Financial Engineering and Risk Management (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/ferm.2025.080105
ISSN 2523-2576 Vol. 8 Num. 1

# *Digital Transformation, Supply Chain Spillovers and Corporate Innovation Capabilities*

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***Keywords:*** Supply chain, digital transformation, innovation capacity, spillover effects

***Abstract:*** Advancing digital transformation has become a consensus and trend in the industry. Using data from China's Shanghai and Shenzhen A-share listed companies from 2010 to 2022, this study investigates the spillover effects of digital transformation in China's manufacturing industry and its impact on the innovation capabilities of midstream enterprises within supply chains. The findings reveal that downstream enterprises' digital transformation significantly enhances the innovation capabilities of midstream manufacturing firms by increasing cash flow and strengthening IT capabilities. However, upstream firms' digital transformation does not show a significant positive impact, as it often focuses on internal process optimization and cost control, with limited spillover effects along the supply chain. Furthermore, the study explores the heterogeneity of these spillover effects at both micro and macro levels. Results indicate that non-state-owned enterprises, firms with highly innovative leadership, high ESG scores, and those located in regions with strong innovation capabilities and advanced digital economies benefit more significantly from digital transformation. This paper identifies the transmission pathways of digital transformation spillovers in supply chains, offering insights and references for supply chain enterprises to implement digital transformation effectively.

## 1. Introduction

In recent decades, digitalization is not only reshaping industrial structures and driving high-quality economic development but also increasingly becoming a focal point of national competitiveness. According to industry analyses on the current state of digital transformation, the global digital transformation market size is projected to grow from $521. 5 billion in 2021 to $1, 247. 5 billion in 2026, with a compound annual growth rate of 19. 1% during the forecast period. The Asia-Pacific region is expected to grow at a robust pace within this period.

The impact of digital transformation on the supply chain has become a hot topic in academia,

with its spillover effects proving particularly significant, influencing the entire value chain from suppliers to end consumers. A group of studies show that digital transformation has a significant positive impact on supply chain integration and overall sustainable supply chain performance (Oubrahim et al., 2023) [1]. Some Chinese scholars have also noted the positive informational spillover effects of customer enterprises' digital transformation on supplier firms (Li et al., 2023) [2]. Other studies have highlighted how digital transformation among leading enterprises can significantly diversify supply chain structures (Xi et al., 2023) [3].

Both theory and practice highlight that innovation is the core driving force of the real economic development. A group of scholars have extensively explored the drivers, processes, and influencing factors of corporate innovation, as well as the differences between management innovation and social innovation. These studies provide insights into understanding innovation that transcends technology (Lopes et al., 2017) and clarify the relationship between economic innovation and sustainable development innovation (Rauter et al., 2019)[4][5]. A different group of scholars, from various perspectives, have explored factors influencing corporate innovation, including government policies (Liu et al., 2020) and market demand (Qian et al., 2021)[6][7]. At the same time, the role of digital transformation in enhancing corporate innovation capacity cannot be overlooked. Digital transformation improves management efficiency, optimizes human resource structures, promotes internal and external collaborative innovation, and enhances R&D investment and efficiency, all contributing to increased corporate innovation capacity.

In the global wave of digital transformation, manufacturing enterprises, as the main economic pillar of China, are transitioning toward digitalization and intelligence to improve production efficiency and market responsiveness, thereby enhancing global competitiveness. Although China's manufacturing sector ranks first globally in scale, and the digital economy accounts for 41. 5% of GDP (ranking second globally), the sector faces significant pressures for transformation and upgrading. Digital transformation has become a critical strategy for addressing market challenges across all links of the manufacturing supply chain. In the digital age, any disruption in the supply chain can propagate through networks, amplifying impacts on overall chain stability (Hertzel et al., 2008) [8].

## 2. Theoretical Analysis and Research Hypotheses

### 2.1 The Impact of Downstream Firms' Digital Transformation on Midstream Firms' Innovation Capacity

The digital transformation of downstream firms reshapes their business models and market positions while exerting a significant influence on midstream firms through the supply chain. This influence operates primarily through two mechanisms: (1) improving midstream firms’ cash flow and (2) enhancing their information technology capabilities.

First, the digital transformation of downstream firms can lower transaction costs and enhance operational efficiency (Chen et al., 2023) [9]. It enables more efficient resource utilization, boosting

production efficiency and service quality, ultimately increasing cash flow and improving performance (BinSaeed et al., 2023)[10].

