

DIGITAL TRANSFORMATION AND PATENT CITATION: BASED ON THE PERSPECTIVE OF CO-DIRECTOR

YuChong Hu¹, AoYang Ma², QiYuan Li^{1*}

¹ *International Business College, Dongbei University of Finance and Economics, Dalian, China.*

² *School of Business Administration, Dongbei University of Finance and Economics, Dalian, China.*

Corresponding Author: Qiyuan Li, Email: 2075583243@qq.com

Abstract: Will the information of digital transformation diffuse upstream through the supply chain to promote technological spillover and corporate learning and innovation? This study selects data of the A-share listed corporates in China from 2008 to 2020 of the top five customer and supplier relationships of listed corporates. Through text analysis methods, the level of corporate digital transformation is depicted to examine the impact mechanism of customer corporates' digital-driven upstream corporate learning and innovation. The research reveals that the digital transformation of customer corporates has a promoting effect on the patent citations of supplier corporates. At the same time, when there is a connection between customer and supplier corporates through common directors, the impact of customer corporate digital transformation on supplier corporate patent citations is more significant. Further research finds that when the supplier corporate has higher total factor productivity and a greater number of highly educated talents, the impact of customer corporate digital transformation on supplier corporate patent citations is more pronounced. This study provides micro-level evidence for exploring the diffusion effects of supply chain information and corporate digital transformation, offering important insights for the innovation and development of corporates.

Keyword: Digital transformation; Supply chain; Patent citation

1 INTRODUCTION

Currently, the Chinese economy is facing a serious structural imbalance between supply and demand, with the primary contradiction hindering economic development concentrated on the supply side. The 20th National Congress of the Communist Party of China's proposal points out that China's economy has transitioned from a high-speed development stage to a high-quality development stage. To address the current issues of unbalanced and insufficient economic and social development, there is a need for supply-side reform. Supply-side reform aims to further liberate and develop social productivity, promote structural adjustment through reform, reduce ineffective and inefficient supply, and expand effective and high-end supply. With the development of the times, fields centered around digital technologies such as cloud computing, big data, artificial intelligence, and ICT are continuously maturing, driving the development of the digital economy and attracting attention. The "White Paper on the Development of China's Digital Economy (2020)" indicates that the digital economy takes digitized knowledge and information as key production factors, with digital technology as the core driving force. It achieves deep integration with the real economy through digital technology, enhances the digitalization, networking, and intelligence level of the economic and social aspects, and accelerates the emergence of new economic forms in the restructuring of economic development and governance models. The development of the digital economy brings opportunities for businesses. The "14th Five-Year Plan for the Development of the Digital Economy" provides detailed deployment to further promote the healthy development of China's digital economy. It focuses on optimizing and upgrading digital infrastructure, leveraging the role of data elements, advancing industrial digital transformation, promoting digital industrialization, and improving the governance system of the digital economy.

In the trend of corporate digital development, whether the digital transformation of customer corporates can promote

supplier corporates' citation of patents and whether corporate digital transformation can facilitate high-quality economic development have become focal points in the academic community. In the era of continuous integration of the digital economy and industrial transformation, the digital transformation of customer corporates is undoubtedly a wise move in keeping with the times. Research on whether the digital transformation of customer corporates can promote the patent citations of supplier corporates, alleviating issues such as low supply chain efficiency and insufficient corporate innovation capacity, holds practical guidance significance and socioeconomic value.

This research based on third person perspective, With the premise of the "information spillover effect" existing in the supply chain, text analysis techniques are employed to position and identify key terms related to digital transformation. The frequency of these terms is then utilized as an index to construct indicators for corporate digital transformation [1]. Through Python, annual reports of A-share listed corporates were collected and organized from major financial data websites. Jieba's segmentation and counting functionalities were employed to conduct text analysis on each listed company's annual report. This process was aimed at identifying indicators of corporate digital transformation, defining them as variable X. Referring to Aguilera-Caracuel et al. research, proactive patent citations were utilized to characterize corporate learning [2]. Due to the truncation characteristics of patent citation data, this study employed the logarithm of the number of patents cited by a company per patent application as the count of patents applied by the corporate, defining it as variable Y. By researching under the moderating effect of common directors, the benefits of digital transformation on the mechanism of corporate patent citations change. Further analysis examined whether the total factor productivity and highly educated talent of supplier corporates significantly impacted this mechanism, leading to conclusive findings. The study investigated whether the digital transformation of customer corporates could affect the production behavior and decision-making of supplier corporates through the information spillover effect in the supply chain. Positive benefits were expected in terms of information acquisition, technological innovation, and other aspects, thereby promoting their citations of patents. Heterogeneity analysis and robustness testing were conducted to further explore whether the digital transformation of customer corporates had an impact on the patent citations of supplier corporates when there were common directors between upstream and downstream corporates. This research provides empirical references for exploring whether supply chain information diffusion is influenced by corporate digital transformation and for promoting innovation and development in supplier corporates.

