The Impact of Digital Transformation on Supply Chain Collaborative Innovation

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Abstract. Taking Chinese A-share listed firms from 2010 to 2023 as the sample, this paper empirically analyzes the impact and heterogeneity of digital transformation on supply chain collaborative innovation. The results show that digital transformation significantly improves supply chain collaborative innovation through information, governance and innovation coordination channels. The effect is significantly positive for private, technology-intensive and high-tech firms, significantly negative for asset-intensive firms, and insignificant for state-owned, labor-intensive and non-high-tech firms. Finally, differentiated policy recommendations are proposed to promote the integration of digital transformation and supply chain collaborative innovation.

Keywords: Digital Transformation; Supply Chain Collaborative Innovation; Heterogeneous Effect; Listed Firms

1 Introduction

Digital transformation is reshaping organizational processes, innovation activities and value creation in the digital economy[11]. It promotes innovation through knowledge spillovers, greater information transparency and improved resource allocation[12,13], and can enhance innovation efficiency by reorganizing innovation resources[3,7]. However, most studies focus on internal innovation rather than supply chain collaborative innovation.

With deeper industrial division and supply chain integration, innovation increasingly depends on inter-organizational cooperation. Supply chain collaborative innovation improves competitiveness through resource and knowledge integration[8]. Digital capability and core firm digitalization can promote supply chain innovation and resilience[1,4], while digital supply chains improve performance through integration and information sharing[5]. However, collaborative innovation still faces trust, coordination and profit distribution problems[2,6].

Despite growing research on digital transformation and innovation, several gaps remain. Few studies examine supply chain collaborative innovation as an inter-organizational outcome[4]. Existing work often relies on theoretical models or case studies rather than large-scale panel data[2,8]. In addition, the coordination mechanisms of digital

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transformation and differences across industry competition, supply chain relationships and regional conditions are rarely explored. Using panel data of Chinese A-share listed firms from 2010 to 2023, this study examines the impact of digital transformation on supply chain collaborative innovation.

This paper contributes in three ways. First, it extends the focus from internal innovation to supply chain networks by examining digital transformation and supply chain collaborative innovation. Second, drawing on supply chain coordination theory and the dynamic capability perspective, it identifies three channels: information, governance, and innovation coordination. Third, the findings offer implications for governments promoting the digital economy and for firms improving digital and innovation strategies.

2 Research Hypotheses

2.1 Digital Transformation, Supply Chain Collaboration Capability, and Collaborative Innovation

Digital transformation can significantly improve supply chain collaboration capability, which is reflected in three dimensions: information collaboration, governance collaboration, and innovation collaboration. Digital technologies strengthen enterprises' data processing capabilities, improve information transparency and real-time sharing, and enhance supply chain integration efficiency[5]. Digital transformation also improves supply chain agility and resilience by enhancing absorptive capacity and digital capabilities, promoting cross-organizational integration of innovation resources[1]. In addition, the digitalization level of core enterprises generates spillover effects through information, governance, and innovation collaboration, improving the overall coordination level of the supply chain[4]. From the perspective of innovation factor flow, digital transformation promotes knowledge diffusion and optimal allocation of R&D resources, thereby improving innovation efficiency and quality[3]. The application of different digital technologies also helps improve innovation returns and diversity[7]. The improvement of supply chain collaboration capability helps reduce transaction costs, improve profit distribution mechanisms, alleviate conflicts among members, and further promote collaborative innovation[6]. Therefore, digital transformation enhances supply chain collaborative innovation performance by strengthening supply chain collaboration capability.

H1: Corporate digital transformation can significantly improve the level of supply chain collaborative innovation.

2.2 Heterogeneity between Digital Transformation and Supply Chain Collaborative Innovation

The impact of digital transformation on supply chain collaborative innovation shows significant heterogeneity. Compared with state-owned enterprises, private enterprises have more flexible organizational structures and decision-making mechanisms, and can more easily achieve resource integration and innovation-driven development through

digitalization[13]. Technology-intensive and high-tech enterprises rely more on knowledge integration and technological collaboration, so their innovation performance is more easily affected by digital empowerment[3]. In contrast, in labor-intensive and non-high-tech industries where technological dependence is relatively low and innovation focuses on incremental improvement, the collaborative innovation effect of digital transformation is relatively weak[2]. Based on this, this paper argues that the promotional effect of digital transformation on supply chain collaborative innovation varies with enterprise characteristics and industry attributes.

H2: Corporate digital transformation exerts heterogeneous effects on supply chain collaborative innovation across ownership types, industry attributes and factor intensity types. The effect is significantly positive for private, technology-intensive and high-tech firms, significantly negative for asset-intensive firms, and statistically insignificant for state-owned, labor-intensive and non-high-tech firms.

