is a time dummy variable. Considering the balance of the samples, this paper defines the year of the policy release (2020) and subsequent years as the year of policy effectiveness, with a value of 1, and 2018 and 2019

[2] Due to space limitations, the PSM balance test results are detailed in Appendix 2 published on the website of *Economic Research Journal*.

[3] The corresponding Chinese name is 关于加快推进国有企业数字化转型工作的通知.

as the years before the policy effectiveness, with a value of 0. For the DID test, the interaction term *Treat*Post* is generated. The results in column (4) of Table 4 show that in comparison with customer enterprises that are not affected by the digital transformation policy, customer enterprises that are affected by the policy exert a more significant promoting effect on supplier enterprises' ESG performance after the policy release. This further supports the benchmark regression results.

Table 4 Robustness Tests: The Instrumental Variable Method, PSM, and DID

Variable	First stage (1) *Digital_customer*	Second stage (2) *ESG_supplier*	PSM (3) *ESG_supplier*	DID (4) *ESG_supplier*
IV	0.243*** (3.439)			
Digital_customer		0.421** (2.101)	0.051** (2.886)	
Treat∗Post				0.178* (1.937)
Controls	Yes	Yes	Yes	Yes
_cons	–1.216* (–1.655)	–2.089** (–2.394)	–2.763* (–1.863)	–3.468** (–2.422)
Year fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
n	2,135	2,135	1,832	1,471
Adj. R^2	0.338	0.188	0.284	0.345

Note. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. *t*-values are provided in parentheses. The results are clustered at the industry level.

(4) *Heckman two-stage model.* The sample in this paper is constructed based on the data about the top five suppliers of customer enterprises. Since such information is not within the scope of mandatory disclosure of listed companies, not all customer enterprises have disclosed their supplier information in detail. That is, there may be a problem of sample selection bias. The Heckman two-stage model is used to deal with this problem. First, the probit regression model was used to estimate the possibility of supplier enterprises obtaining ESG ratings, and the inverse Mills ratio (*IMR*) of the self-selection parameter was obtained. Specifically, in the first-stage regression, we calculated the median of the supplier enterprises' ESG scores for each year. If a supplier enterprise's score was greater than the median, *ESG_Dummy* was assigned a value of 1; otherwise, it was 0. The exogenous variable (*Mandatory*) in this paper represents whether a supplier enterprise is required to disclose an annual social

responsibility report or sustainability report. *Mandatory* is a virtual variable. If a supplier enterprise was required to disclose corporate social responsibility reports or sustainability reports in a given year, *Mandatory* was assigned a value of 1; otherwise, it was 0. Other control variables were kept consistent with those in model (1). After that, the *IMR* obtained in the first-stage regression was involved in the second-stage model as an additional control variable for re-regression. The results are shown in columns (1) and (2) of Table 5. In the first stage, *Mandatory* is significantly positively correlated with *ESG_Dummy* at the 1% level. In the second stage, after controlling for the sample selection bias, the coefficient of *Digital_customer* is still significantly positive, which is consistent with the benchmark regression results.

(5) *Change model.* To better mitigate endogeneity concerns arising from omitted variables, we employ a first-difference model by replacing all variables in the benchmark regression with their year-to-year changes. As shown in column (3) of Table 5, there remains a significantly positive correlation between the changes in customer digitalization (*Digital_change*) and the changes in supplier ESG performance (*ESG_change*), further confirming the robustness of our main findings.

Table 5 Robustness Tests: Heckman Two-Stage Model and Change Model

Variable	First stage (1) *ESG_Dummy*	Second stage (2) *ESG_supplier*	Change model (3) *ESG_change*
Mandatory	0.231*** (3.093)		
Digital_customer		0.034** (2.574)	
Digital_change			0.051** (2.754)
IMR		0.871*** (10.783)	
Controls	Yes	Yes	Yes
_cons	–4.867** (–2.311)	–2.171 (–1.428)	0.422*** (5.341)
Year fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
n	3,876	2,489	2,153
Adj. R^2		0.558	0.068

Note. *** $p < 0.01$ and ** $p < 0.05$. *t*-values are provided in parentheses. The results are clustered at the industry level.