The marginal contributions of this paper are as follows: ①This study offers micro-level evidence, exploring the effects of supply chain information diffusion and corporate digital transformation. It enriches the economic consequences of digital transformation, providing a reference basis for promoting high-quality economic development. ②Against the backdrop of the era of corporate digital transformation, this paper innovatively enhances the literature on corporate digital transformation by starting from the impact of customer corporate digital transformation on supplier corporates. ③This paper provides data support for subsequent research on upstream corporate patent citations. In-depth analysis of these data can yield insights into technological development trends, research and development dynamics of competitors, and potential market demands. This information holds significant reference value for the product development and strategic planning of upstream corporates.

2 THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

2.1 Theoretical Framework

2.1.1 Corporate digital transformation

As corporate digital transformation gradually advances, it assumes an increasingly critical role in business activities [3]. Many scholars have explored the economic consequences of corporate digital transformation, examining it from an empowering perspective. Digital technologies facilitate high-quality development, promote the specialization of corporate division of labor, further enhance overall factor productivity, and reduce costs and inputs in the production process [4]. From an enabling standpoint, the introduction of digital technologies can bring about information spillover effects in the supply chain. When customer corporates within the supply chain undergo digital transformation, significant information spillover effects can be generated for supplier corporates, further influencing their strategic

decision-making behaviors [5]. This also aids corporates in filtering and analyzing vast amounts of data, reducing information asymmetry between corporates and investors. From an internal perspective, the efficiency of internal information transmission and communication within corporates can be substantially improved through the digital transformation of corporate information systems.

2.1.2 Corporate patent citation

In order to promote high-quality development and contribute to the construction of an innovative nation, we continually explore factors driving corporate innovation. As knowledge flow and technological innovation are further reflections of patent activities, the greater the number of patents a company applies for, the broader and stronger its innovative knowledge scope and capabilities. Corporates with strong innovation capabilities exhibit higher driving forces for digital transformation. Therefore, this paper referred Boly et al. method which use proactive patent citations as an indicator of corporate innovation learning [6]. After analyzing data from 29 national-level corporate studies, corporate governance was the driving force of technological innovation, and information transparency are highly correlated. However, this research primarily focuses on foreign corporates. Further analyses by Chinese scholars reveals that supply chain information transparency indeed promotes innovation in Chinese corporates. The main promoting effect is through alleviating innovation financing constraints rather than through governance or other means. It is evident that alleviating innovation financing constraints is the primary channel through which information transparency promotes innovation [7]. Corporate digital transformation not only enhances its driving force for innovation but also significantly improves innovation efficiency, with this effect being more pronounced in state-owned corporates [8].

In summary, current researches on corporate digital transformation mostly focus on the internal aspects of corporates, with limited studies combining digital transformation with upstream and downstream corporates. The quality of information obtained by service provider corporates from customer corporates is inseparable from their business decision-making behaviors. However, existing research often overlooks the economic consequences brought about by the digital transformation of customer corporates. Furthermore, although scholars have explored related issues from various perspectives and achieved certain results, most studies focus on the quantity and efficiency of innovation brought about by corporate digital transformation, neglecting further examination of the impact of the digital economic development of customer corporates on the introduction of technology in upstream corporates. Given this, the paper aims to expand the understanding of the economic consequences of digital transformation for both upstream and downstream corporates in the supply chain, with the goal of driving economic high-quality development and fostering coordinated corporate efforts.

