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Original scientific paper

Peer Effects in Corporate Digital Transformation within Supply Chain Networks

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Abstract: Digital transformation has become an inevitable choice for enterprises to survive and compete. This article aims to investigate mechanisms and impacts of peer effects in digital transformation within supply chain networks. Using a sample of listed companies in China from 2011 to 2020, the findings suggest the existence of peer effects in the digital transformation of enterprises within supply chain networks. These effects become more significant as the perception of uncertainty and environmental uncertainty increase. Further analysis reveals that the greater the disparity in discourse power and the degree of digital transformation among peer enterprises within the supply chain, the stronger the peer effects. The study also examines various scenarios in which enterprises operate, finding that greater supply chain stability significantly enhances the peer effects of digital transformation. Heterogeneity tests indicate that peer effects in digital transformation are more evident when peer enterprises within the supply chain are located in different regions, operate in different industries, are non-state-owned, have directorial connections and common institutional ownership, and possess fluctuating executive teams. Additionally, the study discusses the spillover effects of digitalization among peer enterprises on the focal company. This research provides a micro-level exploration of the peer effects of digital transformation from a supply chain perspective, offering theoretical references and practical insights for enterprises seeking to achieve digital transformation.

Keywords: digital transformation; networks; peer effect; supply chain

1 INTRODUCTION

With the rapid advancement of digital technologies, such as big data, cloud computing, and artificial intelligence, coupled with the interconnectedness of the global economy and the high degree of uncertainty in the external environment, both risks and opportunities are exerting profound influences on the sustainable development of supply chains and the digital transformation of enterprises. The Government Work Report of 2023 stressed the importance of maintaining stability in supply chains and expediting the digital transformation of traditional enterprises. The report from the 20th National Congress of the Communist Party highlights that the resilience and security of industrial and supply chains are integral to constructing a modern industrial system. Across the industry, using digital technologies to develop resilient and sustainable supply chains has emerged as a focal point for organizations and a crucial component of national strategic planning. How enterprises can capitalize on the opportunities presented by the digital wave, construct a comprehensive industrial chain ecosystem to stimulate the collaborative and synergistic development of upstream and downstream enterprises, and facilitate the upgrade of the national supply chain and the restructuring of the global value chain, have become salient topics attracting widespread attention in academia.

In the current era of deep integration between the digital economy and the physical economy, the digital transformation of enterprises has become an irreversible trend and inevitable choice. Digital transformation refers to the fundamental change of business processes and practices using the innovation and integration of digital technologies [1], and the reconstruction of the enterprise value chain. However, digital transformation involves multiple aspects of enterprises, including strategy, organization, process, technology, and culture. It represents a protracted and intricate process, fraught with uncertainties and risks. During the transformation process, the practice activities of enterprises are often influenced by the behaviors of other enterprises in their network. This influence can be regarded as a peer effect, that is, enterprises tend to imitate or refer to the decision behaviors of other enterprises in their network when confronted with uncertainty and complexity, to mitigate risk and enhance efficiency.

A salient characteristic of peer effects is to incorporate the interactive impact of enterprise into the study of corporate decision-making behavior, thereby transcending the confines of traditional autonomous management decision-making [2]. Existing research has uncovered evidence of peer effects in areas such as corporate mergers and acquisitions [3], cash holdings [4, 5], social responsibility [6], and information disclosure [7]. Some scholars have also classified peer enterprises based on geographical space and industrial attributes and examined issues related to digital transformation [8, 9]. Specifically, enterprises enhance their digital transformation strategies and behaviors through emulation and learning from other enterprises, which will show similar characteristics within enterprises operating in the same industry or geographical region. However, such a classification method may overlook the network externality mechanism between enterprises, thereby engendering weak linkages. Specifically, due to higher information barriers and complex environments, peer enterprises within the same industry and region are likely to experience significant information asymmetry and decision uncertainty. This may potentially inhibit inter-enterprise cooperation and learning. Moreover, the competitive and substitutive dynamics among enterprises within the same industry and region may affect individual enterprises' profits and market shares. This can result in conflicts of interest and a breakdown of trust between enterprises, ultimately diminishing the synergistic effects and efficiency of digital transformation efforts. Consequently, compared to the horizontal linkages of enterprises within the same industry or region, the vertical linkages of enterprises within the supply chain are more conducive to the construction of a robust and closely-knit peer network. Direct interest associations and business dealings exist between upstream and downstream enterprises within the supply chain, and the contractual mechanisms between enterprises can effectively enhance

the predictability and stability of the supply chain, thereby amplifying the peer effects between enterprises. Additionally, the dynamic competitive-cooperative relationships between upstream and downstream enterprises can motivate enterprises to respond to the digital transformation practices of peer enterprises, to achieve their interests and optimize the configuration of the supply chain.

In light of this, our study, predicated on the data about digital transformation and supply chains disclosed by enterprises listed on China's A-shares, employs text mining analysis to establish surrogate indicators for enterprise digital transformation. It investigates the relational mechanisms of peer effects in enterprise digital transformation within the context of supply chain networks and the interplay effects under disparate scenarios. Compared to existing research, this paper makes several marginal contributions. (1) This paper broadens the research boundary of peer effects in digital transformation by examining these effects from the perspective of supply chain network. Different from horizontal linkages among enterprises across regions and industries, enterprises within the same supply chain create substantial connection points and positive network externalities, fostering a stronger inclination for enterprises to emulate and learn from each other's digital-related decision-making behaviors. (2) This paper provides new evidence and theoretical insights into understanding the motivating factors behind enterprise digital transformation. It introduces environmental uncertainty and enterprise uncertainty perception as external and internal factors respectively. It also clarifies the disparities in status resulting from the discourse power of upstream and downstream enterprises and the characteristics of the digital transformation degree within the supply chain. This offers fresh empirical evidence for exploring the intrinsic mechanisms of peer effects in digital transformation within the supply chain. (3) This paper explores the influence of peer effects on digitalization within the context of supply chain stability. It introduces a dynamic perspective by considering directorial connections, common institutional ownership within social networks, and changes in executive teams, thereby paving the way for new research directions in academia. (4) Further analysis of this paper indicates that the digital transformation of peer enterprises has a spill-over effect on the productivity growth of the focal enterprise, contributing to a more comprehensive understanding of enterprise productivity growth. (5) The high degree of uncertainty in current economic provides policy implications for exploring the impetus for enterprise digital transformation and ensuring the safety and stability of the supply chain.