4.3.2 Other Robustness Tests

(1) *Changing the fixed effects.* This paper draws on the study of Tang et al. (2023) and constructs the following two fixed-effect models: The first is to replace the industry and year fixed effects with firm and year fixed effects; the second is to simultaneously control for the industry fixed effect of the customer enterprise, the industry fixed effect of the supplier enterprise, and the year fixed effect. The results are shown in columns (1) and (2) of Table 6. The coefficient of *Digital_customer* remains significantly positive at the 1% level, which is consistent with the benchmark regression results.

(2) *Changing the method to measure the explanatory variable.* This paper draws on the study of Lee and Oh (2019) and adopts the TF-IDF method to re-measure corporate digitalization, where TF represents word frequency, which is obtained by dividing the total word frequency of a digitalization keyword of an enterprise by its total word frequency in corporate annual reports and is used to measure the frequency of a digitalization keyword in an enterprise's annual report. IDF is the inverse document frequency, which is measured by the logarithm of the calculation result of this procedure: dividing the number of annual reports of a listed company by the sum of 1 and the number of corporate annual reports containing a certain digitalization keyword. Because the measurement of corporate digitization in the benchmark regression involves 75 keywords, it is necessary to average the IDFs of different keywords obtained by the above method. Finally, TF-IDF is equal to the product of TF and IDF. In addition, the re-measurement of corporate digitalization (*Digital_alter*) is realized through the logarithm of the sum of the total word frequencies of 127 keywords related to corporate digitalization. The corporate-digitalization re-measurement result obtained by the above two methods is used to replace the original explanatory variable for re-regression. The results are shown in columns (3) and (4) of Table 6. The coefficients of *TF-IDF* and *Digital_alter* are significantly positive, which is consistent with the results of the benchmark regression.

Table 6 Robustness Tests: Changing the Fixed Effects, Changing the Method to Measure the Explanatory Variable, and Changing the Sample

Variable	Changing the fixed effects	Changing the fixed effects	Changing the measurement method of the explanatory variable	Changing the measurement method of the explanatory variable	Changing the sample
	(1)	(2)	(3)	(4)	(5)
	ESG_supplier	*ESG_supplier*	*ESG_supplier*	*ESG_supplier*	*ESG_supplier*
Digital_customer	0.058***	0.088***			0.081***
	(2.595)	(4.126)			(3.099)
TF-IDF			85.021*		
			(2.138)		

(*To be continued*)

(*Continued*)

Variable	Changing the fixed effects	Changing the fixed effects	Changing the measurement method of the explanatory variable	Changing the measurement method of the explanatory variable	Changing the sample
	(1)	(2)	(3)	(4)	(5)
	ESG_supplier	*ESG_supplier*	*ESG_supplier*	*ESG_supplier*	*ESG_supplier*
Digital_alter				0.059**	
				(2.816)	
Controls	Yes	Yes	Yes	Yes	Yes
_cons	8.523*	–3.245***	–2.742**	–2.662**	–1.376*
	(1.963)	(–3.115)	(–2.444)	(–2.337)	(–1.654)
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	No	No	No	No
Customer industry fixed effects	No	Yes	No	No	No
n	2,503	2,503	2,503	2,503	1,426
Adj. R^2	0.655	0.294	0.289	0.289	0.248

Note. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. *t*-values are provided in parentheses. The results are clustered at the industry level.

(3) *Changing the sample.* Considering that the manufacturing enterprises account for a large share of the sample, reaching 57%, manufacturing customer enterprises are selected for re-regression. The results are shown in column (5) of Table 6. The coefficient of *Digital_customer* is significantly positive at the 1% level, which is basically consistent with the benchmark regression results. This also proves that the benchmark results are relatively robust.