2.2 Hypothesis Development

The widespread application of digital technology has significantly enhanced the information transparency of the supply chain. As digital technology continues to advance, an increasing number of scholars recognize that corporate digital transformation is an inevitable requirement for future economic growth. Most theoretical perspectives posit that digital technology can bring economic benefits to corporates, exerting an indispensable impact on their innovation and overall factor productivity [9]. It helps corporates gain a significant advantage in market competition. Moreover, existing research indicates that the digital transformation of customer corporates contributes to mitigating the "bullwhip effect" in the supply chain, thereby significantly improving information transparency and enhancing the information environment among supply chain partners [10]. Against the backdrop of rapid digital technology development, the timely analysis of big data in production and operations through digital platforms and real-time data analysis tools enhances decision-making quality. This improvement in information transparency not only aids in reducing information transmission delays and errors but also strengthens communication and collaboration among partners, thus improving the efficiency and flexibility of the supply chain.

Corporate digital transformation is a crucial driver for promoting innovative development and facilitating high-quality growth, contributing to the sustainability of society. Whether a modern corporate falls into the category of high-tech corporates often depends on whether its products have reached modern levels. The key to achieving product

modernization lies in the application of advanced digital technology in the manufacturing process. Digital transformation not only makes it more likely for corporates to achieve product modernization but also reduces transaction costs for businesses. According to data released by the Chinese National Bureau of Statistics, in 2023, over 80% of transactions occurred on online platforms, significantly reducing search, transportation, and inspection costs. Moreover, digital management virtually eliminates the marginal cost of corporate assets, facilitating large-scale replication and dissemination. In addition, corporate digital transformation promotes better communication with customers, enables the provision of personalized services to different users, accurately identifies customer needs, and innovates resource allocation patterns. The digital transformation of customer corporates not only benefits their own high-quality development but also inevitably influences upstream corporates. The application of digital technology provides robust support for the long-term development of corporates and makes a significant contribution to the sustainable development of society.

Based on the above analysis, this paper will propose the following hypothesis:

H1: Keeping other conditions unchanged, digital transformation of customer corporates have positive effect on patent citation of supplier corporates.

3 METHODOLOGICAL DESIGN

3.1 Sample Selection and Data Source

This paper selects data of the A-share listed corporates in China from 2008 to 2020 of the top five customer and supplier relationships of listed corporates as the initial research sample. The financial data of the listed corporates and patent application data utilized in this study were sourced from the CSMAR database. The textual information from management analysis and discussion in the text analysis was obtained from the China National Research Data Service Platform (CNRDS). In instances where text data was missing, supplementation was performed by consulting annual report disclosure information on the SSE and SZSE's websites, and the following data are excluded: (1) exclude corporates with industry code J (financial industry) (2) exclude corporates' data that are ST or ST*. In order to mitigate the impact of extreme values, all variable data mentioned above underwent winsorization at the 1% and 99% percentiles. Ultimately, a total of 2,215 observations were obtained for analysis

3.2 Variable Definition

3.2.1 Explanatory variable: *Customer corporate digital*

Currently, there is no unified indicator to measure the extent of customer corporate digital transformation. Literatures have employed various methods when exploring the measurement of corporate digital transformation. Some studies utilize sub-item metrics of macro or industry-level digital economic indices, while others attempt to use survey data from corporates. In surveys, researchers may set specific indicators such as digital systems, digital software, and the prevalence of digitization to better capture the overall picture of corporate digital transformation. However, there is still a lack of a universally applicable and comprehensive metric standard that adequately reflects the degree of corporate digital transformation.

This paper addresses this gap by utilizing text analysis techniques to locate and identify key terms related to digital transformation, using word frequency as the basis for constructing indicators of corporate digital transformation. Through Python, annual reports of A-share listed corporates were collected and organized from major financial data websites. Jieba's segmentation and counting functionalities were employed to conduct text analysis on each listed company's annual report.

3.2.2 Explained Variable: *Supplier corporate patent citation (InPtnCiting)*

The duration of the same supply chain's existence (SC_Duration) is considered as an indicator of measuring corporate learning. This study employs proactive patent citations by corporates to describe the learning situation of corporates. This choice is based on the notion that a company's patent activities represent the process of knowledge flow and learning. The more patents a company cites when applying for a patent, the broader the scope of learning from other

innovative knowledge, indicating a stronger learning ability. Corporates with robust learning capabilities also tend to have stronger driving forces for digital transformation. Given the truncation characteristics of patent citation data, this study utilizes the logarithm of the number of patents cited by a company per patent application from other organizations (InPtnCiting) as another control variable for measuring corporate learning.