The remainder is organized as follows. Section 2 presents the literature review. Section 3 presents the theoretical framework and hypothesis development. Section 4 presents the data source and the model. Section 5 shows the empirical results of baseline regressions, robustness tests, and mechanism analysis. Section 6 further discusses and analyzes based on various circumstances. Section 7 offers the conclusions.

2 LITERATURE REVIEW

Digital transformation refers to an organizational process wherein enterprises utilize innovative technologies to improve interactions between the organization and its employees, customers, suppliers, partners, and stakeholders. This aims to enhance the organization's competitive edge in the digital economy [20]. This definition underscores one of the focal points of digital transformation, which is to construct a deeply integrated network among supply chain participants and achieve sustainable competitive performance. Present academic research on the digital transformation of supply chain enterprises can generally be bifurcated into two categories: research on the antecedents and consequences of its transformation, and research on its transformation under specific scenarios. Supply chain digitalization refers to a customer-centric, information and data-driven management approach. At the organizational level, digital transformation can significantly enhance the supply chain capabilities of members [21], and promote innovation among partner members [22]. At the supply chain level, the application of digital technology optimizes business processes between enterprises [23] and enhances enterprise innovation performance [24] and production efficiency [25]. In addition, related research has expanded from a single object to a broader ecosystem. Scholars have found that digital transformation promotes collaboration between supply chain enterprises [22], empowers the construction and upgrading of industrial value chains, and produces the bullwhip effects [26]. These studies, based on different scenarios, and from the perspectives of supply chain management and upstream and downstream relationships, have greatly enriched the academic understanding of the characteristics and evolution of enterprises' digital transformation in the supply chain. Considering that the imitation motivation and peer effects of digital transformation of peer upstream and downstream enterprises have not been fully explored, this paper attempts to reveal its potential intrinsic mechanism.

3 THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

3.1 The Peer Effect of Digital Transformation

The digital transformation of peer enterprises is influenced and constrained by a multitude of factors, which can be examined through different theoretical perspectives. Viewed through the lens of resource dependence theory, enterprises are required to procure and exploit scarce resources to bolster their digital transformation, thereby augmenting their competitive edge and survivability. These resources predominantly originate from the external environment, encompassing other enterprises and stakeholders. Consequently, enterprises may engage in resource sharing and collaboration with peer enterprises, facilitating the realization of complementarity and peer effects in digital transformation. The theory of market competition suggests that enterprises attain the optimal allocation of production elements through market competition. To alleviate the pressure of market competition and preserve their market standing, enterprises may establish cooperative relationships or even collusions

with peer enterprises. As a result, their actions and practices in digital transformation may tend to converge with those of peer enterprises. Moreover, the information mechanism also constitutes the foundation for comprehending the peer effects of enterprises. From the perspective of social learning theory, there are existing imitation behaviors and synergistic effects among organizations and members [27]. Digital transformation is a comprehensive process that encompasses multiple facets and strata, necessitating enterprises to adopt and implement diverse digital technologies and methodologies under varying environmental conditions and circumstances. However, in devising and executing digital strategies, enterprises frequently encounter substantial uncertainty and complexity, making it challenging to effectively forecast and evaluate the specific contexts and potential outcomes of digital transformation. Under such circumstances, enterprises are inclined to reference and emulate other peer enterprises' digital transformation decisions and practices. This approach facilitates the assimilation of experiences and outcomes from other enterprises' digital transformations, thereby mitigating the risks and costs associated with digital transformation and enhancing its efficiency and effectiveness. The institutional theory posits that the relationship between enterprises represents a transmission and influence of institutions. Enterprises can adapt to and meet external norms and expectations by imitating and complying with the behaviors of other enterprises, thereby accruing more legitimacy and recognition. Enterprises will imitate the digital practices of peer enterprises to conform to the standards and norms recognized by the industry or market. Concurrently, within the supply chain network, there exist enduring cooperative relationships and interaction frequencies between upstream and downstream enterprises, which can engender stronger institutional pressures and inductions and also engender higher institutional consistency and efficiency. The decision-making of the focal enterprise will be influenced and propelled by the behaviors of upstream and downstream enterprises within the supply chain network [28], thereby fostering the vertical peer effect. In light of this, this paper proposes the following hypothesis.

H1: The digital transformation of enterprises in the supply chain network has a peer effect, and the digitalization of peer enterprises has a significant positive impact on the digital transformation of focal enterprises.

3.2 The Peer Effect and Motivation of Enterprise Digital Transformation Based on Supply Chain Networks

Contingency theory posits that when external environmental factors, technology, scale, strategy, and other situational factors undergo alterations, organizations necessitate corresponding adjustments [29]. By contingency theory, the selection of enterprise behavior is contingent upon the degree of alignment between internal and external circumstances. In the realm of peer enterprise behavior research, external uncertainty is regarded as a significant impetus for the imitation behavior of enterprises [30, 31]. When an enterprise's perception of uncertainty and external uncertainty is elevated, it will enhance the motivation to emulate the digital transformation of peer enterprises. However, enterprises within the supply chain often lack lucid cognition and expectations about the relationship between actions and outcomes in digital transformation. From the perspective of opportunity cost motivation, when an enterprise's perception of uncertainty and environmental uncertainty is high, the digital capabilities of enterprises may be insufficient to cope with complex and dynamic internal and external situations. To circumvent the risks and costs associated with digital transformation, enterprises may tend to decelerate or abandon digital transformation. Moreover, opportunistic behavior engendered by incomplete contracts among supply chain enterprises can also diminish the degree of trust among peer enterprises [32], and amplify the subjective uncertainty of enterprise decision-making, thereby impeding the process of enterprise digital transformation. Therefore, when an enterprise confronts high environmental uncertainty or possesses a robust perception of uncertainty, its emulation of peer enterprises in digital transformation may be influenced by two opposing motivations. To explore its impact effect, this paper proposes the following hypotheses:

H2: The higher the perception of uncertainty of the focal enterprise, the more pronounced the promotional effect of the peer effect of digital transformation in the supply chain network.