5 Mechanism Analysis

5.1 The Structural Empowering Effect

The structural empowering effect refers to the mechanism through which customer digitalization enhances supplier ESG performance by improving supply chain collaboration in risk management, operations, and transparency. To measure risk management collaboration, we first measured corporate risk management capability using the Dibo Internal Control Index (DIB Index). Then, following Ge et al. (2020), we applied a coupling degree model to compute the customer-supplier risk-management coupling value, *C*1. The calculation formula is shown in equation (2):

$$C1 = 2 \times [Index_customer * Index_supplier / (Index_customer + Index_supplier)^2]^{\frac{1}{2}}, \quad (2)$$

where *Index_customer* is the internal-control index of customer enterprises, and *Index_supplier* is the internal-control index of supplier enterprises. To avoid pseudo evaluation results of the above coupling degree model when the two indicators are simultaneously small, it is necessary to calculate the coupling coordination degree based on this coupling degree model (Ge et al., 2020). Therefore, a coupling coordination model is constructed, as shown in equation (3):

$$Index_digicor = (C1 * T1)^{\frac{1}{2}}, \quad (3)$$

$$T1 = \alpha\ Index_customer + \beta\ Index_supplier,$$

where *Index_digicor* represents the coupling coordination degree value for customer enterprises' risk management and supplier enterprises' risk management, and the value range is between 0 and 1: As the value increases, the coordination degree rises (Ge et al., 2020). $T1$ is the comprehensive evaluation index for customer enterprises' and supplier enterprises' risk management, and α and β represent their weight, respectively. It is generally believed that supply-chain coordination entails upstream-downstream coordination, so it is considered that the contribution of each party is equal: $\alpha = \beta = 1/2$ (Ge et al., 2020).

This paper draws on the research of Ling et al. (2023) and uses the inventory turnover rate to measure corporate operation and management abilities. With reference to the research of Li and Wang (2011), the paper uses information disclosure evaluation scores of listed companies, which are publicly traded on the Shanghai Stock Exchange or the Shenzhen Stock Exchange, to measure corporate transparency. The information disclosure evaluation scores are divided into four grades: "unqualified" assigned the value of 1; "qualified" assigned the value of 2; "good" assigned the value of 3; and "excellent" assigned the value of 4. The coupling degree model is used to calculate the customer-supplier operation and management coupling degree C2 value and customer-supplier transparency coupling degree value C3. On this basis, the coupling coordination degree model is used to calculate customer-supplier operational synergy degree (*Operation_digicor*) and customer-supplier transparency synergy degree (*Opaque_digicor*).

The Ordinary Least Squares (OLS) regression model is used to test whether customer enterprises' digitalization promotes customer-supplier risk-management synergy, operational synergy, and transparency synergy. The regression results are shown in columns (1), (2) and (3) of Table 7. When the explained variable is *Index_digicor*, *Operation_digicor*, or *Opaque_digicor*, the coefficients of *Digital_customer* remain significantly positive at the 5% level, indicating that customer enterprises' digitalization promotes customer-supplier risk-management synergy, operational synergy, and transparency synergy.

5.2 Resource Empowering Effect

The resource empowering effect is that customer enterprises' digitalization can alleviate the financing constraints on supplier enterprises and promote their green innovation, thereby boosting their ESG performance. Specifically, the SA index constructed by Hadlock and Pierce (2010) is used to measure the financing constraints on enterprises. The increase in the SA index reflects the increasing tightness of the financing constraints. This paper follows Ke et al. (2023) and measures corporate green innovation (*Greeninnovation*) as the natural logarithm of one plus the citation count of an enterprise's green patents. The regression results are shown in columns (4) and (5) of Table 7. When the explained variable is *SA*, the coefficient of *Digital_customer* is significantly negative at the 1% level, indicating that the customer enterprises' digitalization can alleviate the financing constraints on supplier enterprises. When the explained variable is *Greeninnovation*, the coefficient of *Digital_customer* is significantly positive at the 1% level, indicating that customer enterprises' digitalization can promote supplier enterprises' green innovation.

