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Can supply chain digital innovation policy improve the sustainable development performance of manufacturing companies?

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As societal concerns around environmental protection, and corporate governance are increasing, entities like consumers, investors, and others are raising their expectations of companies' corporate social responsibility. Companies that pursue sustainable development goals will receive more attention and support from these stakeholders. The pilot policy for supply chain innovation and application (SCIA) is a systemic experiment launched by the Chinese government that aims to facilitate the digitalization of supply chains and encourage companies to adopt innovative technological methods to optimize traditional supply chain management practices. Based on data from 508 manufacturing companies from 2013 to 2022, this research utilizes SCIA in the framework of a quasi-natural experiment, employing research methods DID, EM, PSM-DID, and SDID to evaluate the effect of the SCIA on SDP. Through empirical evidence, it concludes that the rollout or enforcement of the SCIA pilot policy significantly promotes SDP. SCIA impacts corporate sustainable development by increasing their intention to invest in innovation, ensuring the sustainability of corporate innovation, and reducing company cost expenditures. There is significant heterogeneity in the effectiveness of establishing pilot cities for the digitization and application of supply chain innovations: the pilot policy can significantly promote the SDP of state-owned enterprises; compared to small-scale companies, the SDP of large companies has been significantly improved due to the pilot policy; SCIA pilot policies have a greater impact on SDP of low agency cost companies than high agency cost companies; and companies located in cities with a high degree of digitalization are more favorable impacts from the pilot policy. Companies with weak monopoly power have a more significant improvement in SDP. The study enriches the research on the effectiveness of SCIA pilot policies and provides insights into how local governments can facilitate the enhancement of the SDP of manufacturing companies.

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Introduction

The uncertainties stemming from global economic fluctuations, natural disasters, and health crises necessitate the development of more resilient and reliable supply chains to effectively mitigate potential risks (Kulinich et al. 2023). Globalization has significantly increased supply chain complexity, engaging multiple countries and regions. However, inefficient information flow within supply chains hampers companies' adaptability to demand fluctuations, escalates operational costs, and reduces overall responsiveness. Limited supply chain visibility exacerbates vulnerability to disruptions, while inadequate communication mechanisms and misaligned objectives among stakeholders further hinder collaborative efficiency. To navigate these challenges and align with rapidly evolving market dynamics, companies must implement real-time supply chain monitoring and optimization strategies.

The digital transformation of supply chains offers a strategic avenue to reduce costs, enhance efficiency, and improve risk management, thereby strengthening companies' competitiveness (Helo and Hao, 2022; Wamba and Queiroz, 2022). The World Trade Organization (WTO) highlights in its World Trade Report that digitalization is reshaping global trade patterns, with supply chain digitization serving as a catalyst for trade expansion (WTO, 2023). Similarly, the International Monetary Fund (IMF) underscores in its Global Economic Outlook that digital transformation lowers trade costs, enhances supply chain efficiency, and fosters global economic growth (IMF, 2024). The United Nations Industrial Development Organization identifies supply chain digitalization as a key driver of future industrial progress (UNIDO, 2021). Within the framework of the digital economy, the evolution of supply chains demands greater flexibility and security, which are essential for fostering industrial resilience, integrating development with security, and advancing a new economic paradigm (Hou, 2023).

China, as one of the most populous nations, faces limited per capita resource availability. Rapid industrialization and urbanization have exerted immense environmental pressure, resulting in air, water, and soil pollution, as well as ecosystem degradation—challenges that significantly hinder the country's transition toward high-quality development (Hao et al. 2020). Given their substantial contributions to environmental degradation, companies bear a critical responsibility for ecological sustainability (Li et al. 2024). As an integral component of corporate strategy, supply chains encompass the entire lifecycle from raw material procurement to final product distribution. Efficient supply chain management is pivotal to corporate success (Chen and Paulraj, 2004). In recognition of this, the General Office of the State Council introduced the "Guiding Opinions on Actively Advancing Supply Chain Innovation and Implementation" (GOST, 2017), advocating for the deep integration of supply chains with the Internet of Things (IoT) and digital technologies to enhance efficiency and global competitiveness. Following this, in April 2018, the Ministry of Commerce, along with seven other governmental departments, initiated the Pilot Program for Supply Chain Innovation and Application (MCPRC, 2024), selecting qualified enterprises to conduct a 2-year trial. This study examines the effectiveness of this policy in enabling companies to leverage the digital economy while contributing to national sustainable development, thereby offering a strategic pathway for refining supply chain digitalization practices.

Accordingly, this study focuses on the Supply Chain Innovation and Application (SCIA) initiative launched in April 2018. It selects a sample of 508 manufacturing companies from 2013 to 2022 and employs a difference-in-differences model to investigate the impact of supply chain digital innovation on companies' sustainable development performance (SDP). The study explores the mechanisms through which SCIA influences corporate SDP and assesses whether variations exist across different firm types, considering their internal characteristics and external environmental factors. Specifically, companies are categorized based on ownership structure (private vs. state-owned enterprises), corporate governance quality, firm size, and the degree of marketization in their operating regions. This classification enables a comprehensive analysis of SDP disparities among different firm types.

While extensive research has examined corporate sustainable development and supply chain digital innovation at the macro-level, relatively few studies have investigated the micro-level impact of supply chain digital innovation on firm SDP (Centobelli et al. 2020; Cai and Choi, 2020; Khan et al. 2021). This study addresses this gap by focusing on manufacturing companies and evaluating the implications of supply chain digital innovation for their SDP. The key contributions of this study are as follows: (1) It shifts the research focus to the micro-level, assessing how supply chain digital innovation differentially affects the SDP of small and medium-sized enterprises (SMEs). (2) From an SDP perspective, it provides a novel lens to assess the economic impact of the SCIA policy, supplementing existing literature that primarily focuses on firm productivity and valuation (Chen et al. 2023; Li, 2024; Nayal et al. 2022). By employing the entropy value method, this study systematically evaluates SCIA's impact on production, financial, and environmental performance, thereby enriching the discourse on supply chain digital innovation and sustainability. (3) It examines whether companies' willingness to invest in innovation, their innovation sustainability, and cost expenditure function as effective transmission mechanisms through which supply chain digital innovation enhances SDP. (4) By incorporating both internal and external determinants of SDP, this study deepens the understanding of how firm-specific and environmental factors shape the economic outcomes of supply chain digitalization. Specifically, it explores the roles of property rights, regional digitalization levels, firm size, and agency costs in mediating the relationship between supply chain digitalization and firm SDP, offering novel insights into the broader economic implications of supply chain digitalization at the firm level.

Literature review

Economic consequences of supply chain innovation and application. Supply chain digital innovation refers to the application of digital technologies to reform, optimize, and innovate supply chain processes, enhancing efficiency, transparency, cost reduction, and adaptability to market dynamics (Evtodieva et al. 2020; Tripathi and Gupta, 2020). The implementation of SCIA policies encourages companies to engage in supply chain transformation, promoting competitiveness and sustainable growth.

Microeconomic Impact of SCIA on companies. From a microeconomic perspective, existing research primarily focuses on how SCIA influences firm competitiveness and high-quality development. According to Endogenous Growth Theory, innovation is central to enhancing productivity (Griffith et al. 2004). Supply chain innovation facilitates improvements in product quality, operational efficiency, and cost reduction by incorporating new technologies and process optimizations (Fiala, 2016). Policy incentives also drive companies to seek high-quality suppliers (Wu et al. 2016), fostering R&D investment and the adoption of innovative supply chain strategies.

Through collaboration with suppliers and partners, companies can accelerate innovation and develop high-value-added products that enhance market competitiveness (Chavez et al. 2017; Cong et al. 2021). Supply chain digitalization enhances decision-making speed and accuracy, improving data acquisition, processing, and integration (Gupta et al. 2019; Stank et al. 2019; Zimmermann et al. 2016). Optimized supply chains contribute to carbon footprint reduction, waste minimization, and green supply chain development, fostering environmental sustainability (Bechtsis et al. 2018; Benner and Waldfogel, 2023).