3 Data and Methodology

3.1 Data and Sample

This study uses a sample of China's A-share listed firms from 2010 to 2023. Data on digital transformation and other firm-level variables are obtained from CSMAR and firms' annual reports, while supply chain collaborative innovation data are collected from CSMAR and CNRDS. Financial and insurance firms, ST and *ST firms, and observations with missing key variables are excluded. All continuous variables are winsorized at the 1st and 99th percentiles. The final sample includes 4,502 firms and 25,751 firm-year observations.

3.2 Variable Construction

Digital: Following Li et al. [9], we collect annual reports of A-share listed firms using Python crawlers and extract textual content via Java PDFBox. Based on prior literature and policy documents, digital transformation keywords (e.g., artificial intelligence, big data, cloud computing, and blockchain) are identified. After removing irrelevant expressions, keyword frequencies are calculated and log-transformed to construct the firm-level digital transformation index.

scCoInn: Following He et al. [10], supply chain collaborative innovation is measured as the product of firms' co-patent counts and supply chain concentration, capturing both the scale of collaborative innovation outcomes and the intensity of supply chain cooperation. The co-patent count is log-transformed after adding one, yielding two measures: scCoInn1 and scCoInn2.

Control Variables: Drawing on existing literature[13], this paper mainly selects the following control variables: ROA, Size, Firm Age, Lev, Cashflow, Indep, and TobinQ.

3.3 Regression Specification

The econometric model used in the study is specified as follows:

$$scCoInn_{i.t} = \beta_0 + \beta_1 digital_{i.t} + X'_{i.t} + \mu_i + \lambda_t + \epsilon_{i.t} \quad (1)$$

where i and t represent the company and year; $scCoInn_{i.t}$ is the dependent variable representing the collaboration innovation of the supply chain ; $digital_{i.t}$ is the core independent variable measuring the digital transformation of enterprises ; $X'_{i.t}$ refers to control variables; μ_i and λ_t capture firm fixed effects and year fixed effects respectively; $\epsilon_{i.t}$ denotes the random disturbance term, capturing other unobserved determinants in the model.

3.4 Descriptive Statistics

Table 1 reports descriptive statistics for 25,751 firm-year observations. The mean of Digital is 1.677, indicating a moderate but dispersed level of digital transformation. The mean of scCoInn2 is 0.181, suggesting relatively low yet heterogeneous supply chain collaborative innovation. The control variables exhibit notable variation in firm size, financial conditions (Lev, ROA, Cashflow), governance (Indep), market valuation (TobinQ), and operating history (FirmAge).

Table 1. Descriptive statistics

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
digital	25,751	1.677	1.462	0	6.306
scCoInn2	25,751	0.181	0.358	0	2.010
Size	25,751	22.18	1.246	18.90	28.70
Lev	25,751	0.393	0.190	0.00797	1.074
ROA	25,751	0.0445	0.0702	-0.743	1.285
Cashflow	25,751	0.0513	0.0695	-1.077	0.839
Indep	25,751	37.74	5.544	14.29	80
TobinQ	25,751	2.045	1.333	0.662	31.40
FirmAge	25,751	2.940	0.322	1.099	4.190

4 Empirical Results

4.1 Baseline Regression

Table 2 presents a statistically and economically significant positive correlation between corporate digital and scCoInn2. In all specifications, the coefficient of digital is significant at the 1% level: the coefficient of 0.0106 in Column (1) indicates that a one-unit increase in digital transformation is associated with a 1.06% rise in scCoInn2; after incorporating control variables and fixed effects in Column (2), the coefficient (0.0081)

remains significant, confirming the robustness of the positive impact of digital transformation on supply chain collaborative innovation. These results suggest that firms' digital investments can enhance their capacity for supply chain collaborative innovation, highlighting the strategic value of digitalization.

Table 2. Baseline Regression Results

	(1) scCoInn2	(2) scCoInn2
digital	0.0106***	0.0081***
	(7.0241)	(4.3529)
Control variables	NO	Yes
_cons	0.1635***	-1.5776***
	(51.0655)	(-25.3021)
Year fe	No	Yes
Industry fe	No	Yes
N	25751	25751
r2_a	0.0018	0.1012

4.2 Heterogeneity Analysis

To explore heterogeneity, subsample regressions are conducted by ownership, industry attribute, technology intensity, and factor intensity (Table 3). The coefficient of Digital is positive and significant for private firms (0.0124, $p<0.01$) but insignificant for state-owned enterprises. By industry, the effect is significant for high-tech industries (0.0114, $p<0.01$) but not for non-high-tech industries. By factor intensity, the coefficient is positive and significant for technology-intensive firms (0.0136, $p<0.01$), negative for asset-intensive firms (−0.0170, $p<0.01$), and insignificant for labor-intensive firms.