Table 7 Mechanism Analysis: The Empowering Effect of Customer Enterprises' Digitalization on Supplier Enterprises' ESG

Variable	(1) *Index_digicor*	(2) *Operation_digicor*	(3) *Opaque_digicor*	(4) *SA*	(5) *Greeninnovation*
Digital_customer	0.280** (2.815)	0.064** (2.351)	0.007** (2.681)	–0.013*** (–5.369)	0.084*** (6.236)
Controls	Yes	Yes	Yes	Yes	Yes
_cons	11.048*** (4.904)	2.216 (1.241)	0.708*** (4.717)	8.406*** (11.505)	–7.687*** (–4.342)
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
n	2,372	2,494	1,672	2,510	2,510
Adj. R^2	0.101	0.204	0.303	0.851	0.433

Note. *** $p < 0.01$ and ** $p < 0.05$. *t*-values are provided in parentheses. The results are clustered at the industry level.

6 Heterogeneity Analysis

6.1 Differences in Government Environmental Attention

This paper believes that when the government environmental attention of a customer enterprise's city differs from that of its supplier's city, the willingness of the customer enterprise to empower the supplier enterprise to achieve sustainability will be different. This is because government environmental attention reflects the degree of importance that

government attaches to the environment and embodies the guiding role of government in environmental governance (Cheng et al., 2023). High government environmental attention means that the local government implements strong government supervision to achieve the synergy of economic goals and environmental goals (Cheng et al., 2023). Therefore, when the government environmental attention of a customer enterprise's city is higher than that of its supplier's city, the customer enterprise, in comparison with its supplier, is subject to stricter environmental protection supervision. Under this pressure of environmental supervision, the customer enterprise may put forward high environmental-protection requirements to its supplier enterprise. This way, the customer enterprise is more likely to improve the supplier enterprise's ESG performance through digital empowerment.

This paper draws on Cheng et al. (2023) to measure government environmental attention as the frequency of keywords related to ecological civilization efforts, extracted from prefecture-level government work reports. The sample used for the main regression is divided into two groups: customer enterprises' cities have higher government's environmental attention in comparison with supplier enterprises' cities (the high environmental attention group) and customer enterprises' cities have lower government's environmental attention in comparison with supplier enterprises' cities (the low environmental attention group), and the above two groups are empirically regressed, respectively. The regression results (shown in Table 8) show that when customer enterprises' cities have higher government environmental attention (columns [1] and [3]), customer enterprises are more likely to promote supplier enterprises' sustainability through digital empowerment. The *p*-values of the differences between the coefficients of the groups are 0.0428 and 0.0980, respectively, which pass the inter-group coefficient difference test.

Table 8 Heterogeneity Analysis: Analysis: Differential Governmental Environmental Attention in the Locations of Customer Enterprises and Supplier Enterprises

Variable	High government environmental attention group (number of sentences)	Low government environmental attention group (number of sentences)	High government environmental attention group (keywords frequencies)	Low government environmental attention group (keywords frequencies)
	(1)	(2)	(3)	(4)
	ESG_supplier	*ESG_supplier*	*ESG_supplier*	*ESG_supplier*
Digital_customer	0.104***	0.013	0.090***	0.016
	(5.591)	(0.672)	(5.280)	(0.828)
Controls	Yes	Yes	Yes	Yes
_cons	–1.352	–3.220***	–1.567	–3.069***
	(–0.836)	(–6.007)	(–1.019)	(–5.142)
Suest_P	0.0428**		0.0980*	

(*To be continued*)

(*Continued*)

Variable	High government environmental attention group (number of sentences)	Low government environmental attention group (number of sentences)	High government environmental attention group (keywords frequencies)	Low government environmental attention group (keywords frequencies)
	(1)	(2)	(3)	(4)
	ESG_supplier	*ESG_supplier*	*ESG_supplier*	*ESG_supplier*
Year fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
n	798	1,035	801	1,030
Adj. R^2	0.268	0.328	0.251	0.330

Note. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. *t*-values are provided in parentheses. The results are clustered at the industry level.