Additionally, supply chain innovation enhances production efficiency by integrating new technologies, process improvements, and network optimizations (Balakrishnan and Ramanathan, 2021). It also strengthens market responsiveness, enabling companies to deliver high-quality products that meet consumer demands while maximizing profitability (Batista et al. 2018). Close collaboration within the supply chain improves product and service quality, ultimately enhancing customer satisfaction (Ishfaq et al. 2022).

A critical advantage of supply chain digitalization is its ability to mitigate risks associated with production disruptions and supply shortages. By developing resilient supply networks, diversifying suppliers, and leveraging advanced technologies, companies can minimize operational risks and enhance overall productivity (Li et al. 2024; Ivanov et al. 2019).

Macroeconomic impact of SCIA on industrial development. At the macroeconomic level, SCIA fosters industrial collaboration, economic efficiency, and competitive advantage, driving industrial upgrading and transformation (Hahn, 2020). One key benefit is employment growth, as optimized supply chains and improved production efficiency increase labor demand (Ambrogio et al. 2022). SCIA also influences structural shifts in employment. On one hand, automation and mechanization reduce labor demand in traditional industries, decreasing reliance on manual labor. On the other hand, the rise of logistics, e-commerce, and digital services expands opportunities for skilled, innovative, and professionally trained workers (Liu et al. 2021).

By enhancing supply chain management, adopting new technologies, and refining production processes, companies boost market competitiveness, improve product quality, and lower costs, strengthening their position in the industrial value chain (Zouari et al. 2021). This contributes to increased industry value-added and accelerated industrial evolution. Moreover, the "substitution effect" optimizes human capital structures, ensuring a more skilled workforce (Acemoglu and Restrepo, 2018, 2020).

The integration of IoT, AI, big data, and digital technologies fuels intelligent monitoring, advanced data analytics, and automated production controls, accelerating the digitalization and automation of manufacturing. These advancements enhance productivity and quality, enabling companies to expand into new markets, refine service offerings, and improve financial performance. Policy-driven R&D investments and industrial skill development further promote high-value-added, sustainable, and smart industrial growth (Doh and Kim, 2014).

Factors affecting sustainable development performance. To achieve sustainable development, companies must balance economic, social, and environmental objectives, reinforcing green growth and corporate social responsibility. The triple-bottom-line framework evaluates SDP across these three dimensions (Henry et al. 2019). Economic performance is typically measured through financial indicators (Hao et al. 2023), while environmental outcomes are assessed based on production efficiency, administrative effectiveness, and community contributions (Kitsikopoulos et al. 2018). Social performance focuses on companies' compliance with policies, regulations, and stakeholder interests (Zhu et al. 2019). As economic systems evolve, extensive research continues to explore the determinants of corporate sustainability.

Internal determinants of SDP. Corporate SDP is significantly influenced by internal factors. Leadership diversity and an innovation-driven culture foster sustainability, while large companies benefit from stronger financial capacity, enabling sustained improvements in sustainable performance (Perera Aldama et al. 2009). Efficient environmental management helps reduce resource consumption and emissions, facilitating a low-carbon transition in production processes and ensuring the harmonious development of economic and environmental objectives (Li et al. 2024).

Additionally, resource recycling strategies optimize economic and social resource utilization, reducing costs and enhancing profitability (Kruse et al. 2019). By intensifying R&D efforts, reducing emissions, improving energy conservation, and leveraging innovative supply chain technologies, companies can maximize economic benefits while minimizing environmental and social impacts. These efforts reinforce long-term sustainability. Moreover, corporate social responsibility (CSR) initiatives—such as stakeholder engagement and alignment with societal needs—strengthen corporate reputation and sustainable development (Lombart and Louis, 2012; Porter and Linde, 1995). Engaging with stakeholders also mitigates risks, anticipates social challenges, and enhances resilience (Jones, 1995; Flammer and Kacperczyk, 2016).

External determinants of SDP. Industry characteristics, economic conditions, and regulatory policies also shape corporate sustainability. Resource consumption and environmental impact vary by industry, with sectors like heavy industry and energy facing greater sustainability challenges (Zhang and Huang, 2012). Market demand fluctuations, tied to economic cycles, further influence SDP. Economic expansion fuels production growth, often increasing resource consumption and environmental pollution, whereas downturns prompt reductions in both (Azevedo and Leshno, 2016). Additionally, corporate profitability and financing costs, shaped by economic conditions, affect SDP outcomes (Xu and Li, 2020).

Regulations and policies impact SDP through environmental regulations, market competition, and financing constraints. Stricter environmental policies drive innovation, compelling companies to adopt low-carbon production processes while enhancing competitiveness (Porter and Linde, 1995; Yu et al. 2017; Zhang et al. 2021). Well-designed regulations stimulate technological advancements and encourage sustainable business practices.

SDP is a multidimensional and interdependent process requiring continuous refinement across environmental, social, and economic dimensions. Achieving sustainability necessitates a holistic approach, integrating internal and external factors to drive long-term, resilient corporate development.

Mechanisms of SCIA on SDP. Supply chain digital innovation is pivotal in enhancing companies' sustainable development performance (SDP). The implementation of SCIA policies sets new benchmarks for green development, prompting firms to adopt sustainable practices such as waste reduction, optimized resource use, and improved energy efficiency (Costantini et al. 2017). It also stimulates green technology innovation (Seman et al. 2019), strengthens external governance mechanisms, and promotes the integration of sustainable supply chains, leading to greater environmental efficiency.

From a financial standpoint, SCIA enhances ESG performance by improving corporate governance (Zhu and Zhang, 2024), boosting total factor productivity, and alleviating financial constraints. These benefits are particularly evident in state-owned enterprises, firms with lower supply chain concentration, and industries characterized by intense competition. Moreover, SCIA positively affects operating expenses, inventory turnover, and return on assets (Wong et al. 2020).

Digital innovation within supply chains also strengthens industrial networks, accelerating digitization and intelligence in supply chain modernization (Zhao et al. 2023). Under robust corporate governance and state-backed supply chain operations, digital transformation alleviates production constraints, improves corporate cash flow, and fosters technological breakthroughs (Lee et al. 2022). Enhanced collaboration further drives operational efficiency.

Additionally, digitalization improves risk management capabilities, enabling firms to prevent, mitigate, and recover from crises, ensuring stable performance despite external disruptions (Gupta et al. 2021). Based on these observations, we propose the following hypothesis:

H1: SCIA contributes to the improvement of company SDP.

The advancement of the digital marketplace has driven profound transformations in corporate operations (Büyüközkan and Göçer, 2018; Seyedghorban et al. 2020). In an evolving market environment, establishing digital platforms allows companies to respond swiftly to shifting market demands, adjust innovation strategies, and maintain competitive advantage (Rialti et al. 2018). This adaptability provides a strong foundation for strategic decision-making regarding innovation investments. By gaining deeper insights into customer needs, companies can allocate innovation resources more effectively, ensuring that limited financial, human, and material resources are directed toward high-potential projects. This accelerates the transformation of ideas into market-ready products, facilitating the commercialization of innovation (Menon and Ravi, 2021).

Moreover, companies' willingness to invest in innovation is consistently reinforced, driving the development of new products, technologies, and service improvements, all of which enhance market competitiveness—a critical element of sustainable development (Tsou and Chen, 2023). Increased innovation investment also ensures that companies' production activities remain compliant with legal and environmental standards, thereby reducing costs associated with pollution control and regulatory compliance (Xie et al. 2015; Yu et al. 2017).

Thus, we propose:

H2: SCIA improves SDP by increasing companies' willingness to invest in innovation.

Digital transformation strengthens dynamic capabilities, allowing companies to adapt swiftly to market changes, develop new products and services, and sustain competitive advantage through continuous innovation (Warner and Wäger, 2019; Liu et al. 2023). By leveraging digital management systems, companies can enhance supply chain monitoring and resource control, optimizing the allocation of raw materials, inventory, and logistics. This efficiency reduces waste and fosters a more sustainable innovation environment (Cong et al. 2021).

Collaboration is essential for corporate growth, and supply chain digital innovation facilitates synergy across stakeholders, including customers, manufacturers, suppliers, and distributors (Alexy et al. 2013). This interconnectedness not only enhances supply chain performance but also accelerates knowledge and technology sharing, expanding access to innovation resources (Griffith et al. 2004) and driving companies' innovation activities (Bharadwaj et al. 2013).