3.2.3 Other variable

To validate the hypothesis, this study controlled for company size (Size), debt ratio (Lev), return on equity (ROE), revenue growth capability (Growth), cash flow ratio (Cashflow), years of listing (Listage), research and development expenditure (RD), and industry competitiveness (HHI).

3.2.4 Model construction

To assess the impact of customer corporate digital transformation on supplier corporate patent citations, the following regression model was constructed in this study:

$$\text{InPtnCiting}_{i,t} = \alpha + \beta \text{Digital}_{i,t} + \text{Control}_{i,t} + \text{Industry}_i + \text{Year}_t + \varepsilon_{i,t}$$

The dependent variable is supplier corporate patent citations (InPtnCiting), and the independent variable is customer corporate digital transformation (Digital). Additionally, industry and year dummy variables were included in the regression analysis to control for industry fixed effects (Industry) and time fixed effects (Year).

4 EMPIRICAL RESULTS

4.1 Correlation Analysis

Correlation testing assesses whether there is a relationship between variables, indicating the degree of closeness between them. By employing Pearson correlation coefficient analysis, it was found that the correlation coefficient between corporate digital transformation and corporate patent citations is 0.119, and it is significant at the 1% level. This suggests that digital transformation has a promoting effect on corporate patent citations, providing preliminary validation for the hypothesis.

Table 1. Correlation analysis

lnP~g	L1 D~l c	L1 CoD~r	Size	Lev	ROE	Growth	
lnPtnCi~g	1						
Digital c	0.119***	1					
CoDiretor	0.051**	0.0220	1				
Size	0.432***	-0.093***	0.0140	1			
Lev	0.134***	-0.107***	-0.00900	0.373***	1		
ROE	0.148***	0.0280	0.044**	0.118***	-0.223***	1	
Growth	0.043**	0.046**	0.0240	-0.00300	0.0120	0.292***	1
Cashflow	0.0300	-0.039*	0.0130	0.148***	-0.104***	0.295***	-0.0300
Listage	0.00600	-0.050**	0.059***	0.301***	0.436***	0.00200	-0.083***
RD	0.362***	0.136***	-0.0290	0.088***	0.0300	0.0140	-0.0320
HHI	0.0260	-0.129***	0.044**	0.333***	0.064***	0.0130	-0.053**
Cashflow	Listage	RD	HHI				
Cashflow	1						
Listage	0.157***	1					
RD	-0.038*	-0.106***	1				
HHI	0.125***	0.0280	-0.186***	1			

4.2 Descriptive Statistics

According to the descriptive statistics in Table 1, the mean of supplier corporate patent citations is 3.32, with a standard deviation of 2.32. The mean of customer corporate digital transformation is 0.59, with a standard deviation of 0.93. Additionally, the mean of common directors is 0.12, with a standard deviation of 0.50. This suggests that supplier corporates, in assessing their innovation status, exhibit a lack of impetus in patent citations, and the differences among peers are not substantial.

Table 2. Descriptive statistics

	count	mean	sd	min	p50	max
lnPtnCiting	2215	3.3201	2.3202	0.0000	3.6109	10.4436
Digital_c	2215	0.5911	0.9306	0.0000	0.0000	3.5553
CoDirector	2215	0.1151	0.5055	0.0000	0.0000	4.0000
Size	2215	22.5407	1.4598	19.7396	22.3723	27.8520
Lev	2215	0.4583	0.2088	0.0000	0.4690	0.9246
ROE	2215	0.0554	0.1197	-0.5269	0.0653	0.3138
Growth	2215	0.1336	0.3404	-0.5625	0.0978	2.3429
Cashflow	2215	0.0460	0.0631	-0.1872	0.0447	0.2542
Listage	2215	2.2634	0.7429	0.0000	2.3979	3.3322
RD	2215	14.9248	6.9696	0.0000	17.5738	23.8553
HHI	2215	0.0991	0.1189	0.0000	0.0638	1.0000

4.3 Baseline Results

Table 1 presents the results of the baseline regression. Columns (1), (2), and (3) all represent the regression outcomes of the impact of customer corporate digital transformation on supplier corporate patent citations. Based on the regression results in columns (1), (2), and (3), the parameter estimates for the regression coefficient of lnPtnCiting with respect to Digital are 0.1841, 0.1834, and 0.1539, respectively, all significant at the 1% level. This indicates that customer corporate digital transformation reduces transaction costs among corporates, promotes patent citations by supplier corporates, and facilitates high-quality development. This provides preliminary validation for the hypothesis that customer corporate digital transformation promotes patent applications by supplier corporates. Furthermore, the regression results in columns (2) and (3) also suggest that the effect becomes more pronounced when there are common directors between customer and supplier corporates.