H3: The higher the environmental uncertainty of the focal enterprise, the more pronounced the promotional effect of the peer effect of digital transformation in the supply chain network.

4 METHODOLOGICAL DESIGN

4.1 Sample and Data Source

This study selects enterprises listed on the Shanghai and Shenzhen A-shares from 2011 to 2020 as the initial research sample. The data on supply chains and digital transformation are sourced from the CSMAR database and the annual report information available on the official websites of the Shenzhen and Shanghai Stock Exchanges. As listed companies disclose their supplier and customer information voluntarily, some missing supply chain information is obtained from the cninfo website. The original sample undergoes the following processing: all ST and *ST samples and samples with substantial data missing are excluded. In terms of identifying supply chain network relationships, since a multitude of upstream and downstream enterprises in the sample are non-listed companies and it is challenging to procure relevant digital and financial information, this study retains samples where both the focal enterprise and upstream and downstream enterprises are listed companies, and constructs a focal enterprise - customer (supplier) - annual data set. Specifically, a focal enterprise may correspond to multiple customers or suppliers in a given year, thereby constructing observation values such as A – X - 2020, and A – Y - 2020, and ultimately obtaining 2923 observation values.

4.2 Variable Definitions

4.2.1 Dependent and Independent Variable

Enterprise digital transformation. As drawn on the research of Wu et al. [33], this study uses the word

frequency related to digital transformation in listed companies' annual reports as a measure of the degree of digital transformation. The exact processing method is as follows: ① Utilize Python's web crawling functionality to collect the annual reports of all Shanghai and Shenzhen A-share listed companies, extracting all text content. ② Following the research feature word map established by Wu et al. [33], this report searches and matches word frequency related to five aspects: enterprise artificial intelligence technology, big data technology, cloud computing technology, blockchain technology, and the application of digital technology. Further, Exclude word frequencies and keywords that do not belong to the sample company and words that have negative expressions such as "no" and "non" before them. Given the typical "right-skewness" characteristic of this data, take the natural logarithm of the frequency of feature words of enterprise digital transformation. This transformed data serves as an overall indicator to depict the digital transformation of the focal enterprise (*Digfocus*) and the peer enterprise (*Digchain*).

4.2.2 Moderator Variables

① Environmental Uncertainty (Uncertainty). It is measured by the ratio of the standard deviation of industry-adjusted abnormal sales revenue to the average within five years. ② Enterprise Uncertainty Perception (Uword). The words frequency related to uncertainty in the MD&A section of listed companies' annual reports is tallied, and the percentage of words related to uncertainty in the total number of words is used as a proxy indicator.

4.2.3 Control Variables

This study controls for company size (*Size*), asset-liability ratio (*Lev*), return on equity (*ROE*), cash flow ratio (*cash flow*), R&D expenditure (*RD*), management cost (*Mcost*), and corporate governance level (*Governance*). Simultaneously, to control for the characteristics of peer enterprises, this study also incorporates the level of digital transformation in the industry (*Digind*) into the control variables.

4.3 Model Construction

To verify the impact of the digital transformation of upstream and downstream peer enterprises on the digital transformation of the focal enterprise, this study constructs the following regression model:

$$Digfocusi,t = \alpha + \beta 1\, Digchaini,t + \beta 2 Controli,t + \\ + Industryi + Yeart + \varepsilon i,t \quad (1)$$

In this model, the dependent variable is the digital transformation of the focal enterprise (*Digfocus*), and the explanatory variable is the digital transformation of peer enterprises in the supply chain network (*Digchain*). Additionally, this study sets industry and year dummy variables in the regression analysis to control for industry-fixed effects (*Industry*) and timefixed effects (*Year*).

Table 1 Variable definition

Variable Name	Symbol	Variable Definition
Digital Transformation of the Focal Enterprise	*Digfocus*	Digital Transformation degree of the focal enterprise.
Digital Transformation of the Peer Enterprise	*Digchain*	Average Digital Transformation degree of the peer enterprise.
Enterprise Uncertainty Perception	*Uword*	The percentage of uncertainty-related words in the annual report of the focal enterprise, divided by the total number of words in the report.
Environmental Uncertainty	*Uncertainty*	The ratio of the standard deviation of industry-adjusted abnormal sales revenue of focal enterprise to the average abnormal sales revenue within five years.
Company Size	*Size*	Natural logarithm of total assets of focal enterprise.
Leverage ratio	*Lev*	Total liabilities of the focal enterprise at the end of the year divided by total assets at the end of the year.
Return on equity	*ROE*	Net profit of focal enterprise divided by average balance of owner's equity.
Cash flow	*Cashflow*	Net cash flow from operating activities of the focal enterprise divided by total assets.
Industry digital transformation	*DigInd*	Average digital transformation degree of other enterprises in the same industry except focal Enterprise.
R&D expenditure	*RD*	R&D expenditure of focal enterprise +1 and take the natural logarithm.
Corporate governance	*Governance*	Use principal component analysis to construct a corporate governance index.
Management Cost	*Mcost*	The ratio of administrative expenses of focal enterprise to sales income.

5 EMPIRICAL RESULTS

5.1 Descriptive Statistics

As depicted in the descriptive statistical analysis of Tab. 2, the focal enterprises exhibit a mean digital transformation degree of approximately 9.05, accompanied by a standard deviation of approximately 12.20. On the other hand, the peer enterprises demonstrate a mean digital transformation degree of approximately 5.68, with a standard deviation of approximately 10.72.