Second, digital transformation helps firms transcend traditional resource limitations by mitigating resource constraints (Sadeghi et al., 2018) [11], improving management efficiency and decision-making. H1: The digital transformation of downstream firms positively impacts midstream firms' innovation capacity through improved cash flow and information technology effects.

### 2.2 The Impact of Upstream Firms' Digital Transformation on Midstream Firms' Innovation Capacity

Upstream firms often hold significant monopolistic power (Li & Mao, 2017) [12], controlling key resources and technologies in the supply chain. Furthermore, the monopolistic position of upstream firms allows them to extract profits from midstream firms by raising the cost of intermediary goods. The resultant resource misallocation and financial constraints diminish midstream firms' ability to pursue innovation.

H2: The digital transformation of upstream firms, constrained by monopolistic tendencies and self-serving strategies, does not have a significant positive impact on midstream firms' innovation capacity.

## 3. Research design

### 3.1 Variable Selection and Definition

Drawing on panel data from 2010 to 2022 on firms' digital transformation and innovation capabilities, along with the top five supplier and customer lists of listed companies, this study constructs a matched upstream–midstream–downstream dataset. This study selects manufacturing firms as the research object due to the critical role of manufacturing in the global economy and its significance for innovation and industrial development.

1) Dependent Variable

Invention patents have the highest degree of innovation among enterprise patents, which is more significant in reflecting the height and quality of enterprise technological innovation (Hall and Harhoff, 2012)[13], and at the same time, it can timely reflect the enterprise's innovation intention and strength, and more accurately depict the instantaneous situation of the enterprise's innovation activities. Following Li et al. (2016) and Li et al. (2020)[14][15], this study quantifies corporate innovation capacity as the logarithm of the total number of invention patent applications. Data on innovation capability are sourced from the China Research Data Service Platform (CNRDS).

2) Key Independent Variable

The degree of digital transformation of upstream and downstream enterprises is measured using the frequency of digital technology-related keywords in annual reports of listed companies. Specifically, following Wu et al. (2021) [16], the text of annual reports is analyzed for keyword frequencies across five dimensions: artificial intelligence technology, big data technology, cloud computing technology, blockchain technology, and digital technology. The aggregated frequency

across these dimensions constitutes the digital transformation indicator for this study. Digital transformation data are sourced from Wu et al. (2021), who analyze the frequency of relevant keywords in Chinese listed companies' annual reports from 2010 to 2022.

3) Control Variables

Return on total assets ($ROA$), return on net assets ($ROE$), enterprise growth ($Growth$), enterprise size ($Lnsize$), proportion of shares held by the first largest shareholder ($TOP1$), two jobs in one ($Dual$), enterprise age ($Lnage$), cash flow ratio ($Cash$), gearing ratio ($Lev$), and board size ($Lnboard$) are the variables chosen as control variables in this paper in order to control the impact of other factors on firms' innovation capability, with reference to the practices of the existing literature. Table 1 displays the variables' definitions.

To ensure the reliability of empirical results, the study excludes midstream listed companies with abnormal statuses (e.g., ST or delisted firms) and removes data related to the financial and real estate industries.

Table 1 Definitions of key variables

| Variable type | variable name | variable symbol | Variable Definition |
|---|---|---|---|
| explanatory variable | Enterprise innovation capacity | IAPPLY | ln (1 + number of patent applications for inventions) |
| explanatory variable | Degree of digital transformation | DIG | Using the total number of word frequencies in 5 dimensions of AI technology, big data technology, cloud computing technology, blockchain technology, and digital technology in the annual report |
| control variable | return on total assets | ROA | Net profit/average total assets x 100 percent |
| | return on net assets | ROE | Net profit/average balance of shareholders' equity x 100 per cent |
| | Enterprise growth | Growth | Total asset growth rate |
| | Enterprise size | Lnsize | ln (1 + total assets of the enterprise at the end of the period) |
| | Shareholding ratio of the largest shareholder | TOP1 | Number of shares held by the largest shareholder/total number of share capital |
| | two jobs in one | Dual | Chairman and general manager of the two positions in one for 1, otherwise 0 |
| | Age of business | Lnage | ln (current year - year of incorporation + 1) |
| | Cash flow ratio | Cash | Ratio of cash and cash equivalents to total assets |
| | gearing | Lev | Ratio of liabilities to total assets |
| | Board size | Lnboard | Logarithmic number of board members |

## 3.2 Econometric modelling

In order to study whether the digital transformation of upstream and downstream enterprises can have a positive impact on the innovation ability of midstream enterprises, this paper constructs the following benchmark regression model for empirical analysis:

$$Y_{itp} = a_1 + a_2 DIG^{l}_{it\_mean} + X\beta + \theta_i + \varphi_t + \phi_p + \varepsilon_{itp}$$