Table 3. Baseline Results.

	(1)	(2)	(3)
	r1	r2	r3
VARIABLES	L1_lnPtnCiting	L1_lnPtnCiting	L1_lnPtnCiting
Digital_c	0.1841*** (0.0417)	0.1834*** (0.0416)	0.1539*** (0.0424)
CoDirector		0.1824** (0.0728)	0.0032 (0.0889)
Digital_c*CoDirector			0.2679*** (0.0767)
Size	0.8739*** (0.0330)	0.8720*** (0.0330)	0.8739*** (0.0329)
Lev	-0.6267***	-0.5900**	-0.5849**

	(0.2365)	(0.2367)	(0.2361)
ROE	1.0861***	1.0833***	1.0980***
	(0.3679)	(0.3674)	(0.3665)
Growth	0.0130	0.0088	0.0193
	(0.1168)	(0.1166)	(0.1164)
Cashflow	0.2221	0.2091	0.2061
	(0.6395)	(0.6388)	(0.6372)
Listage	-0.0210	-0.0339	-0.0379
	(0.0613)	(0.0615)	(0.0613)
RD	0.0592***	0.0591***	0.0586***
	(0.0068)	(0.0068)	(0.0068)
HHI	-0.4448	-0.4816	-0.4781
	(0.4059)	(0.4057)	(0.4046)
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	-20.0275***	-19.9528***	-19.9585***
	(2.2074)	(2.2050)	(2.1993)
Observations	2,215	2,215	2,215
R-squared	0.4764	0.4779	0.4808
F	50.74	49.75	49.08

4.4 Robustness Test

4.4.1 Change the explanatory variable measure method

During the process of customer corporate digital transformation, the degree of management attention can be quantified by specific indicators, namely the proportion of the word frequency of digital transformation keywords to the total word frequency in management analysis and discussion, and the proportion of the sentence frequency of digital transformation keywords to the total sentence frequency. This study employs these two indicators as measurement metrics for the variable of corporate digital transformation. The regression results in rows (1) and (2) of Table 2 indicate that, even after replacing the measurement methods for explanatory variables, the regression results remain significant at the 1% level, consistent with the hypothesis stated earlier.

Table 4. Change the explanatory variable measure method

VARIABLES	(1)	(2)
	r1	r2
	L1_InPtnCiting	L1_InPtnCiting
Digital_wrds_c	338.3700*** (55.6359)	
Digital_sentence_c		5.6829*** (1.0131)
Lev	-0.6051**	-0.6066**

	(0.2355)	(0.2359)
ROE	1.0466***	1.0655***
	(0.3665)	(0.3669)
Growth	0.0165	0.0143
	(0.1163)	(0.1164)
Cashflow	0.2299	0.2359
	(0.6370)	(0.6378)
Listage	-0.0204	-0.0226
	(0.0611)	(0.0611)
RD	0.0580***	0.0583***
	(0.0068)	(0.0068)
HHI	-0.4275	-0.4255
	(0.4043)	(0.4048)
Industry FE	Yes	Yes
Year FE	Yes	Yes
Constant	-19.9118***	-20.0037***
	(2.1975)	(2.2007)
Observations	2,215	2,215
R-squared	0.4805	0.4792
F	51.58	51.32

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

4.4.2 PSM

Selecting the same control variables as in the previous text, we utilized the principle of PSM (Propensity Score Matching) for sample matching and removed unsuccessful sample content. The results of the PSM test are presented in the table, where the coefficient for ESG_C is 0.0689 and significant at the 5% level, indicating that the hypothesis remains significant.