Table 2 Summary statistics of the main variables

Variables	N	Mean	Std	Min	Max
Digfocus	2923	9.045	12.202	0.000	64.850
Digchain	2923	5.684	10.717	0.000	59.720
Uword	2923	0.087	0.097	0.000	0.752
Uncertainty	2923	1.327	1.499	0.000	16.000
Size	2923	21.950	1.297	16.117	28.504
Lev	2923	0.447	0.694	0.013	31.467
ROE	2923	0.036	0.774	–29.881	11.159
Cashflow	2923	0.036	0.078	–0.748	0.661
Digind	2923	7.859	7.555	0.000	46.076
RD	2923	14.513	6.709	0.000	21.913
Governance	2923	9.960	5.031	–0.443	24.517
Mcost	2923	0.120	0.186	0.000	3.931

Furthermore, the Average level of industry digital transformation is approximately 7.86 and has a standard deviation of approximately 7.56. This suggests a relatively minor disparity in the degree of digital transformation among enterprises within the same industry. On the whole, the focal enterprises present a higher degree of variance in digital transformation compared to their peer enterprises,

and they also possess a superior mean transformation degree.

5.2 Baseline Results

Tab. 3 presents the empirical examination results of the peer effect of digital transformation within supply chain networks. This study uses recursive regression. The first column controls for industry fixed effects, while the second column controls for year fixed effects. The parameter estimates for the digital transformation of peer enterprises are 0.0557 and 0.0573, both statistically significant at the 1% level. The third column simultaneously controls for both industry and year fixed effects. Economically, for every standard deviation increase in the degree of digital transformation of peer enterprises, the degree of digital transformation of the focal enterprises is expected to increase by approximately 0.52 units. The findings suggest that within supply chain networks, the digital transformation of focal enterprises demonstrates a growth trend as the degree of digital transformation of peer enterprises increases, providing fundamental support for Hypothesis 1 (H1).

Following the research of Mugge et al. [34] , this study also constructs a first-order difference model of digital transformation between focal enterprises and peer enterprises. It calculates the difference between the digital degree of the current year and the previous year and conducts a group test based on whether the difference result of the focal enterprises exceeds zero. As shown in columns (4) and (5) of Tab. 3, when the digital transformation of the focal enterprises achieves progress, the digital transformation of peer enterprises exerts a significant positive transmission effect. However, when the focal enterprises decelerate their transformation process, the transformation behavior of peer enterprises does not significantly influence them.

Table 3 Baseline results

Variables	*Digfocus*	*Digfocus*	*Digfocus*	*Diff_digfocus* > 0	*Diff_digfocus* < 0
	(1)	(2)	(3)	(4)	(5)
Digchain	0.0557***	0.0573***	0.0488***		
	(0.0178)	(0.0181)	(0.0178)		
Diff_digchain				0.0747***	0.0295
				(0.0226)	(0.0403)
Size	0.5418***	0.0893	0.5760***	0.0516	–0.2963
	(0.1912)	(0.1570)	(0.1918)	(0.1833)	(0.3399)
Lev	0.5644	–0.0796	0.4798	–0.8404*	2.1544**
	(0.5132)	(0.3036)	(0.5126)	(0.4827)	(0.9876)
ROE	–0.0385	–0.0160	–0.0011	–0.4112	–0.9443
	(0.2458)	(0.2488)	(0.2447)	(0.3087)	(0.9324)
Cashflow	–7.8787***	–10.0368***	–8.2922***	–3.1877	–5.3183
	(2.6494)	(2.5444)	(2.6478)	(2.6699)	(4.9315)
Digind	0.4297***	0.7835***	0.3378***	0.2716***	0.2354**
	(0.0384)	(0.0272)	(0.0415)	(0.0458)	(0.0938)
RD	0.0781**	0.0615**	0.0370	–0.1044**	–0.1124
	(0.0379)	(0.0296)	(0.0390)	(0.0436)	(0.0893)
Governance	0.1078***	0.1513***	0.1198***	0.2638***	–0.1244
	(0.0403)	(0.0393)	(0.0405)	(0.0441)	(0.0893)
Mcost	2.3971*	2.9467**	2.0118	–4.3109***	–0.9676
	(1.3468)	(1.1517)	(1.3437)	(1.3251)	(3.8121)
Industry & Year	Yes	No	Yes	Yes	Yes
Constant	–6.4700	–3.2955	–8.2109	9.6504	11.4106
	(5.8625)	(3.5391)	(5.8733)	(6.6407)	(11.7177)
Observations	2,923	2,923	2,923	1,705	737
R-squared	0.3342	0.2842	0.3434	0.3817	0.3641

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

5.3 Robustness Tests

5.3.1 Replace Explained Variables

The quantification of the degree of digital transformation in enterprises has not reached a consensus in current literature. This study employs the proportion of the digital transformation-related segment within the intangible assets as a proxy variable for the digital transformation of focal and peer enterprises, conducting robustness tests. As indicated by the results in column (1) of Tab. 4, upon substituting the proxy variable for digital transformation, the degree of digital transformation of peer enterprises remains significantly at the 1% level. The regression outcomes align with the conclusions drawn earlier in the text.

5.3.2 Replace Sample Object

This study further refines the sample data, retaining only the primary customers or suppliers of the focal enterprises. The test results for this altered sample are shown in Column (2). The coefficient of *Digchain* is approximately 0.093, statistically significant at the 5% level, confirming the robustness of the conclusion.

5.3.3 Competitive Exclusion

When supplier or customer enterprises have not undergone digital transformation, focal enterprises may also consider customer and supplier demand for digital transformation. Therefore, this study excludes samples where the degree of digital transformation of supplier and customer enterprises is zero to rule out the competitive

hypothesis. Column (3) displays the test results, with *Digchain* being significantly positive, indicating the robustness of the research conclusion.

5.3.4 PSM

This study uses the selected control variables as matching variables, adopts a 1:1 nearest neighbor matching method for sample matching, and simultaneously controls for industry and year fixed effects. Column (4) presents the Propensity Score Matching (PSM) test results, with the explanatory variable being significant at the 10% level, which supports the research findings.