Where, the $i$ denotes midstream firms;$l = 1$ denotes upstream enterprises, and$l = 2$ denotes downstream firms;$t$ denotes the year, and$p$ denotes the province to which the midstream enterprises belong;$Y_{itp}$ is the explanatory variable, indicating the innovation ability of midstream enterprises; $DIG_{it\_mean}^{l}$ is the core explanatory variable, indicating the degree of digital transformation of upstream and downstream enterprises. Given the characteristics of multiple upstream and downstream enterprises' digital transformation influencing the innovation capability of a single midstream enterprise, this study addresses the issue of dimensional inconsistency between core explanatory and explained variables. Using upstream and downstream firms' revenue as weights, the digital transformation term frequencies were weighted to derive the upstream and downstream average digital transformation frequencies corresponding to midstream firms.

In addition, the individual fixed effects of midstream firms$\theta_i$ , year fixed effects$\varphi_t$ and province fixed effects$\phi_p$ The residual term is$\varepsilon_{itp}$ The residual term is Finally, the empirical regressions in this paper all use the robustness standard error of clustering at the level of midstream enterprises, and the rest of the special cases will be described separately in the regression results table.

## 4. Empirical analysis

### 4.1 Baseline Regression Analysis

Table 2 examines the impact of upstream and downstream enterprises' digital transformation on the innovation capabilities of midstream enterprises. Columns (1) to (3) focus on the downstream–midstream enterprise sample, analyzing the effect of downstream enterprises' digital transformation on midstream innovation. Specifically: Column (1) controls for midstream enterprise-specific and year-fixed effects while including seven control variables (excluding ROA, ROE, and cash flow ratio). Column (2) incorporates ROA, ROE, and cash flow ratio as additional control variables. Column (3) further includes province-fixed effects. The results demonstrate that downstream enterprises' digital transformation (DIG) significantly enhances midstream enterprises' innovation capabilities.

Columns (4) to (6) shift the focus to the upstream–midstream enterprise sample while maintaining consistency with the model settings in Columns (1) to (3). However, the coefficient for upstream digital transformation is not statistically significant, indicating that upstream enterprises' digital transformation does not have a notable impact on midstream innovation.

Table 2 Regression to basics

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Downstream - midstream | | | upstream - midstream | | |
| | IAPPLY | IAPPLY | IAPPLY | IAPPLY | IAPPLY | IAPPLY |
| DIG | 0. 00665** | 0. 00611** | 0. 00611** | 0. 000836 | 0. 000839 | 0. 000839 |
| | (0. 00285) | (0. 00296) | (0. 00303) | (0. 00418) | (0. 00420) | (0. 00434) |
| Controls | YES | YES | YES | YES | YES | YES |

| | | | | | | |
|---|---|---|---|---|---|---|
| Year FE | YES | YES | YES | YES | YES | YES |
| Midstream FE | YES | YES | YES | YES | YES | YES |
| Province FE | | | YES | | | YES |
| Observations | 665 | 658 | 658 | 492 | 492 | 492 |
| R-squared | 0. 831 | 0. 832 | 0. 832 | 0. 787 | 0. 787 | 0. 787 |

Note: ***, **, and * represent significant at the 1 per cent, 5 per cent, and 10 per cent levels, respectively; clustered robust standard errors in parentheses, clustered to the midstream firm level.

## 4.2 Robustness Tests

Replacing the clustering level to the midstream firm-year level, the results are shown in Table 3, column (1), where it can be seen that the regression coefficients for digital transformation of firms are all positive and satisfy a significance level of less than 5%. At the same time, the omitted variable problem is fully considered, city fixed effects are introduced as well as letting city fixed effects and year fixed effects interact, and the regressions are conducted again, and the results are shown in column (2) and column (3) of Table 3. It can be seen that the regression coefficients for digital transformation of firms are all positive

Table 3 Replacement of clustering levels and consideration of omitted variables

| | (1) | (2) | (3) |
|---|---|---|---|
| | IAPPLY | IAPPLY | IAPPLY |
| DIG | 0. 00611** | 0. 00600* | 0. 0142*** |
| | (0. 00288) | (0. 00324) | (0. 00477) |
| Controls | YES | YES | YES |
| Year FE | YES | YES | YES |
| Midstream FE | YES | YES | YES |
| Province FE | YES | YES | |
| Midstream City FE | | YES | |
| Year # Midstream City FE | | | YES |
| Observations | 658 | 658 | 207 |
| R-squared | 0. 832 | 0. 833 | 0. 939 |

Note: ***, **, and * represent significant at the 1%, 5%, and 10% levels, respectively; clustered robust standard errors in parentheses, column (1) clustered to the midstream firm-year level, columns (2) and (3) clustered to the midstream firm level.