Innovation is a long-term, accumulative process, where technical expertise and experience play a crucial role in strengthening SDP. companies with sustained innovation efforts develop robust risk assessment and management systems, enabling them to navigate uncertainties, identify opportunities, and mitigate risks. Additionally, continuous innovation fosters a strong market reputation, attracting consumers and collaborators, thereby promoting long-term growth and competitiveness (Zhang et al. 2018).

Thus, we propose:

H3: SCIA improves company SDP by enhancing company innovation sustainability.

Through real-time data analytics, digital supply chains enhance demand forecasting, enabling optimized inventory management. Efficient inventory control minimizes excess stock and related costs while enhancing supply chain adaptability and responsiveness (Delic and Eyers, 2020). In logistics, digital supply chain management streamlines route planning, reducing unnecessary transportation and idling, which lowers logistics costs. Additionally, real-time tracking and scheduling allow companies to adjust swiftly to demand fluctuations, further optimizing transportation expenses.

By leveraging live tracking and predictive analytics, companies can proactively identify and mitigate supply chain risks, preventing disruptions that may lead to emergency procurement and temporary logistics costs (Ivanov et al. 2019; Kim and Wemmerlöv, 2015). Reduced expenditures contribute to higher profit margins and financial stability, freeing up internal resources for R&D, market expansion, and equipment upgrades, which drive innovation and long-term growth (Benfratello et al. 2008). From a market perspective, cost efficiency enables companies to offer competitive prices while maintaining product quality, strengthening market position and profitability (Benner and Waldfogel, 2023).

Thus, we propose:

H4: SCIA improves company SDP by reducing cost expenditures.

A market economy thrives on the diversity and distinctiveness of its participants, with companies varying in historical background, financial strength, resource allocation, and geographical distribution, leading to differentiated responses to policy interventions. Large corporations, equipped with greater financial and operational flexibility, can adapt more efficiently to policy changes, whereas smaller companies often face resource constraints that hinder their responsiveness. Similarly, companies with strong financial standing are better positioned to absorb the costs of policy transitions, while those with weaker financials are more vulnerable. Additionally, technologically advanced companies are more adept at aligning with digital and innovation-driven policies, whereas less technologically developed companies may require significant investment to meet policy requirements. Given these disparities, this study proposes the following hypothesis:

H5: SCIA has heterogeneous impacts on the SDP of companies based on property rights, firm size, agency costs, regional digitalization levels, and monopolistic power.

Following these theoretical arguments, this study constructs a supply chain digital innovation mechanism framework that contains three components: company innovation investment willingness, company innovation sustainability, and company cost expenditure, as shown in Fig. 1.

Description of data and variables

Sample selection and data sources. This study examines Chinese A-share manufacturing companies listed on the Shanghai and Shenzhen stock exchanges from 2013 to 2022. Companies are

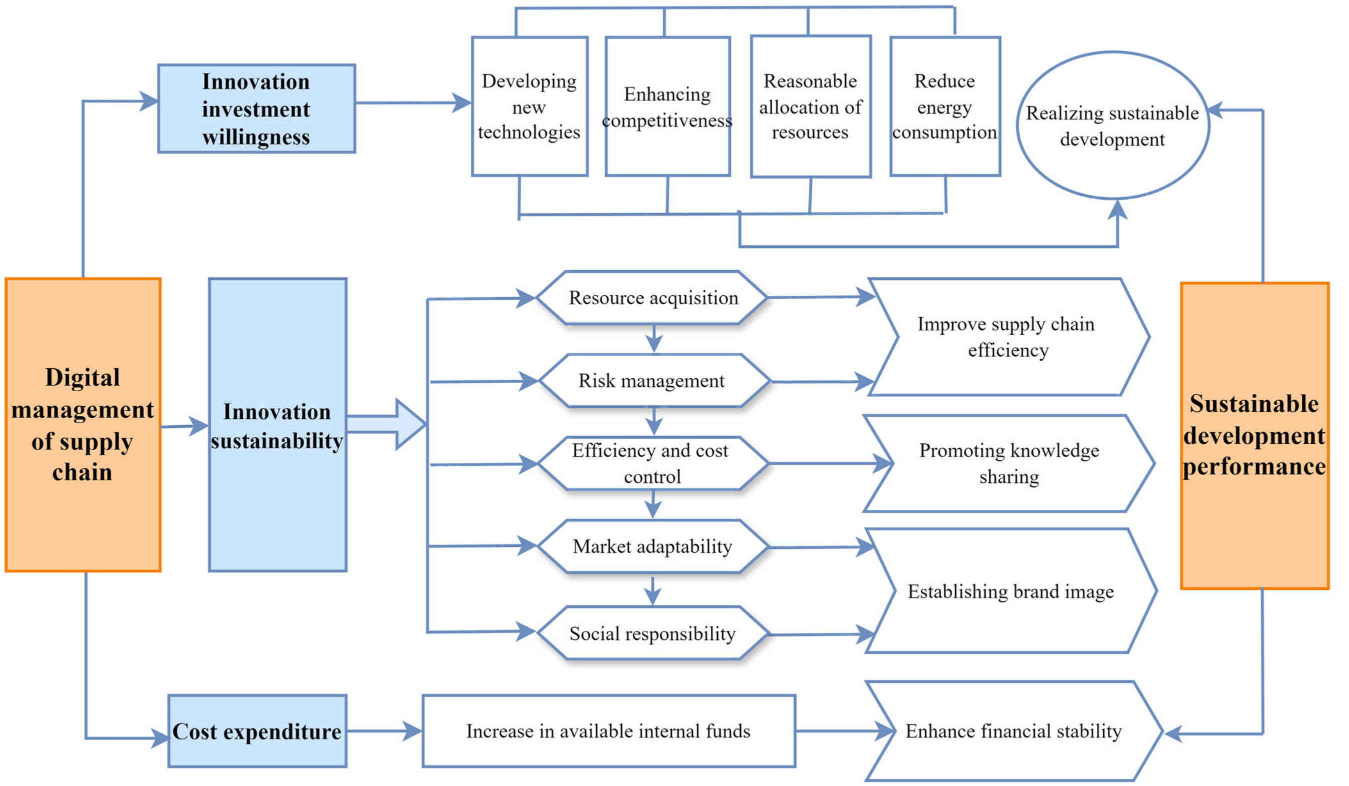

Fig. 1 Mechanism diagram of digital supply chain management. This figure illustrates how innovation investment and digital management enhance supply chain efficiency, competitiveness, and sustainability, driving financial stability, knowledge sharing, and brand image development.

categorized into two groups: the experimental group, comprising companies in SCIA pilot cities, and the control group, consisting of companies in non-pilot cities. The cut-off period (2022) is determined based on two factors: (1) SCIA policy implementation began in 2018, and using 2022 as the endpoint ensures sufficient time to capture its full impact. (2) Environmental performance is measured using the E-score from ESG ratings, with the most recent data available up to 2022.

To ensure data completeness and consistency, companies labeled as **S, ST, and ST*, as well as those listed after 2013, are excluded. This results in a final dataset of 5080 firm-year observations, including 236 companies in the experimental group and 272 in the control group. To mitigate the influence of outliers, continuous variables are winsorized at the 1st and 99th percentiles.

Data sources include CSMAR (microdata), WIND (macro-data), and the National Bureau of Statistics (NBS).

Definition of variables

Explained variable. The explanatory variable in this study is sustainable development performance (SDP), a key indicator of a firm's long-term sustainability, reflecting its role in green development and social responsibility (Lamichhane et al. 2021). Unlike ESG performance, which primarily serves external communication purposes, SDP focuses on a firm's strategic direction and operational model, encompassing sustainability in products, services, supply chains, and production processes, as well as the long-term viability of its business model.

SDP measurement follows the Triple Performance Theory, which evaluates sustainability across three dimensions: social, environmental, and economic performance (López et al. 2007; Martínez-Ferrero and Frias-Aceituno, 2015). In this study, SDP is categorized into financial, environmental, and production dimensions. Specifically, production performance is assessed through total factor productivity (TFP), detailed in Table 1.

To ensure objectivity, the entropy weighting method is applied, offering a data-driven approach that minimizes subjective bias common in structured ESG evaluation systems (Isik, 2010; Masca and Genç, 2024), such as the Huazheng Rating Index.