5.3.5 Instrumental Variable Approach

The process of digital transformation in enterprises is a complex systemic project that carries substantial risk and is full of uncertainty. Enterprises typically learn from and imitate the transformation measures of neighboring peer enterprises during the transformation process to improve their probability of success. This article refers to Chen's [35] research while making adjustments, employing the cubic difference between the digital transformation indices of upstream and downstream enterprises and the average digital transformation index classified by secondary industry codes and provinces as an instrumental variable (IV). Columns (5) and (6) exhibit the regression outcomes of the instrumental variable method. In the first stage, the instrumental variable is significantly positive at the 1% level. In the second stage, the coefficient of the digital transformation of peer enterprises (*Digchain*) is 0.071, significant at the 1% level, corroborating the baseline regression conclusion.

5.3.6 Heckman Two-stage Model

Concerning the nature of the voluntary disclosure of digital transformation information by listed companies, this study may potentially be subject to sample self-selection bias. Thus, this study employs the Heckman two-stage model for regression testing. In the initial stage, the implementation of digital transformation by the focal enterprises is treated as the dependent variable, and the control variables delineated in the preceding text are incorporated for Probit regression. Upon obtaining the IMR, it is integrated into the model for the second-stage regression. Columns (7) and (8) present the outcomes of the two-stage regression, wherein the Inverse Mills Ratio is not statistically significant. In these results, the IMR is not statistically significant, suggesting that the model does not suffer from a severe sample self-selection issue. The digital transformation index of peer enterprises is significantly positive, corroborating the baseline regression results.

Table 4 Robustness tests results

Variables	Replace Explained Variables	Replace Sample Object	Competitive Exclusion	PSM	Instrumental Variable Approach		Heckman two-stage	
	Digfocus_invest	*Digfocus*	*Digfocus*	*Digfocus*	*Digfocus*	*Digfocus*	*First*	*Second*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digchain		0.0926**	0.0489***	0.0399*		0.071***	–0.0029	0.0584***
		(0.0437)	(0.0178)	(1.6719)		(2.848)	(–0.8564)	(3.2123)
Digchain_invest	0.1648***							
	(0.0337)							
IV					0.001***			
					(53.067)			
imr								–1.4533
								(–0.5389)
Size	–0.0114	1.2211***	0.5808***	0.5481**	–0.129	0.578***	0.1617***	0.0446
	(0.0118)	(0.4152)	(0.1915)	(2.0094)	(–0.899)	(3.061)	(5.1999)	(0.2509)
Lev	–0.0139	1.3348	0.4735	0.3233	0.308	0.469	–0.0496	–0.0711
	(0.0304)	(1.1289)	(0.5124)	(0.3943)	(0.802)	(0.929)	(–0.7028)	(–0.2337)
ROE	0.0109	–1.6263	–0.0013	0.0096	0.050	–0.002	0.0045	–0.0170
	(0.0166)	(1.1811)	(0.2446)	(0.0174)	(0.273)	(–0.010)	(0.1153)	(–0.0682)
Cashflow	–0.1411	–1.4677	–8.2377***	–14.8526***	–0.265	–8.308***	0.2113	–10.0615***
	(0.1654)	(6.2862)	(2.6459)	(–3.6946)	(–0.134)	(–3.185)	(0.4611)	(–3.9532)
Digind	–0.0030	0.4375***	0.3373***	0.3953***	0.008	0.337***	0.0636***	0.7660***
	(0.0027)	(0.0982)	(0.0415)	(6.2543)	(0.247)	(8.220)	(9.0218)	(18.0694)
RD	–0.0007	–0.0010	0.0367	0.0925*	0.002	0.037	–0.0015	0.0609**
	(0.0025)	(0.0882)	(0.0390)	(1.7606)	(0.052)	(0.958)	(–0.2947)	(2.0573)
Governance	–0.0018	0.1579*	0.1197***	0.0175	–0.027	0.120***	0.0615***	0.1310**
	(0.0025)	(0.0890)	(0.0405)	(0.3135)	(–0.883)	(3.011)	(7.9097)	(2.4064)
Mcost	0.2672***	7.1859**	2.0225	–3.8097	0.789	1.972	0.9106**	2.8097**
	(0.0846)	(2.9629)	(1.3433)	(–1.4649)	(0.785)	(1.489)	(2.1306)	(2.3820)
Constant	0.3117	–26.5111**	–8.3083	–18.2270**	1.795	–8.196	–3.1446***	–1.7121
	(0.3862)	(11.5882)	(5.8687)	(-2.2550)	(0.409)	(–1.416)	(–4.4748)	(–0.3722)
Industry& Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,923	620	1,925	1,509	2,923	2,923	2923	2923
R-squared	0.228	0.415	0.343	0.369	0.524	0.343	0.181	0.280

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

5.4 Mechanism Analysis

The results of the mechanism analysis are presented in Tab. 5. This study divides the samples of enterprise uncertainty perception and environmental uncertainty into two groups, high and low, predicated on the median. Columns (1) and (2) delineate the regression outcomes of the moderating effect of enterprise uncertainty perception. For the samples with pronounced uncertainty perception, the parameter estimate for the digital transformation of peer enterprises approximates 0.062, significant at the 1% level. The regression coefficient for the samples with diminished uncertainty perception is not statistically significant. Columns (3) and (4) exhibit the results of the group test predicated on environmental uncertainty. The regression coefficient for high environmental uncertainty approximates 0.073, significant at the 1% level, while the results for the group with low environmental uncertainty are not statistically significant.

The aforementioned regression outcomes suggest that under conditions of elevated environmental uncertainty or when focal enterprises possess a heightened perception of uncertainty, the digital transformation of peer enterprises within the supply chain network exerts a more pronounced propelling effect on the digital transformation process of focal enterprises. The mechanism test conclusion consistent with the findings of Liberman and Asaba [30], substantiating Hypotheses H2 and H3.