6.2 Customer-Supplier Closeness

As the customer-supplier closeness increases, customer enterprises become increasingly willing to empower supplier enterprises' sustainability through digital technologies. Refer to the existing research, the customer-supplier closeness is measured by the customer-supplier business credit relationship and by whether supplier enterprises are among the top three suppliers of customer enterprises. Regarding the customer-supplier business credit relationship. In accounting terms, business credit refers to the credit sales formed by delaying payments when an enterprise sells goods or provides services to its downstream customers. It is generally believed that only when a good relationship is formed within the supply chain may suppliers offer goods to their customers on credit. Therefore, drawing on the research of Chen and Li (2021), the ratio of a supplier enterprise's accounts receivable to its main business revenue is used to measure the customer-supplier business credit relationship. Specifically, the median of the ratios is calculated. A ratio greater than the median indicates high customer-supplier closeness and is assigned the value of 1; otherwise, it is assigned the value of 0. Regarding whether the supplier enterprises are the top three suppliers of the customer enterprises, if a supplier enterprise meets this criterion, which indicates high customer-supplier closeness, the value is 1; otherwise, it is 0. Finally, the regression test is carried out for the two groups based on the above-mentioned values. According to the regression results (shown in Table 9), when customer-supplier closeness is high (columns [1] and [3]), the coefficient of *Digital_customer* is significantly positive at the 1% level, and the inter-group difference coefficient of the two groups' results is significant, indicating that customer enterprises are more willing to empower, through digitalization, the sustainability of their closely related supplier enterprises.

Table 9 Degree of Customer-Supplier Closeness

Variable	High-degree closeness (business credit)	Low-degree closeness (business credit)	High-degree closeness (top-three suppliers)	Low-degree closeness (non-top-three suppliers)
	(1)	(2)	(3)	(4)
	ESG_supplier	*ESG_supplier*	*ESG_supplier*	*ESG_supplier*
Digital_customer	0.095***	0.021	0.089***	0.024
	(6.178)	(0.602)	(4.600)	(1.062)
Controls	Yes	Yes	Yes	Yes
_cons	–2.605**	–2.498	–2.260*	–4.106**
	(–2.236)	(–1.386)	(–1.940)	(–2.334)
Suest_P	0.0939*		0.0982*	
Year fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
n	1,252	1,250	1,629	874
Adj. R^2	0.284	0.309	0.296	0.279

Note. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. *t*-values are provided in parentheses. The results are clustered at the industry level.

7 Effect Study

Given the increasing importance of supply chain security and stability, whether customer enterprises' digitalization enhances supply chain resilience by promoting supplier enterprises' ESG performance becomes an issue worth studying. This paper expects that customer enterprises' digitalization can promote supplier enterprises' ESG performance, which is conducive to the establishment of a long-term and solid customer-supplier partnership and the improvement in supply chain resilience. The reasons are as follows. When supplier enterprises lose the trust and support of their stakeholders for poor ESG performance, this causes problems on two levels: On the enterprise level, this increases supplier enterprises' risks, adversely impacts their production and operation, and causes delays in the delivery of their products or services; on the supply chain level, this causes instability of supply-chain relationships, destroys supply-chain resilience, and may lead to the customer-initiated termination of the supplier-customer cooperation for worries about business interests and reputation, which seriously damages the stability of their customer-supplier relationship. According to the signaling theory, good corporate ESG performance has an information effect. With excellent ESG performances, a supplier enterprise can increase the stickiness of customers and consumers to its products, build up its reputation, and, in the event of a crisis, divert the attention of its stakeholders from its misconduct,

which can reduce the negative impact of the crisis on the future development of itself and its customer enterprises, ensure stable corporate production and operation, and enhance supply chain resilience.