Key explanatory variable. In this paper, SCIA is the core explanatory variable (Treat × Post), and a double-difference approach is employed to examine the influence of the establishment of pilot cities for SCIA on the SDP of manufacturing companies. The article constructs spatial and temporal dummy variables and their interaction terms, respectively, specifically: the spatial dummy variable (Treat) is assigned the value of 1 if the company is part of the pilot region, indicating the treatment group, alternatively, it receives a value of 0; the temporal dummy variable (Post) is set to 1 for the year of the policy impact and the year after, and it is assigned a value of 0 for all other years. The interaction term (Treat × Post) is the cross-multiplication term between the spatial and temporal dummy variables.

Control variables. This paper selects gearing ratio (Lev), capital intensity (Tang), company age (Age), cashflow (Cashflow), company growth (Growth), equity concentration (Coo), integration of two positions (Dual), management expense ratio (Mer), and company value (*Q*) as control variables.

Mediating variables. The mediating variables selected are the companies' willingness to invest in innovation (Iiw), companies' innovation sustainability (Eis), and companies' cost expenditures (Cost). Detailed descriptions of the variables are displayed in Table 1.

Model settings. The establishment of SCIA is an exogenous policy disruption for local companies, producing varied effects

Table 1 The definitions of the variables in the study.

Variable properties	Variable name	Variable meaning	Variable indicator
Input	*K*	Capital investment	Net fixed assets/10,000
	I	Investment	Cash paid for the purchase and construction of fixed assets, intangible assets, and other long-term assets/10,000
	M	Intermediate investment	(Operating costs + sales expenses + management expenses + financial expenses−depreciation and amortization−cash paid to and on behalf of employees)/10,000
Output	*O*	Total output	Operating income/10,000
Explained variable	SDP	Sustainable development performance	Calculated by the entropy method, it consists of financial performance, environmental performance, and production performance.
Explanatory variables	Treat	Dummy variable	The experimental group is a company located in a pilot city for SCIA, defined as 1; the control group is in a non-pilot city, defined as 0.
	Post	Dummy variable	0 before 2018, otherwise 1
	SCIA	Net effect of policy	Treat × Post
Control variables	Lev	Asset liability ratio	Liabilities/Total assets
	Tang	Asset intensity	The logarithm of the net value of fixed assets of a company/the average number of employees of the company.
	Age	Company age	Take the logarithm of the current year−company opening year + 1.
	Cashflow	Cash flow ratio	Net cash flow/total assets
	Growth	Company growth potential	Market value/asset replacement cost
	Coo	Equity concentration	The logarithm of the total shareholding ratio of the top ten shareholders.
	Dual	Integration of two positions	Use the number of Internet users, and take the logarithm to express.
	Q	Company value	Tobin *Q* value
	Mer	Management expense rate	Management expenses/company income.
Intermediary variable	Iiw	Innovation Investment willing	Increment of intangible assets
	Eis	Company Innovation Sustainability	Incremental intangible assets/total assets
	Cost	Company cost expenditure	Total cost/operating income

Table 2 Descriptive statistics.

Variables	*N*	Mean	s.d.	Min	Max
Treat	5080	0.465	0.499	0	1
Post	5080	0.500	0.500	0	1
SDP	5080	1.840	0.216	0.851	2.573
Lev	5080	0.437	0.186	0.0143	1.096
Tang	5080	12.74	0.862	9.493	16.15
Age	5080	3.222	0.198	2.708	3.761
Cashflow	5080	0.0563	0.0625	−0.257	0.482
Growth	5080	0.290	1.914	−2.624	77.12
Coo	5080	3.931	0.295	2.358	4.591
Dual	5080	0.236	0.425	0	1
Q	5080	1.963	1.288	0.681	21.30
Mer	5080	0.0788	0.115	0.00449	7.284

based on varying attributes of the company's environment, aligning with the basic assumptions of DID. The paper employs DID to assess the impact of SCIA on the SDP of manufacturing companies. The model used is outlined as follows:

$$\mathrm{SDP}_{it} = \alpha + \beta_1 \mathrm{Treat}_{it} \times \mathrm{Post}_{it} + \beta_2 X_{it} + \gamma_i + \mu_t + \varepsilon_{it} \quad (1)$$

where the subscript i indicates the company, t indicates the year, SDP indicates sustainable development performance of the company, Treat represents whether the company is affected by the establishment of the pilot city of SCIA, if the company is in the pilot city, then it is the treatment group, accordingly Treat = 1; if the company is the control group, then Treat = 0. Post indicates whether the SCIA city is established or not, if the time is the policy implementation period and after, then Post = 1; otherwise Post = 0. Variable X encompasses a set of control factors. The paper also considers the following individual effects: γ denotes industry-specific constants, μ denotes year-specific constants, and ε is a random disturbance term.

Empirical analysis

Descriptive statistics. Table 2 presents the findings from the descriptive statistical analysis of the main variables. This result shows that the number of companies between the experimental and control cohorts is comparable, thereby more effectively capturing the impact of policy. The value of the company SDP is 1.84, the standard deviation is 0.216, with the lowest value recorded at 0.851 and the highest at 2.573, indicating a considerable variation in SDP across various companies.

Benchmark regression analysis. The regression results presented in Table 3 provide robust empirical evidence on the impact of SCIA pilot policies on SDP across different model specifications. In the baseline model without control variables or fixed effects (Column 1), SCIA implementation is associated with a significant increase in SDP. When city and year fixed effects are introduced (Column 2), the regression coefficient remains positive at 0.011. Incorporating control variables while omitting industry and year-fixed effects (Column 3) maintains SCIA's significant influence on SDP at the 1% level. The fully specified model (Column 4), which includes both control variables and fixed effects, reports a regression coefficient of 0.02 ($p < 0.01$), further corroborating the policy's positive impact. These results consistently validate H1, underscoring the critical role of SCIA pilot policies in enhancing companies' sustainable development performance.

Robustness test

Parallel trend test. The foundation for employing DID analysis lies in meeting the parallel trend hypothesis, this means that before affected by SCIA, the test and control group samples are equally comparable. We employ the event study method for examination (Degras et al. 2011), introduce the interaction term of the experimental group dummy variable and the annual dummy variable in the regression, and again carry out the two-

Table 3 Benchmark regression results.

	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4
Treat × post	0.056*** (8.03)	0.011*** (5.41)	0.020*** (3.39)	0.020*** (9.48)
lev			0.175*** (11.95)	0.174*** (12.63)
tang			0.023*** (7.76)	0.021*** (6.38)
age			0.056*** (4.46)	0.057*** (5.15)
cashflow			0.728*** (16.87)	0.743*** (24.16)
growth			0.000 (0.05)	0.000 (0.06)
coo			0.097*** (11.44)	0.100*** (10.21)
dual			−0.001 (−0.12)	0.000 (0.03)
q			−0.012*** (−5.05)	−0.013** (−2.29)
mer			−1.713*** (−29.60)	−1.711*** (−9.77)
_cons	1.828*** (541.85)	1.838*** (3955.53)	1.025*** (15.03)	1.032*** (19.48)
Industry FE	No	Yes	No	Yes
Year FE	No	Yes	No	Yes
N	5080	5080	5080	5080
R^2	0.313	0.342	0.359	0.341

***$p < 0.01$, **$p < 0.05$.

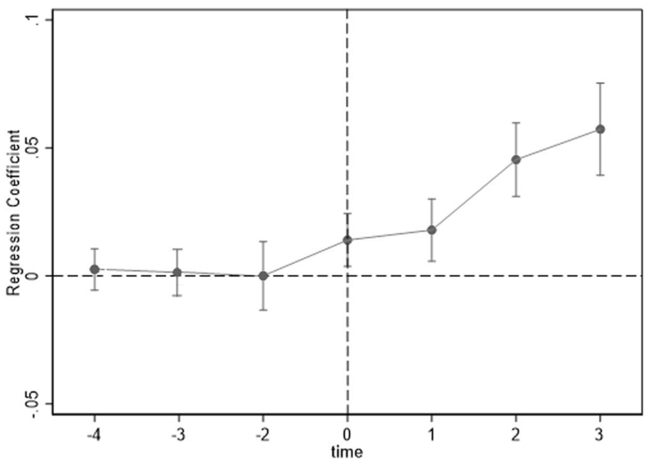

Fig. 2 Parallel trend hypothesis test. This plot shows the regression coefficients over time, with error bars indicating confidence intervals. The vertical dashed line marks the intervention point, highlighting the change in trend post-intervention.