Table 5 Mechanism analysis results

Variables	Uncertainty perception		Environmental uncertainty	
	High	Low	High	Low
	Digfocus	*Digfocus*	*Digfocus*	*Digfocus*
	(1)	(2)	(3)	(4)
Digchain	0.0620***	0.0389	0.0734***	0.0340
	(0.0240)	(0.0264)	(0.0257)	(0.0247)
Size	0.3111	1.2277***	0.6063**	0.1824
	(0.2451)	(0.3510)	(0.2676)	(0.3310)
Lev	0.5532	–0.4165	0.0754	1.7148
	(0.5202)	(1.8564)	(0.5546)	(1.8736)
ROE	–0.0932	1.0280	0.0126	2.5325
	(0.2393)	(1.0757)	(0.2460)	(2.6302)
Cashflow	0.9367	–19.1604***	–11.3162***	–5.6390
	(3.5170)	(4.1627)	(3.5426)	(4.2266)
Digind	0.4552***	0.2545***	0.4046***	0.3037***
	(0.0599)	(0.0608)	(0.0603)	(0.0607)
RD	–0.0017	0.0936	0.0118	0.0612
	(0.0463)	(0.0718)	(0.0528)	(0.0606)
Governance	0.1280**	0.1217*	0.0894	0.0887
	(0.0554)	(0.0628)	(0.0572)	(0.0609)
Mcost	2.2397	3.0588	5.1093**	1.6716
	(1.7189)	(2.1037)	(2.1444)	(1.7625)
Constant	–0.2278	–28.1139***	–4.4437	–0.8512
	(7.8246)	(9.3847)	(9.1818)	(8.6764)
Industry& Year	Yes	Yes	Yes	Yes
Observations	1,489	1,434	1,461	1,462
R-squared	0.3595	0.3724	0.3908	0.3591

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

6 FURTHER RESEARCH

6.1 Motivation for Peer Imitation

6.1.1 Differences in the Degree of Digital Transformation

The preceding analysis reveals that the digital transformation of peer enterprises in the upstream and downstream supply chain significantly promotes the digital transformation of focal enterprises. However, the academic community holds different views on whether the digitization linkage effect is driven by the upstream or pulled by the downstream. One perspective posits that the digital linkage typology is characterized by a downstream customer pull [21], while another perspective contends that upstream suppliers exert a more substantial impetus on focal enterprises [36]. Focal enterprises procure a diverse array of supply chain resources from peer customer enterprises and supplier enterprises to bolster their digital transformation. However, the intrinsic mechanisms require further scholarly exploration. This part of the study aims to dissect the operational mechanisms of the peer effect from two perspectives: supply chain relationships and the disparity in digital transformation.

The digital transformation degree gap indicator is calculated by taking the absolute value of the difference between the digital transformation of the focal company and the mean degree of peer company samples in the upstream and downstream supply chain and is divided into two groups, high and low, based on the median. Columns (3) and (4) of Tab. 6 show that when the difference in the degree of digital transformation between peer enterprises and focal enterprises is large, the promoting effect of the peer effect is more significant. Specifically, when the digital transformation of peer enterprises is at a leading level compared to the focal enterprises, the focal enterprises are more willing to learn from and refer to the transformation methods and decisions of peer enterprises. When the transformation degree of the focal enterprises far exceeds the general level of peer enterprises, the focal enterprises will also draw on the experience and factors of the transformation obstacles of peer enterprises to ensure the rationality and effectiveness of their actions.

Table 6 Supply chain asymmetry results

Variables	Supply chain discourse power		The Digital Transformation degree gap	
	High	Low	High	Low
	Digfocus	*Digfocus*	*Digfocus*	*Digfocus*
	(1)	(2)	(3)	(4)
Digchain	0.0897***	–0.0158	0.0633**	0.0571**
	(0.0221)	(0.0289)	(0.0322)	(0.0276)
Size	0.3172	1.0588***	–0.7385**	0.5657**
	(0.2555)	(0.3309)	(0.3502)	(0.2491)
Lev	0.8200	0.8264	–0.7134	–2.1538
	(1.2225)	(0.6024)	(1.0167)	(1.3514)
ROE	–0.6343	0.0851	1.6327	–0.1301
	(0.5118)	(0.2894)	(1.3440)	(0.4753)
Cashflow	–6.0502*	–9.7093**	–12.3512**	–1.8543
	(3.3514)	(4.3404)	(5.0927)	(3.9655)
Digind	0.3852***	0.2589***	0.5763***	0.3712***
	(0.0537)	(0.0672)	(0.0821)	(0.0580)
RD	0.0318	–0.0260	0.1406*	0.1591***
	(0.0454)	(0.0777)	(0.0849)	(0.0579)
Governance	0.0585	0.1804***	0.2867***	0.2082***
	(0.0506)	(0.0693)	(0.0898)	(0.0607)
Mcost	6.2478***	–5.6472**	4.6807**	0.6908
	(1.5767)	(2.4919)	(2.3019)	(2.1891)
Constant	–0.3417	–30.5097**	16.8494*	0.8020
	(6.9479)	(12.3675)	(9.3960)	(6.4770)
Industry& Year	Yes	Yes	Yes	Yes
Observations	1,717	1,206	868	869
R-squared	0.3546	0.4151	0.4494	0.4051

6.1.2 Supply Chain Discourse Power

The customer-supplier dyadic relationship proposed by Schwieterman et al. [37] explains the asymmetry of supply chain status. Supply chain concentration, as a salient characteristic of enterprise supply chain structure and relationships, reflects the bargaining power of the upstream and downstream enterprises [38], the degree of dependency on the industrial chain [39], and the competitiveness within industry [40]. When one enterprise in the supply chain possesses significantly higher discourse power than the other, the supply chain relationship tends to be more stable. This is attributable to the fact that the enterprise with pronounced discourse power typically acts as the dominant enterprise in the supply chain or a key supplier or customer, thereby inducing upstream and downstream enterprises to adhere to its stipulated rules and conditions, culminating in the formation of stakeholder normative constraints. Moreover, supply chain discourse power also intuitively reflects the distribution of power and influence within the supply chain. Within the digital ecological network, where upstream and downstream interests are interconnected, enterprises with greater discourse power typically have more resources and capabilities to support digital transformation. Consequently, they exert a more significant influence on peer enterprises within the ecological chain. The spillover effect posits that the fluidity and diffusivity of information lead to its propagation and influence among disparate entities. Supply chain networks enhance the fluidity and timeliness of information exchange between upstream and downstream enterprises, effectively mitigating the risks associated with information asymmetry and distortion. Focal enterprises can gain a more comprehensive understanding of the digital transformation dynamics and outcomes of peer enterprises within the supply chain, perceive the disparity in digital transformation levels between themselves and peer enterprises, and accrue a wealth of knowledge and experience pertaining to digital transformation.