To test whether supply chain resilience is impacted by the promoting effect of customer enterprises' digitalization on supplier enterprises' ESG performance, this paper draws on the research of Kim et al. (2021) and adopts a two-stage model for testing. In the first stage, the predicted value of supplier enterprises' ESG performance (*ESG_hat*) is obtained by regressing the impact of customer enterprises' digitalization on supplier enterprises' ESG performance, which reflects the impact of customer enterprises' digitalization on supplier enterprises' ESG performance. In the second stage, the predicted value of supplier enterprises' ESG performance is regressed with the proxy variable of supply chain resilience to test the impact of customer enterprises' digitalization on supply chain resilience after promoting supplier enterprises' ESG performance. For the measurement of supply chain resilience, this paper draws on the research of Tao et al. (2023) and measures it from three aspects: the matching of supply and demand relationships, the maintenance of supply and demand relationships, and the improvement of supply chain quality: (1) the supply-demand matching is measured through the "whip effect" between supplier enterprises and customer enterprises (*supply chain stability*1). This indicator can, to a certain extent, reflect the ability of upstream and downstream enterprises to respond to external disturbances. (2) The maintenance of supply-demand relationships is measured by the standard deviation of the two-year sales proportions of supplier enterprises and customer enterprises (*supply chain stability*2). (3) The improvement of supply-chain quality is measured by the logarithm of the total number of patents applied by supplier enterprises and customer enterprises (*supply chain stability*3), because when external shocks and fierce competition are encountered, supply chains can have stronger independent controllability, market competitiveness, and resilience if the upstream and downstream enterprises possess more core technologies and key resources.

The results in Table 10 reveal the multifaceted impacts of customer digitalization through improved supplier ESG performance (*ESG_hat*). Column (1) shows a significantly negative coefficient for *ESG_hat* at the 10% level, suggesting it helps mitigate the bullwhip effect between firms by enhancing supply-demand matching. In column (2), the significantly negative coefficient at the 5% level implies that it stabilizes the sales proportion between partners, thereby fostering more stable supply-demand relationships. Finally, the significantly positive coefficient in column (3) at the 1% level indicates that it stimulates supply chain patent applications, which enhances overall supply chain quality. In summary, customer enterprises' digitalization can improve supply chain resilience after improving supplier enterprises' ESG performance.

Table 10 Research on the Promoting Effect of Customer Enterprises' Digitalization on Supplier Enterprises' ESG Performance

Variable	(1) *supply chain stability*1	(2) *supply chain stability*2	(3) *supply chain stability*3
ESG_hat	–0.751* (–1.738)	–3.878** (–2.191)	2.202*** (3.709)
Controls	Yes	Yes	Yes
_cons	7.839** (2.226)	35.773** (2.389)	–25.639*** (–5.309)
Year fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
n	2,186	1,238	2,504
Adj. R^2	0.065	0.087	0.386

Note. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. *t*-values are provided in parentheses. The results are clustered at the industry level.

8 Conclusions and Insights

Enhanced modernization of supply chains and ensured supply chain safety and stability constitute important prerequisites for stable and sustainable economic growth, underpin the pursuit of high-quality development and the construction of the new development paradigm, and offer important guarantees for accelerating the development of Chinese modernization. Improving the level of sustainable development of supply chains is an important way to enhance supply chain resilience and ensure supply chain safety and stability. The rise of digital technologies such as artificial intelligence, big data, and cloud computing has provided unprecedented opportunities for building sustainable supply chains. Whether and how customer enterprises' digitalization improves supply chain sustainability is an important issue worth exploring. This paper takes A-share listed companies and their supplier enterprises from 2013 to 2021 as the research objects to explore the impact of customer enterprises' digitalization on supplier enterprises' ESG performance. The research finds that customer enterprises' digitalization has an empowering effect on supplier enterprises' ESG performance and that this effect is asymmetric: It is more significant when customer enterprises outshine supplier enterprises in terms of digitalization. The mechanism test finds that customer enterprises' digitalization enhances supplier enterprises' ESG performance mainly through the structural empowering effect and the resource empowering effect. The former improves supply chain collaboration, including promoting risk management collaboration, operational collaboration, and transparency collaboration between customers and suppliers. The latter alleviates the constraints on supplier factors, including alleviating financing constraints and promoting green innovation. The heterogeneity tests reveal that the positive effect of customer digitalization on supplier ESG performance is more pronounced under two conditions:

Firstly, when the government in the customer's city exhibits greater environmental attention than those in the suppliers' cities; and secondly, when the customer-supplier relationship is closer. The effectiveness test finds that customer enterprises' digitalization promotes supplier enterprises' ESG performance and improves supply chain resilience. To ensure the robustness of the research conclusions, this paper uses a variety of methods to control endogeneity problems, including the instrumental variable method, the propensity score matching method, the DID model, the Heckman two-stage method, and the change model. In addition, robustness tests are carried out by using fixed effects, changing the measurement method of the explanatory variable and adjusting the sample. The research conclusions of this paper provide important insights for supplier enterprises, customer enterprises, and policymakers.

For supplier enterprises, they shall fully utilize the customer-supplier relationships to improve their sustainability. This study shows that customer enterprises' digitalization is conducive to improved ESG performances of supplier enterprises and that this effect becomes increasingly prominent as the customer-supplier closeness grows. Given this, supplier enterprises shall actively engage in close interactions with their customer enterprises and establish good cooperative relations with them. By doing so, supplier enterprises not only learn their customers' excellent operation and management experience through business cooperation but also obtain, through strong links, the "dividends" and the empowering effects of customer enterprises' digitalization, which is conducive to improving their ESG performances.

For customer enterprises, they shall play an active role as core enterprises. This study finds that their digitalization enhances the ESG performances of supplier enterprises through the structural empowering effect and the resource empowering effect, which is conducive to improvements in supply-chain sustainability and resilience. Therefore, customer enterprises shall encourage their managers to support the development of the digital economy, play an exemplary and enabling role as core enterprises, and promote and support the digital transformation of all enterprises in their industries. This way, they can make positive contributions to the construction of digital sustainable supply chains.

For policymakers, they shall provide guidance and policy support for the construction of digital sustainable supply chains. The research in this paper shows that customer enterprises' digitalization can improve supply chain resilience after improving supplier enterprises' ESG performance. Therefore, when formulating strategies and policies to ensure supply-chain safety and stability, attention shall be paid to the positive role of the construction of digital sustainable supply chains; when formulating policies to promote the development of ESG and the digital transformation of enterprises, attention shall be paid to the digitalization of core supply chain enterprises, emphasizing supply chain enterprises' digital interaction and sustainable-development interaction and giving full play to the enabling role of core enterprises.

There are still some shortcomings in this study. Firstly, due to the availability of data and the sample size limitation, the main test only considers the relationship between customer

enterprises' digitalization and their direct upstream enterprises' ESG performance and does not include multi-level supplier enterprises. Therefore, it is impossible to observe the impact of customer enterprises' digitalization on the ESG performance of multi-level supplier enterprises. Secondly, there are significant differences in economy, politics, culture, and other aspects among different countries and regions. The impact of customer enterprises' digitalization on supply chain sustainability under different contexts is an important and interesting issue. Since this study is based on the Chinese institutional background and uses Chinese supply chain data, it is impossible to observe whether there are differences in the research conclusions made against different institutional backdrops. Thirdly, there are currently no widely recognized measurement methods for the indicators of supply chain resilience. Although the variable selection in this paper draws on existing research, the scientific reasonableness of these selections needs to be further analyzed and tested.

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