## 4.3 Discussion on Endogeneity

Enterprises aiming to enhance their innovation capabilities might have a stronger incentive to pursue higher levels of digital transformation. To address the potential endogeneity arising from reverse causality, this study employs the instrumental variable (IV) approach for testing. Drawing on the studies of Liu (2023) and Zhao (2023) [17][18], this study uses the interaction between the internet penetration rate and the number of fixed telephones per 100 people in 1984 as an instrumental variable.

Table 4 shows that the instrumental variable has a significant positive effect on enterprise digital

transformation and passes a series of robustness tests, indicating that the instrumental variable is both reasonable and valid. Moreover, the coefficients of IV and IT in the regression are both significant and consistent in sign with the baseline regression results. This suggests that after addressing endogeneity with the instrumental variable approach, the conclusions of the regression remain robust and continue to support the baseline findings.

Table 4 Endogeneity test

| | First-stage regression results | Second-stage regression results |
|---|---|---|
| | DIG | IAPPLY |
| c. 1984Tel#c. Int | 0. 0152** | |
| | (0. 00649) | |
| DIG | | 0. 0528* |
| | | (0. 0300) |
| Controls | YES | YES |
| Year FE | YES | YES |
| Midstream FE | YES | YES |
| Province FE | YES | YES |
| Observations | 674 | 658 |
| R-squared | 0. 046 | -0. 226 |

Note: ***, **, and * represent significant at the 1 per cent, 5 per cent, and 10 per cent levels, respectively; clustered robust standard errors in parentheses, clustered to the midstream firm level. Same below.

## 5. Mechanism testing

### 5.1 Impact of Upstream and Downstream Enterprises on Midstream Enterprises' Cash Flow

Building on the above studies, we further explore how the digital transformation of upstream and downstream enterprises impacts the cash flow of midstream enterprises. A two-step mediation effect model is constructed, with midstream enterprise cash flow as the dependent variable and the digital transformation of upstream and downstream enterprises as the independent variable. Since the dependent variable is replaced with the cash flow indicators of midstream enterprises, control variables such as ROA, ROE, and cash flow ratios are excluded to avoid multicollinearity, which could undermine the accuracy of the empirical results. Referring to existing studies, the cash flow of midstream enterprises is measured using indicators such as Tobin's Q, operating revenue/total assets, and net profit. The empirical results are presented in Table 5. As the cash flow of midstream enterprises increases, they gain greater flexibility and capacity to invest in innovation and pursue new projects, driving technological advancements and product optimization (Song, 2023)[19]. Furthermore, increased internal cash flow enables higher investments in human capital (Tie and Liu, 2021)[20], contributing to talent acquisition and skill development.

Table 5 demonstrates that the digital transformation of downstream enterprises significantly boosts the cash flow of midstream enterprises. Combined with previous findings, it is evident that the digital transformation of downstream enterprises not only improves their own operational performance but also significantly enhances the cash flow of midstream enterprises. However, the

transmission channel between upstream and midstream enterprises appears to be obstructed.

Table 5 Impact of cash flows

| | (1) | (2) | (3) |
|---|---|---|---|
| | Tobinq | OE_TA | Netprofit |
| DIG | 0. 00710* | 0. 00165* | 3. 170e+06** |
| | (0. 00402) | (0. 000872) | (1. 532e+06) |
| Controls | YES | YES | YES |
| Year FE | YES | YES | YES |
| Midstream FE | YES | YES | YES |
| Province FE | YES | YES | YES |
| Observations | 647 | 681 | 681 |
| R-squared | 0. 822 | 0. 919 | 0. 501 |

## 5.2 The Information Technology Effect of Upstream and Downstream Enterprises' Digital Transformation

According to the study by Wu et al. (2023)[21], digitalization enhances technological innovation and promotes high-quality development through knowledge empowerment and ecosystem co-empowerment. Therefore, the digital transformation of upstream and downstream enterprises facilitates their own high-quality development. The information technology of midstream enterprises can be measured in terms of both inputs and outputs. Thus, we select three comprehensive indicators: digital investment, R&D expenditures, and digital performance score.

Based on this framework, we group firms by median values and use innovation capability as the dependent variable, while employing digital investment, R&D expenditures, and digital performance scores as independent variables. The results, as shown in the table 6, indicate that midstream enterprises with R&D expenditures, digital investment, and digital performance scores above the median exhibit stronger innovation capabilities. This suggests that higher investments in information technology and favorable evaluations of digital outcomes more effectively enhance firms' innovation capabilities, thereby supporting Hypothesis 1.