Table 5. PSM

	(1)
	SCT_Num
ESG_C	0.0689**
	(2.2668)
Size	-0.7373***
	(-4.9204)
Lev	-0.2551
	(-0.2725)
ROE	-1.3476
	(-0.9478)
Growth	-0.0757
	(-0.1598)

Cashflow	-3.4782 (-1.3390)
Listage	0.3994* (1.6846)
RD	0.0355 (1.3781)
HHI	1.1057 (0.6981)
Industry FE	Yes
Year FE	Yes
_cons	12.0642* (1.9130)
<i>N</i>	748
adj. <i>R</i> ²	0.339

t statistics in parentheses

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

4.5 Endogeneity Test

4.5.1 Heckman two-stage method

The potential endogeneity issue arising from sample selection bias between customer corporate digital transformation and supplier corporate patent citations is addressed in this study using the Heckman two-stage model. The results of the two-stage regression are presented in two columns of the table, with regression coefficients significant at the 1% level in both stages. This indicates that customer corporate digital transformation has a promoting effect on supplier corporate patent citations, strengthening the likelihood of the null hypothesis.

Table 6. Heckman two-stage method

	(1)	(2)
	First	Second
main		
Digital_c	0.0975** (2.2650)	0.2001*** (4.6641)
Size	0.3975*** (10.8831)	0.9455*** (17.7829)
Lev	-0.0944 (-0.4235)	-0.6411*** (-2.7090)
ROE	0.5885* (1.7102)	1.2754*** (3.3236)
Growth	0.1513 (1.3043)	0.0512 (0.4315)
Cashflow	-0.8598 (-1.4423)	0.0076 (0.0116)
Listage	-0.0274 (-0.4925)	-0.0340 (-0.5502)

RD	0.0430*** (7.2280)	0.0696*** (7.6341)
HHI	-0.7229** (-2.0423)	-0.5952 (-1.4275)
Industry FE	Yes	Yes
Year FE	Yes	Yes
imr		0.5425* (1.7207)
_cons	-10.6581*** (-12.5547)	-19.8128*** (-13.1288)
N	2211	2211
adj. R ²		0.467

t statistics in parentheses

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

4.6 Further Research

4.6.1 Total factor productivity

Total Factor Productivity (TFP), distinct from individual factor productivity, typically refers to the comprehensive productivity of a firm across various factors and is a crucial indicator of the overall production capacity of the corporate. In recent time, digitization has become an unstoppable trend for business development, corporates are gradually transitioning from a "vertical" management structure to a "flatter" structure, which contributes to an increased overall factor productivity, making the mechanism of the impact of corporate digital transformation on patent citations more significant [11]. To examine this, the median of TFP is used as the test indicator to differentiate between high and low values. The results of the test reveal that when the TFP median is higher, the regression coefficient for corporate digital transformation is 0.1815. Conversely, when the TFP median is lower, the regression coefficient is 0.1421. Both coefficients are significant at the 1% level, indicating that when median of TFP is higher, the promotional effect of customer corporate digital transformation on supplier corporate patent citations is more significant when TFP is higher.

Table 7. Total factor productivity

	(1)	(2)
VARIABLES	r1 L1_InPtnCiting	r2 L1_InPtnCiting
Digital_c	0.1815*** (0.0544)	0.1421** (0.0644)
Size	0.9232*** (0.0429)	0.6408*** (0.0600)
Lev	-0.2777 (0.3125)	-0.7841** (0.3702)
ROE	1.7678*** (0.4778)	0.2232 (0.5822)
Growth	-0.2146 (0.1560)	0.2636 (0.1744)

Cashflow	-0.5504 (0.8315)	0.9262 (1.0143)
Listage	-0.0541 (0.0823)	0.0793 (0.0900)
RD	0.0436*** (0.0092)	0.0680*** (0.0102)
HHI	-0.8760* (0.5267)	-0.3249 (0.6391)
Industry FE	Yes	Yes
Year FE	Yes	Yes
Constant	-18.7061*** (2.5679)	-13.8130*** (2.0589)
Observations	1,245	970
R-squared	0.5586	0.3637
F	39.10	14.81

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

4.6.2 Highly educated group

The educational background of employees in an corporate also plays a positive role in the development of the company. Absorbing highly educated talents can drive high-quality and sustainable development for the corporate. The proportion of supplier corporates' employees with a bachelor's degree or higher is introduced as a moderating variable into the original baseline regression model and is divided into two groups. According to the test results, when there are more highly educated individuals among the employees of supplier corporates, the regression coefficient for customer corporate digital transformation is 0.2223 (row 1), and when there are fewer highly educated individuals, the coefficient is 0.1603 (row 2). Both coefficients pass the 1% significance level test. Regression analysis indicates that as the proportion of highly educated individuals in supplier corporates increases, the promoting effect of customer corporate digital transformation on the mechanism of supplier corporate patent citations becomes more significant.