The proxy indicator for supply chain discourse power primarily employs supply chain concentration as a measure. Specifically, this study calculates the proportion of the sum of the top five suppliers to the total annual procurement and the proportion of the sum of sales of the top five customers to the total annual sales of the enterprise and then takes the absolute value of the difference between the two indicators. The larger the value of this indicator, the greater the inequality within the supply chain. Further, it is bifurcated into high and low groups based on the median of the sample. The results in columns (1) and (2) of Tab. 7 indicate that when the supply chain forms a single dominant party or one party possesses stronger bargaining power, the peer effect of digital transformation is more pronounced. Simultaneously, this indicates that focal enterprises exhibit a tendency to rely on large customers or large suppliers during the digital transformation process, and the digital transformation linkage effect between enterprises is also more conspicuous.

6.1.3 Supply Chain Stability

The stability and risk management of the supply chain plays an integral role in the operating and manufacturing activities of enterprises. Viewed through the lens of resource dependence theory, inter-enterprise relationships are driven by resource asymmetry and information uncertainty.

Table 7 Supply chain stability results

Variables	Customer stability past one year		Customer stability past two years		Supplier Stability past one year		Supplier Stability past two years	
	High	Low	High	Low	High	Low	High	Low
	Digfocus	*Digfocus*	*Digfocus*	*Digfocus*	*Digfocus*	*Digfocus*	*Digfocus*	*Digfocus*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digchain	0.0690**	0.0473**	0.0585**	0.0449**	0.0949***	0.0163	0.0966***	–0.0055
	(0.0295)	(0.0222)	(0.0284)	(0.0226)	(0.0247)	(0.0253)	(0.0232)	(0.0280)
Size	–0.1333	1.0056***	0.1760	0.9127***	0.7083***	0.6206**	0.3720	0.8559***
	(0.2955)	(0.2856)	(0.2958)	(0.2869)	(0.2657)	(0.2864)	(0.2438)	(0.3264)
Lev	–0.4916	3.8693**	–0.2570	3.0377*	–0.0002	1.2008	0.0726	1.5162*
	(0.5876)	(1.5305)	(0.5639)	(1.5588)	(0.6756)	(0.8163)	(0.6840)	(0.8477)
ROE	0.0956	0.8413	0.1726	1.2645	-0.7325	0.1513	–0.4588	0.1153
	(0.2505)	(1.1696)	(0.2488)	(1.2342)	(0.5757)	(0.2784)	(0.5616)	(0.2804)
Cashflow	–11.4500***	–8.0759**	–7.9746**	–11.9263***	–8.1571**	–6.6100*	–4.2169	–9.1265**
	(4.1272)	(3.5066)	(3.8728)	(3.7014)	(4.1302)	(3.5792)	(3.5812)	(4.3221)
Digind	0.4017***	0.2578***	0.3005***	0.2745***	0.4057***	0.2267***	0.4323***	0.1648**
	(0.0677)	(0.0535)	(0.0672)	(0.0550)	(0.0586)	(0.0612)	(0.0537)	(0.0707)
RD	–0.0395	0.1119**	0.0125	0.0481	0.0894	–0.0000	–0.0114	0.0776
	(0.0572)	(0.0546)	(0.0572)	(0.0542)	(0.0551)	(0.0571)	(0.0512)	(0.0642)
Governance	–0.0014	0.1320**	0.0663	0.0960*	0.1162**	0.1074*	0.1446***	0.0843
	(0.0652)	(0.0531)	(0.0649)	(0.0533)	(0.0556)	(0.0604)	(0.0516)	(0.0686)
Mcost	–0.7478	6.9487***	–0.5740	7.6892***	6.0579***	–1.2456	3.2376**	–2.0720
	(1.6324)	(2.4404)	(1.6253)	(2.4747)	(1.6502)	(2.5901)	(1.5253)	(2.8103)
Constant	15.1252*	–33.0541***	5.6312	–17.2452**	–14.3205**	2.7218	–7.2660	–3.0764
	(8.2582)	(9.1441)	(9.4788)	(7.9174)	(7.2529)	(12.0150)	(6.9514)	(12.3841)
Industry& Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,169	1,754	1,228	1,695	1,361	1,562	1,711	1,212
R-squared	0.3881	0.3779	0.3799	0.3889	0.3467	0.3864	0.3321	0.4054

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

When supply chain risk is low and the supply chain is stable, the interdependence between peer companies in the upstream and downstream supply chain increases. This fosters resource sharing and exchange between enterprises and peer companies, providing vital resource support for the digital transformation of focal enterprises. From the vantage point of transaction cost theory, upstream and downstream enterprises strive to minimize transaction costs. When peer upstream and downstream enterprises establish stable supply chain relationships, inter-enterprise transaction costs and friction costs are mitigated, thereby providing a conducive transaction environment for the digital transformation of focal companies, reducing transactional risks and obstacles, and fostering the effective circulation of channel resources, market information, and digital transformation experience. It is generally posited that alterations in customers and suppliers impact the stability of the supply chain [41]. This study specifically bifurcates into customer and supplier groups and measures the average number of occurrences of each of the top 5 customers/suppliers in the past 1/2 years. The larger the value of this indicator, the longer the supply chain continuity and the more stable the supply chain relationship. The test results are delineated in columns (5) to (8) of Tab. 7. When the stability of the supply chain is high, that is, the volatility of changes in upstream and downstream peer companies is minimal, and the impact of the digital transformation peer effect of upstream and downstream companies on the supply chain on focal companies is more pronounced.