Table 6 Impact of IT effects

| | IAPPLY | IAPPLY | IAPPLY | IAPPLY | IAPPLY | IAPPLY |
|---|---|---|---|---|---|---|
| | High R&D expenditures | Low R&D expenditures | High digital investment | Low digital investment | High digital performance score | Low digital performance score |
| DIG | 0. 00851** | 0. 00586 | 0. 0103** | 0. 00130 | 0. 00702* | -0. 00958 |
| | (0. 00351) | (0. 00943) | (0. 00422) | (0. 00409) | (0. 00364) | (0. 00933) |
| Controls | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| Midstream FE | YES | YES | YES | YES | YES | YES |
| Province FE | YES | YES | YES | YES | YES | YES |
| Observations | 418 | 150 | 363 | 256 | 394 | 145 |
| R-squared | 0. 820 | 0. 933 | 0. 849 | 0. 775 | 0. 841 | 0. 887 |

## 6. Further analysis

### 6.1 Micro-Level Heterogeneity Analysis of Enterprises

At the micro level of enterprises, this paper explores the impact of digital transformation of downstream enterprises on the innovation capacity of midstream enterprises from three dimensions: the nature of enterprise property rights, the innovation consciousness of enterprise leaders and ESG scores. From the results in Table 7, we can see that downstream enterprises' digital transformation has a significant positive impact on midstream enterprises' innovation capability in non-state-owned enterprises, enterprises with stronger innovation awareness of enterprise leaders and enterprises with ESG scores ≥5.

Table 7 Tests for micro-level heterogeneity of firms

| | state-owned business | non-state enterprise | High awareness of innovation among executives | Low sense of innovation among executives | Median annual ESG score ≥5 | Median annual ESG score <5 |
|---|---|---|---|---|---|---|
| | IAPPLY | IAPPLY | IAPPLY | IAPPLY | IAPPLY | IAPPLY |
| DIG | -0. 00438 | 0. 0112*** | 0. 00596* | 0. 00420 | 0. 0184* | 0. 00565 |
| | (0. 00691) | (0. 00346) | (0. 00321) | (0. 0113) | (0. 0106) | (0. 00383) |
| Controls | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| Midstream FE | YES | YES | YES | YES | YES | YES |
| Province FE | YES | YES | YES | YES | YES | YES |
| Observations | 237 | 411 | 262 | 283 | 169 | 375 |
| R-squared | 0. 893 | 0. 797 | 0. 852 | 0. 846 | 0. 885 | 0. 836 |

### 6.2 Examination of regional heterogeneity at the macro level

The innovation environment of the region where midstream enterprises are located plays a crucial role in shaping their innovation performance. By dividing the sample enterprises into two groups based on R&D expenditure levels, regression analysis was conducted. As shown in Table 8, while both midstream enterprises with R&D expenditures above and below the median demonstrate a significant positive impact on innovation capabilities at the 5% significance level, the effect is more pronounced for enterprises with R&D expenditures above the median.

Following the method of Li (2022)[22], this study uses the "digital economy" and "digitalization" information indices of prefecture-level cities to measure the level of local digital economy development. The sample is divided into groups based on enterprises located in regions with high and low annual information indices for regression analysis. According to the results in Table 8, the impact of digital transformation on enterprise innovation capabilities is more pronounced in regions with higher levels of digital economy development.

Table 8 Tests for regional macro-level heterogeneity

| | R&D spending above median | R&D spending below median | High yearly information index | Low annual information index |
|---|---|---|---|---|
| | IAPPLY | IAPPLY | IAPPLY | IAPPLY |
| DIG | 0. 00914* | 0. 00680* | 0. 00783* | 0. 00626 |
| | (0. 00501) | (0. 00374) | (0. 00451) | (0. 00520) |
| Controls | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES |
| Midstream FE | YES | YES | YES | YES |
| Province FE | YES | YES | YES | YES |
| Observations | 204 | 403 | 219 | 408 |
| R-squared | 0. 886 | 0. 835 | 0. 833 | 0. 858 |

## 7. Findings and suggestions

First, the government provides solid support and an optimized environment for the digital transformation of enterprises by formulating relevant policies. Second, it establishes a market-oriented incentive mechanism to stimulate the innovation vitality of SOE personnel. Finally, at the regional level, a favorable innovation environment is created to provide support and incentives for enterprises to promote their innovation activities.

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