Table 8. Highly educated group

	(1)	(2)
	r1	r2
VARIABLES	L1_InPtnCiting	L1_InPtnCiting
Digital_c	0.2223*** (0.0593)	0.1603*** (0.0579)
Size	0.8861*** (0.0545)	0.8107*** (0.0430)
Lev	-0.1473 (0.3860)	-0.6194** (0.3001)
ROE	2.0379*** (0.6308)	0.2613 (0.4497)
Growth	-0.1747	0.1740

	(0.1754)	(0.1586)
Cashflow	-0.4966	1.0608
	(1.0353)	(0.8122)
Listage	-0.0709	0.0039
	(0.1034)	(0.0762)
RD	0.0691***	0.0517***
	(0.0121)	(0.0083)
HHI	-1.4027***	1.8488***
	(0.5135)	(0.6841)
Industry FE	Yes	Yes
Year FE	Yes	Yes
Constant	-18.6478***	-19.8867***
	(2.0702)	(2.2288)
Observations	872	1,343
R-squared	0.5452	0.4713
F	27.02	31.44

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

5 CONCLUSIONS

The digital economy is a crucial foundation for future corporate competition and a significant engine for national economic growth. The development of digital technology not only promotes innovation and entrepreneurship in corporate but also aids in patent applications, enhancing their core competitiveness. From the perspective of information asymmetry theory, digital transformation brings substantial advantages and opportunities to customer corporates. It accelerates the speed of information transmission, allowing them to acquire information across various fields, such as markets and technologies, at lower or even zero costs. This efficient access to information enables corporates to more accurately identify market gaps and trends, adjust their research and development directions promptly, and enhance profit margins. Through digital technology, corporates can better understand customer needs, quickly meet market demands, and gain a competitive advantage in the market. In the process of digital transformation, upstream corporates, benefiting from the spillover effects of information, can gain deeper insights into the development changes of customer corporates. Leveraging the opportunities brought by digital transformation, upstream corporates continuously enhance their innovation capabilities, actively apply for patents, and maintain long-term competitive advantages. Digital transformation allows upstream corporates to better adapt to market changes, maintain competitiveness, and stand undefeated in the evolving business environment.

This study constructs a digital transformation indicator based on the annual report texts of listed corporates, measures information spillover effects in the supply chain using the "bullwhip effect," and examines whether customer corporate digital transformation can effectively strengthen the alignment between supplier and customer corporates, leading to positive information spillover effects. The research findings suggest that customer corporate digital transformation contributes to improving the "bullwhip effect" in the supply chain, promoting efficient information exchange between customer and supplier ends. The information spillover effects generated by customer corporates' digital applications, such as big data, cloud computing, and digital technology, alleviate the "bullwhip effect" in the supply chain. The study further explores the mechanisms through which digital transformation affects information spillover, revealing that

customer corporate digital transformation reduces information search costs and information verification costs, thus alleviating the "bullwhip effect" in the supply chain. Heterogeneity tests indicate that the information's spillover effects of digital transformation are more pronounced for larger-scale suppliers, those with longer inventory turnover days, higher market uncertainty, and higher customer concentration.