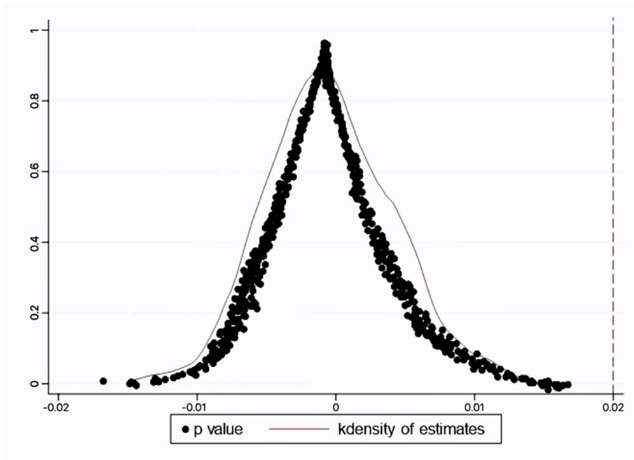

Fig. 3 Placebo test. This plot shows the distribution of *p* values (black dots) along with the kernel density estimate (KDE) curve of the estimates. The vertical dashed line represents the threshold for statistical significance, highlighting the concentration of *p* values around the central peak and illustrating the results of the placebo test.

way fixed effect estimation, and construct the model as follows:

$$\mathrm{SDP}_{it} = \alpha + \sum_{n=4}^{n=3} \beta_n SCIA_{in} + \lambda X_{it} + \gamma_i + \mu_i + \varepsilon_{it} \quad (2)$$

where SCIA_{in} indicates whether the sample year is a dummy variable for the year *n* of the SCIA pilot policy affecting *i* companies, and if *n* takes a negative number, it indicates the *n* year before SCIA; the remaining variables are specified consistently as the regression model (1). In the paper, the year before the policy is used as the base year, which is used to avoid the problem of multicollinearity. The interaction coefficients of the time dummy variables with the policy variables β_n are shown in Fig. 1. The “current” label on the *x*-axis signifies the policy’s implementation year, with the segment to the left representing the years leading up to the policy’s introduction and the segment to the right indicating the years following its implementation. The vertical line represents the 95% confidence band. Should this interval exclude the value of zero, it indicates that the coefficient is statistically significant at the 0.05 significance level; the solid points in the vertical line are the coefficients of each period. Figure 2 parallel trend test reveals that before the implementation of the policy, the coefficients of each period are relatively small, and the confidence interval encompasses 0, indicating that the pre-policy period coefficients are statistically insignificant, and the experimental group and the control group share a similar underlying trend. Following the policy’s enactment, the SDP of companies shows an upward trend, suggesting that the SCIA exerts a beneficial impact on the SDP of the experimental group.

Placebo test. To ensure the robustness of the findings and rule out potential confounding factors, a placebo test is conducted. This approach involves randomly assigning the experimental group to assess whether the observed impact of digital supply chain management on SDP arises from digital transformation itself or extraneous influences. The experimental group is randomly selected from the full sample, with the remaining companies forming the control group, while policy implementation time is set accordingly. Baseline regression following Model (2) is performed iteratively 1000 times. Figure 3 presents the kernel density distribution of *T*-values across these regressions, with a vertical reference line indicating the true regression *T*-value. The distribution predominantly centers around zero, with only a

Table 4 PSM-DID results.

Variables		Mean value		Reduct		*T*-test	
		Treat	Control	Bias (%)	|bias| (%)	*T* value	*P* > |*T*|
Lev	Unmatched	0.45342	0.42254	16.6		5.91	0.000
	Matched	0.45342	0.45136	1.1	93.3	0.38	0.704
Tang	Unmatched	12.683	12.794	−12.9		−4.58	0.000
	Matched	12.683	12.712	−3.3	74.1	−1.15	0.249
Age	Unmatched	3.2168	3.227	−5.2		−1.84	0.065
	Matched	3.2168	3.2167	0.1	98.9	0.02	0.985
Cashflow	Unmatched	0.04927	0.06242	−21.3		−7.52	0.000
	Matched	0.04927	0.0474	3.	85.8	1.08	0.279
Growth	Unmatched	0.33877	0.24835	4.8		1.68	0.093
	Matched	0.33877	0.3308	0.4	91.2	0.14	0.889
Coo	Unmatched	3.9555	3.9103	15.3		5.46	0.000
	Matched	3.9555	3.9647	−3.1	79.5	−1.09	0.274
Q	Unmatched	1.9098	2.0096	−7.8		−2.76	0.006
	Matched	1.9098	1.9272	−1.4	82.6	−0.49	0.622
Mer	Unmatched	0.08126	0.07533	4.1		1.41	0.158
	Matched	0.08126	0.07533	5.3	−30.6	3.78	0.000

Table 5 Robust test results.

	(1) PSM-DID	(2) Replace sample time window	(3) Control synchronization strategy
Treat × post	0.024** (2.07)	0.027*** (7.12)	0.017*** (5.85)
Constant	1.470*** (9.25)	1.036*** (15.77)	1.021*** (19.19)
Control	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	2674	4064	5080
R^2	0.188	0.338	0.343

***$p < 0.01$, **$p < 0.05$.

minority of regressions exhibiting *T*-values exceeding the true coefficient estimates. This finding suggests that SCIA's impact on SDP is unlikely driven by unobserved omitted variables, thereby reinforcing the robustness and validity of the benchmark analysis.

PSM-DID. Although the DID approach effectively captures the average impact of the SCIA pilot policy, selection bias may arise if systematic differences exist between the experimental and control groups, potentially inflating SDP in pilot cities. To address this concern, propensity score matching (PSM) is employed to mitigate endogeneity issues (Heckman et al. 1998). Using control variables as covariates, propensity scores are estimated via logit regression. The 1:1 nearest-neighbor matching method (without replacement) is applied within the common support range, ensuring companies in the experimental group (higher SDP) are paired with comparable companies in the control group (lower SDP). Table 4 reports the balance test results before and after matching, indicating that post-PSM, all standardized differences fall below 10% and *t*-test *p*-values exceed 0.05, confirming the elimination of systematic differences. Reanalysis of the matched sample, as shown in Table 5 (Column 1), verifies a significantly positive effect of SCIA on firm SDP at the 5% level, reinforcing the robustness of the findings.

In this paper, we further plotted the kernel density matching, as depicted in Figs. 4 and 5, the gap between the experimental group and the control group has narrowed following the matching process compared to before the matching, which mitigates the selective difference of the samples, and makes out the results more convincing.

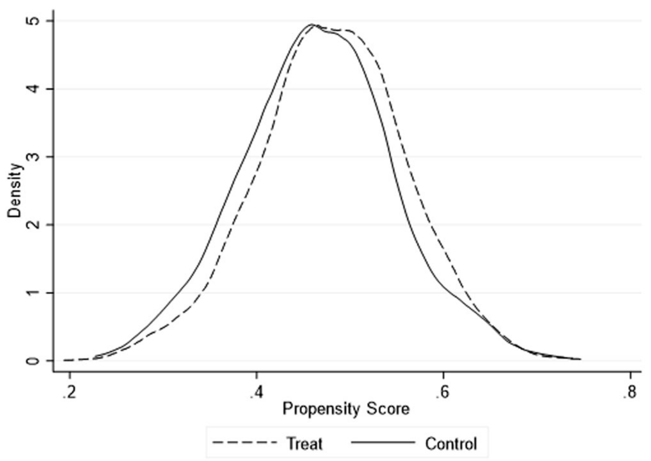

Fig. 4 Kdensity distribution of propensity score before matching. This plot shows the density distribution of the propensity score for the treatment and control groups before matching. The dashed line represents the treatment group, and the solid line represents the control group. The distribution indicates the imbalance in the propensity scores between the two groups before matching.