Table 3. Heterogeneous Effects

	(1) scCoInn2	(2) scCoInn2	(3) scCoInn2	(4) scCoInn2	(5) scCoInn2	(6) scCoInn2	(7) scCoInn2
digital	0.0124***	-0.0020	0.0114***	0.0007	0.0136***	-0.0170***	0.0029
	(5.9378)	(-0.4931)	(4.7538)	(0.2422)	(5.1736)	(-2.6856)	(1.0770)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	-1.5226***	-1.4850***	-1.7860***	-1.0313***	-1.7893***	-2.0465***	-0.9568***
	(-19.7714)	(-12.9516)	(-22.2529)	(-11.9090)	(-19.3028)	(-11.2849)	(-11.2495)
Year fe	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fe	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	18213	7538	17143	8608	13937	4152	7464
r2_a	0.0778	0.1546	0.0860	0.1406	0.0846	0.1271	0.1189

4.3 Robustness Checks

4.3.1. Endogeneity Test.

To ensure the reliability of the conclusions, we first address endogeneity through two-stage least squares (2SLS) regression using an instrumental variable (IV4). Column (1) of the table shows that the coefficient of IV4 on digital is 0.9938. IV4 is highly correlated with corporate digital transformation, exogenous to firm-level factors, and only affects supply chain collaborative innovation through the digital channel, thus satisfying the validity of instrumental variables. The Kleibergen-Paap rk LM statistic rejects the null of underidentification at the 1% level. The Kleibergen-Paap rk Wald F statistic (4440.081) far exceeds the Stock-Yogo critical value (16.38), indicating no weak instrument problem. Since the model is exactly identified, the Hansen overidentification test is not applicable. In Column (2), the coefficient of digital is significantly positive at the 1% level. This is because the core mechanism of digitalization—optimizing supply chain information flow and resource allocation—remains unchanged after resolving endogeneity, ensuring the robustness of its positive impact on supply chain collaborative innovation.

4.3.2. Other Robustness Tests.

To test the robustness of the baseline regression results, the baseline regression is re-estimated using various methods:

1. Shortening the sample period. Restricting the sample to 2015–2023 to mitigate macroeconomic fluctuations, the coefficient of digital remains 0.0081 and significant at the 1% level (column 3, Table 4), confirming the results are not driven by the time window.

2. Alternative measure of the dependent variable. We replace the core dependent variable scCoInn2 with an alternative measure scCoInn1 and re-run the regression. As reported in column (4) of Table 4, the coefficient of digital is 0.1314 and significant at the 1% level, indicating that our main findings are robust to different measurements of supply chain collaborative innovation.

3. Adding additional control variables. Including Board and ssc to address omitted variable bias, the coefficient of digital is 0.0143 and significant at the 1% level (column 5, Table 4), further supporting the reliability of baseline findings.

Table 4. Robustness Checks and Endogeneity Tests

	(1) digital	(2) scCoInn2	(3) scCoInn2	(4) scCoInn1	(5) scCoInn2
IV4	0.9938***				
	(66.6339)				
digital		0.0218***	0.0081***	0.1314***	0.0143***
		(4.2611)	(4.0390)	(5.6803)	(7.6692)
Control variables	Yes	Yes	Yes	Yes	Yes
Board					0.0579***
					(4.1143)

ssc					0.3858***
					(21.3160)
_cons	-2.3793***	-1.5101***	-1.6383***	-25.2410***	-2.0632***
	(-15.9106)	(-25.8685)	(-24.1531)	(-23.7129)	(-28.4924)
Year fe	Yes	Yes	Yes	Yes	Yes
Industry fe	Yes	Yes	Yes	Yes	Yes
N	25745	25745	22064	25751	25751
r2_a	0.4534	0.0980	0.1013	0.1006	0.1254

5 Research Conclusions

This study tests Chinese A-share listed firms (2010–2023) and finds digital transformation significantly boosts supply chain collaborative innovation, with the conclusion robust to endogeneity and robustness tests, acting through information sharing, governance and innovation coordination. The effect is heterogeneous: positive for private, tech-intensive and high-tech firms, negative for asset-intensive ones, and insignificant for state-owned, labor-intensive and non-high-tech firms, due to varying enterprise characteristics. Firm traits also matter—larger, profitable firms perform better, while older, highly leveraged ones face constraints. Governments should roll out differentiated digital support and improve institutions; enterprises need tailored digital strategies, with core firms leading collaboration; industry associations should build platforms and share experience to drive industry synergy.

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