The relationship between customer corporate digital transformation and information spillover effects exhibits cross-sectional differences consistent with previous theories of information disclosure and resource effects. Additionally, the study discusses the relationship between the information spillover effects of customer corporate digital transformation and supplier corporate strategic distinctiveness and total factor productivity. It finds that customer corporate digital transformation mitigates the problems of production plan disruptions and inefficient resource allocation caused by the "bullwhip effect" in supplier corporates. This leads supplier corporates to adopt more novel and unique resource allocation decisions. Moreover, the information spillover effects generated by customer corporate digital transformation effectively improve supplier corporate production processes. The policy implications of this study suggest that, in the current context of China's industrialization driven by information technology, the level of corporate informatization reflects their active response to the national policy of deep integration of the digital economy and the real economy. The degree of industrialization directly reflects the level of corporate specialization. The digital economy presents unprecedented opportunities for corporate development, injecting new vitality. In this context, the government should introduce policies to encourage digital transformation in the supply chain. Policy guidance and financial support can accelerate the pace of corporate digital transformation. The government can also launch relevant tax incentives, provide digital technology training, and consulting services to incentivize corporates to actively invest in digital transformation. These policy measures will help corporates actively respond to the national strategy of deep integration of the digital economy and the real economy, accelerating the reconstruction of the new economic mentality of economy and governance. Innovation is a critical means for corporates to maintain core competitiveness. Continuous innovation allows corporates to stand out in the market and gain a larger market share. After upstream corporates receive the economic consequences of customer corporate digital transformation, they often seize market resources through innovative technologies. In this process, applying for patents becomes a necessary means to protect innovative achievements, stimulating employees' innovation consciousness and enthusiasm, and promoting high-quality development. Therefore, to encourage suppliers to apply for patents, the government should strengthen intellectual property protection, establish a sound legal and regulatory system, improve patent examination efficiency, and intensify efforts to combat infringement. Strengthening intellectual property protection can enhance corporate innovation enthusiasm and patent application willingness, promoting China's economic transformation towards a knowledge-intensive and innovation-driven model. High education and high-quality talents play a crucial role in corporate innovation. To some extent, they signify a broader knowledge reserve and profound professional background, enabling them to propose creative and forward-looking viewpoints. Therefore, the higher the proportion of highly educated and high-quality talents in the management of the corporate, the greater the number of patent applications by upstream corporates. Given this, the government and corporates should attach importance to talent cultivation and recruitment, providing attractive benefits and development opportunities for highly educated talents. This will provide strong support for the innovation and development of supplier corporates.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

References

- [1] Zhang, H., Hong, H., Guo, Y., Yang, C. Information spillover effects from media coverage to the crude oil, gold, and Bitcoin markets during the COVID-19 pandemic: evidence from the time and frequency domains. *International Review of Economics & Finance*. 2022, 78, 267-285.
- [2] Aguilera-Caracuel, J., Hurtado-Torres, N. E., Aragón-Correa, J. A. Does international experience help firms to be green? A knowledge-based view of how international experience and organisational learning influence proactive

- environmental strategies. *International business review*. 2012, 21(5), 847-861.
- [3] Hanelt, A., Bohnsack, R., Marz, D., Antunes Marante, C. A systematic review of the literature on digital transformation: Insights and implications for strategy and organizational change. *Journal of management studies*. 2021, 58(5), 1159-1197.
- [4] Zhou, R., Tang, D., Da, D., Chen, W., Kong, L., Boamah, V. Research on China's manufacturing industry moving towards the middle and high-end of the GVC driven by digital economy. *Sustainability*. 2022, 14(13), 7717.
- [5] Wu, Z., Pagell, M. Balancing priorities: Decision-making in sustainable supply chain management. *Journal of operations management*. 2011, 29(6), 577-590.
- [6] Boly, V., Morel, L., Camargo, M. Evaluating innovative processes in french firms: Methodological proposition for firm innovation capacity evaluation. *Research Policy*. 2014, 43(3), 608-622.
- [7] Zhang, P., Wang, Y., Wang, R., Wang, T. Digital finance and corporate innovation: evidence from China. *Applied Economics*. 2024, 56(5), 615-638.
- [8] Li, S., Gao, L., Han, C., Gupta, B., Alhalabi, W., Almakdi, S. Exploring the effect of digital transformation on Firms' innovation performance. *Journal of Innovation & Knowledge*. 2023, 8(1), 100317.
- [9] Pan, W., Xie, T., Wang, Z., Ma, L. Digital economy: An innovation driver for total factor productivity. *Journal of Business Research*. 2022, 139, 303-311.
- [10] De Almeida, M. M. K., Marins, F. A. S., Salgado, A. M. P., Santos, F. C. A., da Silva, S. L. Mitigation of the bullwhip effect considering trust and collaboration in supply chain management: a literature review. *The International Journal of Advanced Manufacturing Technology*. 2015, 77, 495-513.
- [11] Galbraith, J. R. *Designing organizations: Strategy, structure, and process at the business unit and enterprise levels*. John Wiley & Sons. 2014.