Replacement of the sample time window. The SCIA pilot policy was conducted in April 2018, and the sample period spans from 2013 to 2022. To avoid any distortion in the evaluation of the policy's impact due to the chosen time frame, we have adjusted

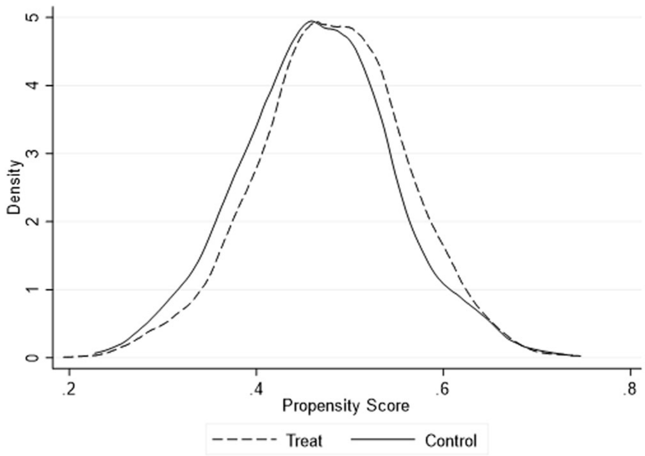

Fig. 5 K-density distribution of propensity score after matching. This plot shows the density distribution of the propensity score for the treatment and control groups after matching. The dashed line represents the treatment group, and the solid line represents the control group. The distributions are now more aligned, indicating that the matching process has balanced the propensity scores between the two groups.

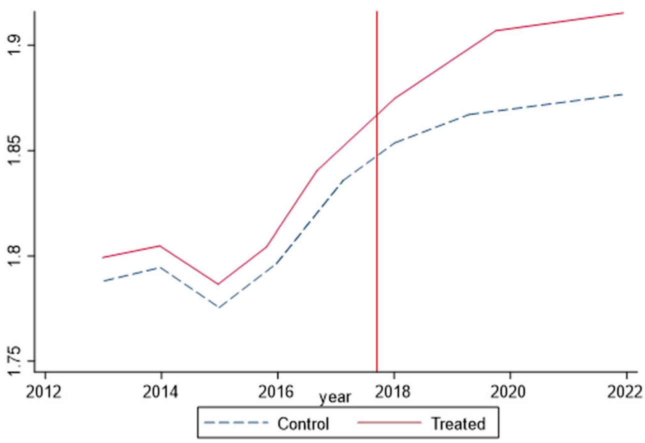

Fig. 6 Dynamic trend based on SDID. This plot shows the dynamic trends for the treated and control groups over time, based on the Synthetic Difference in-Differences (SDID) method. The dashed line represents the control group, and the solid line represents the treated group. The vertical red line marks the intervention year (2018), highlighting the change in trends post-intervention for the treated group, compared to the control group..

the sample period to 2014–2021 and used the DID model to re-examine its impact on the SDP effect, as shown in Table 5 column (2), treat*post coefficient is still significantly positive, then it shows that the time frame chosen for this study accurately captures the magnitude of the SCIA pilot policy's effect on SDP.

Control contemporaneous policy. In April 2015, China's Ministry of Housing and Construction (MOHURD) announced the third batch of sub-smart city pilot policies and a list of pilot cities, which included small, medium, and large cities. This policy greatly enhances the digitization level of the pilot cities and puts new requirements on the green development of local companies, which may have an impact on SDP. To eliminate the potential for the smart city pilot policy to improve companies' SDP, thereby enhancing the robustness of our conclusions, this paper introduces a control variable into the baseline regression model. This variable indicates whether a company's city, labeled as city *i*, is designated as a smart city pilot city in a given year, *t*. The estimation results indicate that the SCIA pilot policy maintains its beneficial impact on the SDP of manufacturing companies, even after accounting for concurrent policy effects. The outcomes are listed in Table 5, column (3).

Table 6 Composite double difference method test results.

	Knife cutting method		Bootstrap method	
	ATT	*T* value	ATT	*T* value
Treat × post	0.064***	3.35	0.064***	2.65
N	4720		4720	

***$p < 0.01$.

Composite double difference method. The composite double difference method combines SCM and DID organically, yielding more sturdy coefficients. It accounts for the varied implementation of policies across different pilot areas and identifies matching treatment groups for each experimental group by considering individual and temporal dimensions. Therefore, using the synthetic double difference to further verify the promoting effect of SCIA on manufacturing enterprise SDP. Firstly, a "policy unaffected" control group is established for each publicly traded company using synthetic double differences. Then, the companies situated within the pilot cities will be regarded as the treatment group, whereas those outside the pilot cities will be regarded as the comparison group. Ultimately, the discrepancy in SDP scores between the treatment and comparison groups will be computed to determine the extent of the policy's influence on SDP. Set the following model:

$$(\hat{\tau}^{sdid}, \hat{\mu}, \hat{\alpha}, \hat{\beta}) = arg \min_{\tau,\mu,\alpha,\beta} \left\{ \sum_{i=1}^{N} \sum_{t=1}^{T} (Y_{it}\, \mu\, \alpha_t\, \beta_t\, W_{it}\tau)^2 \hat{\omega}_t^{sdid} \hat{\lambda}_t^{sdid} \right\} \quad (3)$$

Among them, N signifies the count of participants within the sample, T indicates the time dimension of the sample, Y_{it} represents the SDP of company i in the tth period, and the dummy variable W_{it} is used to represent whether supply chain innovation is carried out. μ, α_i, and β_t represent constant term, individual fixed effect, and year fixed effect, respectively. τ is the processing effect, ω_i and λ_t represent individual weight and time weight, respectively, and ^ represents the estimated value.

Figure 6 illustrates the dynamic trend based on SDID. Statistical inference was conducted utilizing the cut-off technique and the bootstrap procedure, and the results of the composite double difference test are listed in Table 6. The regression coefficient of Treat×Post remains substantially positive, suggesting that the enforcement of policies has indeed improved the SDP.

Introduction of alternative explanatory variables. To test the accuracy of the results and to confirm that the empirical findings are not disturbed by the measurement technique of the predictor variables, we altered the measurement method of SDP. Production performance measured by the total factor productivity obtained from the OP method is replaced by the LP method, and the financial performance and environmental performance remain unchanged. The new SDP (SDP_*N*) is regressed again using the model. As listed in column (1) of Table 7, the cross-multiplier treat*post remains significant after replacing the explanatory variables, which indicates that the SCIA pilot policy does positively enhance the company's SDP, verifying the accuracy of the previous results.

Counterfactual tests. SCIA was officially launched in 2018. To verify that the improvement of SDP is indeed caused by this pilot policy, this paper assumes that 2016 is the time when the pilot city implements the policy and changes the value of the dummy variable post accordingly, and the results are listed in Table 7 Column (2). When it is assumed that 2016 is the time when the pilot city implements the policy and the coefficient of treat*post is insignificant, then it indicates that the 2018 year in which the pilot policy of SCIA was implemented does exert a beneficial impact on companies' SDP in the experimental group.

Adding control variables. To additionally guarantee the stability and dependability of the earlier findings, we refer to Jun Hu's study and introduce control variables to mitigate the issue of omitted variables: the variable of the proportion of independent directors (Ibd) is further controlled at the level of equity characteristics, and the control variable of book-to-market (BM) ratio at the level of the company's investment value characteristics, and the hypotheses are retested. The findings are shown in Table 7, upon incorporating these two control variables into the original model, the coefficient of the impact of the SCIA on company SDP is 0.02, exhibiting significant positivity at the 1% level. This suggests that the regression outcomes, including the additional control variables, align with the earlier results.

Heterogeneous analysis

Heterogeneity test based on the nature of companies' property rights. Firm ownership structure influences business models and management strategies, leading to heterogeneous responses to SCIA pilot policies. As a fundamental institutional arrangement, property rights shape the extent of SCIA's impact on sustainable development performance (SDP), with variations observed between state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs). To examine this heterogeneity, companies are classified by ownership structure.

Regression results in Table 8 (Columns 1 and 2) indicate that SCIA significantly enhances SDP for SOEs ($p < 0.01$), whereas the effect on non-SOEs (coefficient = 0.006) is not statistically significant, suggesting SOEs derive greater benefits from the policy. This disparity is attributed to SOEs' stronger financial backing and national credibility, which facilitate access to investment and financing opportunities (Liu et al. 2018). Their abundant resources enable greater flexibility in corporate restructuring and a more rapid digital transformation.

Conversely, non-SOEs operate in a highly competitive landscape with limited resources, constraining their ability to leverage policy incentives (Guariglia et al. 2011). As a result, the SCIA pilot policy serves as a more effective catalyst for SOEs, which possess both financial stability and institutional support to drive digital transformation and enhance SDP.

Heterogeneity test based on company size. Firm size is a critical determinant of corporate resilience, with larger companies exhibiting stronger social responsibility and corporate citizenship. Supply chain digital innovation further incentivizes these companies to integrate sustainability strategies. To assess the heterogeneous impact of SCIA on sustainable development performance (SDP), companies are categorized as large- or small-scale based on the median total assets (Zhang and Xin, 2024).

Regression results indicate that SCIA significantly enhances SDP for large companies (coefficient = 0.029, $p < 0.01$), whereas the effect on small companies (coefficient = 0.008) is not statistically significant, highlighting the policy's stronger influence on larger entities. This disparity is attributed to large companies' superior economic, human, and technological resources, enabling greater investments in R&D, technological innovation, and process optimization, which drive energy efficiency and environmental sustainability (Zhang and Jin, 2021). Moreover, large companies excel in supply chain optimization and collaboration, leveraging digital innovation to advance green transformation. In contrast, resource constraints hinder small companies from promptly adopting supply chain digitalization and fully utilizing SCIA policies (Yang and Wang, 2023).

Heterogeneity test based on companies' agency costs. Agency costs, arising from information asymmetry and conflicts of interest among stakeholders, influence companies' resource allocation and strategic decision-making. To examine the differential impact of SCIA pilot policies on companies with varying agency costs, the management expense ratio is employed as a proxy, categorizing companies into high and low-agency-cost groups based on the median value. Regression results in Table 9 (Columns 1 and 2) indicate that SCIA pilot policies exert a stronger positive effect on

Table 7 Further robust test results.

	(1) SDP_N	(2) 2016	(3) Add control variables
Treat × post	0.019*** (8.85)	0.001 (0.42)	0.020*** (9.96)
Constant	1.253*** (19.68)	−0.609*** (−6.31)	0.960*** (18.18)
Control	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	5080	5080	5080
R^2	0.367	0.454	0.354

***$p < 0.01$.

Table 8 The estimation results for different nature of Property Rights and Company Scale.

	(1) Non-state owned	(2) State-owned	(3) Large scale	(4) Small scale
Treat × post	0.006 (1.20)	0.034*** (7.20)	0.029*** (11.44)	0.008 (0.98)
Constant	1.108*** (16.97)	1.075*** (22.62)	1.297*** (13.12)	1.730*** (472.50)
Control	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2840	2240	2550	2530
R^2	0.345	0.330	0.244	0.269

***$p < 0.01$.

Table 9 The estimation results for different agency costs and regional digitalization levels.

	(1) High agency costs	(2) Low agency costs	(3) High level of digitization	(4) Low level of digitization
Treat×post	0.016*** (4.74)	0.030*** (10.11)	0.014*** (4.24)	0.001 (0.08)
Constant	1.392*** (11.99)	0.846*** (15.89)	1.046*** (17.80)	0.765*** (5.41)
Control	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2540	2540	3928	1152
R^2	0.234	0.234	0.348	0.403

***$p < 0.01$.

the SDP of companies with lower agency costs. This variation is attributed to the role of agency costs in resource allocation, particularly in R&D and environmental investments. High agency costs often lead to inefficient resource distribution and a preference for short-term profitability over long-term strategic objectives, thereby weakening the impact of supply chain digital innovation on SDP (Zhang et al. 2016). Conversely, companies with lower agency costs allocate resources more efficiently, fostering digital innovation and achieving greater sustainability outcomes (Chi, 2023).

Heterogeneity test based on the degree of digitization in the company's regional location. The DID correlation test suggests that the SCIA pilot policy significantly enhances company SDP. However, regional disparities in digital development across China may influence policy effectiveness. To investigate this, the 2019 Digital China Index (Tencent Research Institute, 2019) is used to classify regions into high-digitization and low-digitization levels.

Regression results in Table 9 (Columns 3 and 4) indicate that the positive impact of SCIA pilot policies on SDP is only significant in high-digitization regions, while low-digitization regions show no significant effect. A likely explanation is that higher digitalization levels correspond to more advanced digital infrastructure, enabling companies to better utilize information technology to enhance productivity and operational efficiency (Gamidullaeva et al. 2020). In well-developed digital environments, companies are more inclined to adopt supply chain digital innovation and leverage digital tools to optimize performance (Pronchakov et al. 2022).

Furthermore, companies in highly digitalized regions benefit from superior market responsiveness. The availability of big data analytics facilitates real-time market monitoring, allowing companies to swiftly adjust their strategies and products, thereby improving both financial and production performance. In contrast, companies in low-digitization regions face challenges due to underdeveloped digital infrastructure and limited technological capabilities. The slower digital transformation process in these areas delays improvements in production performance, explaining why SDP enhancements are observed primarily in high-digitization regions during the study period.

Heterogeneity test based on companies' monopoly capability. Companies with varying monopolistic power exhibit distinct responses to environmental and policy changes. Some actively seek government support, while others leverage market advantages to adapt more passively, resulting in heterogeneous policy effects. To investigate these differences, companies are categorized into two groups based on the median Lerner index: strong monopolistic power and weak monopolistic power.

Regression results in Table 10 (Columns 1 and 2) show that the impact of SCIA pilot policies on companies with strong monopolistic power is weakly significant (coefficient = 0.013), while companies with weak monopolistic power experience a significant effect at the 1% level. This suggests that market dominance moderates the effectiveness of SCIA. Companies with strong monopolistic power exert greater control over market dynamics and can adapt to policy shifts with minimal disruption, thereby diminishing SCIA's marginal effect. In contrast, companies with weaker monopolistic power face more substantial adjustments, resulting in more pronounced improvements from SCIA implementation.

Table 10 The estimation results of different monopolistic abilities.

	(1) Strong monopoly ability	(2) Weak monopoly ability
Treat×post	0.013** (2.87)	0.026*** (5.98)
Constant	0.858*** (11.90)	0.810*** (10.02)
Control	Yes	Yes
Industry FE	Yes	Yes
Year FE	Yes	Yes
Observations	2540	2540
R^2	0.328	0.265

***$p < 0.01$, **$p < 0.05$.

Furthermore, industry leaders with strong monopolistic power generally exhibit higher levels of innovation and have already optimized their supply chains before policy implementation. This pre-existing efficiency reduces the observable benefits of SCIA. Conversely, companies with weaker monopolistic power experience more significant gains from digital innovation. These results support H5.

Mechanism analysis

Model setting. Building a model of mediating effects to examine the pathways through wh ich the creation of a pilot city for SCIA influences the SDP of manufacturing companies:

$$Inter = \omega + \omega_1 Treat_{it} \times Post_{it} + \omega_2 X_{it} + \gamma_i + \mu_t + \varepsilon_{it} \quad (4)$$

$$SDP_{it} = \upsilon + \upsilon_1 Treat_{it} \times Post_{it} + \upsilon_2 X_{it} + \upsilon_3 Inter + \gamma_i + \mu_t + \varepsilon_{it} \quad (5)$$

Among them, Inter is the mediator, and the meanings of the other variables align with the previous section. ϖ_1 reflects the influence of establishing SCIA pilot cities on the mediator and υ_3 reflects the effect of the mediator on the SDP of companies. Stepwise regression is used, and the significance of both indicates the presence of a mediating influence.

Mechanism testing. Table 11 presents regression results assessing the mediating roles of innovation investment propensity,

Table 11 The estimation results of the action mechanism test.

Variables	Iiw (1)	SDP (2)	Eis (3)	SDP (4)	Cost (5)	SDP (6)
DID	0.039*** (3.08)	0.056*** (7.95)	4.652*** (1.73)	0.057*** (8.02)	−0.075** (−2.38)	0.058*** (8.29)
Iiw		0.000*** (9.46)				
Eis				0.001* (1.67)		
Cost						−0.146*** (−12.32)
Constant	1.456*** (10.04)	1.452*** (10.02)	0.004*** (10.93)	1.455*** (10.04)	0.963*** (8.64)	1.529*** (10.59)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080
R^2	0.215	0.30	0.261	0.315	0.214	0.418

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

innovation sustainability, and cost reduction in the relationship between SCIA and companies' sustainable development performance (SDP). Columns (1) and (2) examine the impact of SCIA on innovation investment propensity and its subsequent effect on SDP. Results from Column (1) show that SCIA significantly enhances companies' willingness to invest in innovation at the 1% level, while Column (2) demonstrates that this increased investment positively influences SDP, validating innovation investment as a mediating mechanism. Companies that increase innovation investment in response to SCIA are better positioned to leverage digital technologies for sustainable growth (Marion and Fixson, 2021), thus supporting H2.

Columns (3) and (4) explore the impact of SCIA on innovation sustainability and its effect on SDP. The findings confirm that SCIA significantly enhances innovation sustainability at the 1% level, which in turn leads to improved SDP. Higher innovation sustainability promotes continued investment in digital transformation, reducing the risk of premature termination due to sunk costs, resulting in more substantial SDP benefits for companies. These results validate H3.

Column (5) incorporates company cost expenditures and reveals a significant negative relationship between SCIA and company costs, indicating that digital innovation effectively reduces cost burdens. Even after controlling for cost expenditure, the impact of SCIA on SDP remains significant, confirming that cost reduction serves as a mediating mechanism. By reducing costs, companies are better able to allocate resources, thereby improving financial and operational efficiency (Gao and Wan, 2023; Airout et al. 2023). This supports H4.

Discussion

This study examines the impact of SCIA on companies' SDP, addressing critical gaps in existing research. First, while the link between digital strategies and SDP remains contested, this study leverages big data pilot zones to provide novel insights. These initiatives facilitate companies' adoption of digital technologies, enhancing governance, mitigating earnings management, and improving production efficiency (Sun et al. 2024). Furthermore, digital transformation is integral to both industrial progress and sustainable development, driving companies to enhance digital competencies, reduce carbon emissions, and strengthen environmental responsibility (Gan et al. 2023; Wei et al. 2023; Li et al. 2022). However, some scholars argue that digitalization's impact on firm performance is marginal (Curran, 2018). By employing SCIA as a quasi-natural experiment, this study provides empirical evidence to address this debate.

Second, this study extends existing research by elucidating the mechanisms through which digital policies influence SDP (Chen et al. 2022). Prior literature has largely focused on corporate information disclosure and digital strategies, whereas this study highlights how digital policies strengthen firm capabilities, particularly through sustainable innovation. While innovation is widely acknowledged as a driver of corporate strategy (Ferreira et al. 2019), its sustainability remains underexplored. By analyzing both companies' propensity to invest in innovation and their long-term innovation sustainability, this study offers practical insights into how digital strategies foster corporate innovation and enhance SDP.

Digital supply chain transformation grants companies greater visibility and real-time tracking, optimizing all supply chain stages. Leveraging IoT, big data, and AI, companies can swiftly identify and address operational bottlenecks, enhancing efficiency while reducing costs. Improved supply chain transparency not only fosters cost savings but also boosts customer satisfaction, thereby strengthening market competitiveness (Akinade and Oyedele, 2019; Alqahtani et al. 2019). In a volatile market environment, digital transformation enhances companies' resilience against supply chain disruptions and market uncertainties. Real-time monitoring and predictive analytics facilitate proactive risk management, supporting strategic decision-making and ensuring long-term sustainability.

The acceleration of digital innovations—particularly AI, IoT, blockchain, and cloud computing—has further driven companies to integrate digital supply chain strategies (Ishfaq et al. 2022; Wang et al. 2016; Wamba and Queiroz, 2022). Investment in innovation fosters technological accumulation, a crucial asset for enhancing SDP. Moreover, continuous innovation underpins companies' long-term growth (Zhang et al. 2018), reinforcing their commitment to environmental protection, resource conservation, and social welfare. These initiatives bolster corporate reputation and public trust, reinforcing sustainable development.

A key advantage of digital supply chain management is cost reduction. Digital transformation minimizes manual intervention through automation and intelligent processes, streamlining operations and reducing inefficiencies. Process optimization eliminates redundancies and errors, lowering labor and operational costs. Additionally, enhanced coordination among supply chain partners improves collaboration, strengthens communication efficiency, and minimizes transaction costs (Wu et al. 2019; Queiroz et al. 2020). Greater transparency in information exchange allows for more accurate assessments of corporate capacity, improving companies' access to financial resources (Chod et al. 2020). Furthermore, data-driven decision-making enhances responsiveness and precision, reducing risks and costs associated with suboptimal strategic choices.

Conclusions

This study investigates the impact of SCIA policies on the SDP of manufacturing companies from 2013 to 2022, employing DID, PSM-DID, and SDID methodologies. Findings confirm that SCIA significantly enhances SDP by stimulating innovation investment, strengthening innovation sustainability, and reducing cost expenditures. The policy's effects exhibit heterogeneity: SOEs benefit more due to policy-driven incentives (Cheng et al. 2017), large companies outperform small companies due to superior resources (Hu et al. 2020), companies with lower agency costs achieve stronger SDP improvements, and enterprises in highly digitalized cities experience greater advantages. Additionally, companies with weaker monopoly power exhibit more substantial SDP enhancements.

SDP encapsulates companies' ability to integrate economic, social, and environmental objectives (Ahi et al. 2018). Digital innovation in supply chains facilitates automation and resource efficiency, reinforcing sustainability. SOEs, due to their strategic positioning, swiftly implement policy-driven digitalization (Li et al. 2021), while non-SOEs, prioritizing short-term growth, respond less actively. Large companies, leveraging superior financial, technological, and human resources, advance R&D and operational efficiency (Hu et al. 2020), whereas small companies, constrained by capital and technological maturity, show weaker policy-induced gains. High agency costs hinder managerial commitment to innovation, limiting SDP improvements. Furthermore, companies in highly digitalized regions benefit from advanced IT infrastructure, global innovation access, and open-source ecosystems, while those in less digitalized areas face higher transformation costs and risks, diminishing policy effectiveness.

Given the increasing significance of digital supply chain management, policy interventions should focus on three strategic directions: (1) strengthening policy frameworks with clear operational guidelines, (2) expanding digital infrastructure investment—including broadband, cloud computing, and IoT—to support supply chain transformation, and (3) refining regulatory mechanisms to enhance information exchange, collaboration, and targeted incentives for digital adoption. Additionally, fostering digital talent through industry-academia partnerships is essential to sustaining long-term digital transformation.

For companies, integrating digital transformation into core strategies is crucial. companies should optimize supply chain processes through digital technologies, establish robust data management frameworks for informed decision-making, and enhance real-time collaboration with supply chain partners to maximize policy benefits. Furthermore, investing in workforce development to cultivate digital expertise will drive innovation and maintain long-term competitive advantage.

Data availability

The data used in this study can be accessed through the following link: https://pan.baidu.com/s/1jc2H_wBNZwnfSOvE--9fEQ Access Code: nnbm. The research data contains various variables, including unique identifiers and time information (id, code, year), experimental treatment and time dimension variables (treat, post, treat*post), key dependent variables (y(op), y(lp)), financial characteristics (lev, lntang, age, cashflow, growth), governance-related variables (coo, dual, q, mxr), and additional control variables (iiw(z), eis(z), cost(z)). These data can be used to replicate the study's results and support further analysis. For any inquiries, please refer to the provided link or contact the authors for more details.

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Author contributions

Conceptualization: JZ; Methodology: MC and JZ; Formal analysis and investigation: XT; Writing—original draft preparation: MC; Writing—review and editing: JZ and RD; Resources: MC; Supervision: JZ.

Competing interests

The authors declare no competing interests.

Ethical approval

This study did not involve human subjects, animal experiments, or the collection of personal data, so no ethical approval was required. In addition, this study was based on public data, literature review, or computer simulation, which did not involve the scope of ethical review, so no ethical approval was applied for.

Informed consent

This study did not involve the collection of personal data or identifiable individual information, so no informed consent was required for publication. In addition, this study was based on public data, literature review, or computer simulation, which did not involve situations where informed consent was required.

Additional information

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