6.2 Supply Chain Spillover Effects Analysis

Total Factor Productivity (TFP) measures the contribution of all factors, excluding capital and labor growth, to output growth [42]. Research has shown that digital transformation has a backward spillover effect within the supply chain network, enhancing the productivity of upstream enterprises [43]. The digital transformation of peer companies will exert a more profound influence on the digital transformation and enhancement of total factor productivity of focal companies. From the perspective of supply chain management, digital transformation improves the efficiency of information transmission within the supply chain network. Downstream enterprises can swiftly capture market and customer demand and information [44], and relay it to focal companies, enabling them to better allocate supply chain resources and elevate their production decision-making level. Concurrently, upstream enterprises enhance their own production level through digital innovation and R&D during the digital transformation process. This improvement promotes the flow of data, information, and knowledge within the supply chain network, expanding the scope of knowledge spillover and positively impacting the production efficiency of the entire supply chain. This symbiotic development and interdependent ecosystem create a dynamic relationship between the digital transformation of upstream and downstream peer companies in the supply chain and the digitalization of focal companies. This relationship leads to a spillover effect from peer companies on the production factors of focal companies.

$$TFPi,t = \beta 0 + \beta 1 Digchaini,t + \beta 2 Controlsi,t + \\ + Industryi + Yeart + \varepsilon i,t \quad (2)$$

$$Digfocusi,t = \gamma 0 + \gamma 1 Digchaini,t + \gamma 2 Controlsi,t + \\ + Industryi + Yeart + \varepsilon i,t \quad (3)$$

$$TFPi,t = \lambda 0 + \lambda 1 Digchaini,t + \lambda 2 Digfocusi,t + \\ + \lambda 3 Controlsi,t + Industryi + Yeart + \varepsilon i,t \quad (4)$$

To delve into the intrinsic mechanism of the spillover effect, this paper constructs a mediation effect model to test the economic consequences of the digital transformation of peer companies on the digital transformation of focal companies. Models (2) to (4) illustrate the mediation effect model, where the dependent variable is the total factor productivity (*TFP_GMM*), using the generalized method of moments (*GMM*) as summarized by Di Liberto [45]. The explanatory variable is the digital transformation of peer companies (*Digchain*), and the mediating variable is the digital transformation of focal companies (*Digfocus*). The choice of control variables is consistent with the previous part, and the fixed effects at the industry (*Ind*) and year (*Year*) levels are controlled simultaneously. Columns (1) to (3) of Tab. 8 provide the economic consequence test of the mediation model. The regression results reveal that the estimated coefficient of the digital transformation of peer companies (*Digchain*) is significantly positive, and the coefficient of the digital transformation variable of focal companies (*Digfocus*) is 0.0044, which is significant at the 1% level.

Table 8 Economic consequences results

	TFP_GMM	*Digfocus*	*TFP_GMM*
Variables	(1)	(2)	(3)
Digchain	0.0041***	0.0501***	0.0039***
	(0.0013)	(0.0187)	(0.0013)
Digfocus			0.0044***
			(0.0014)
Size	0.0637***	0.2225	0.0628***
	(0.0116)	(0.1660)	(0.0116)
Lev	0.2029***	–0.2923	0.2042***
	(0.0219)	(0.3122)	(0.0219)
ROE	0.0501**	0.0780	0.0498**
	(0.0196)	(0.2797)	(0.0196)
Cashflow	–0.8856***	–11.9113***	–0.8335***
	(0.2055)	(2.9297)	(0.2057)
Digind	0.0176***	0.7655***	0.0143***
	(0.0019)	(0.0278)	(0.0022)
RD	0.0102***	0.0883***	0.0098***
	(0.0022)	(0.0308)	(0.0022)
Governance	0.0103***	0.1128***	0.0099***
	(0.0029)	(0.0407)	(0.0029)
Mcost	–1.6687***	4.6505***	–1.6891***
	(0.1043)	(1.4871)	(0.1043)
Constant	1.6023***	–4.7917	1.6232***
	(0.2638)	(3.7623)	(0.2635)
Industry& Year	Yes	Yes	Yes
Sobel test (*Z-value*)	1.977**		
Bootstrap	[–0.0000, 0.0004]		
Observations	2,624	2,624	2,624
R-squared	0.1558	0.2707	0.1591

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The above results indicate that the digital transformation of peer enterprises improves the total factor productivity of focal enterprises through the digital

transformation of focal companies, supporting the conclusions of the theoretical analysis in the previous text. In addition, this paper conducts a Sobel test of the mediation effect to explore the significance of the mediation effect. The results show that the z-value is 1.977, indicating that there is a positive mediation effect at the 5% significance level.

6.3 Heterogeneity Analysis

6.3.1 Industry

The process and outcomes of the digital transformation of focal enterprises may be influenced by industry heterogeneity. Enterprises within the same industry may be subjected to analogous market pressures and competitive environments, potentially leading to a convergence in their digital transformation strategies and behaviors. Specifically, enterprises within the same industry may exert a dual impact of demonstration and normative pressure, thereby enhancing the impetus for the digital transformation of focal enterprises. However, when focal enterprises and supply chain peer enterprises belong to different industries, focal enterprises can achieve cross-sectoral and cross-industry resource optimization through the co-construction of innovation networks and social networks, thereby fostering the coordinated development and digital transformation of the upstream and downstream supply chain. This study categorizes into the same industry group and different industry groups based on whether the focal firm and the upstream and downstream enterprises belong to the same industry. Columns (1) and (2) of Tab. 9 display the regression results of the divided industry group. When peer enterprises and focal enterprises belong to different industries, the coefficient of the peer digital transformation index is approximately 0.0613, significant at the 5% level; when peer enterprises and focal enterprises belong to the same industry, the coefficient of the peer digital transformation index is approximately 0.0555, significant at the 5% level. The above results indicate that when focal firms and peer firms do not belong to the same industry, the degree of digital transformation of focal firms is higher.

6.3.2 Area

From the vantage point of geographical economics, it is postulated that enterprises within the same region could be subjected to analogous geographical, cultural, and other factors. They could potentially exhibit congruent characteristics in their digital transformation journey by observing and emulating the experiences and decisions of other enterprises [8]. In addition, the geographical proximity of enterprises within the same region may reduce the cost of information transmission. This facilitates the transfer of digital-related information to the focal enterprise through the supply chain. However, enterprises located in different regions could potentially adopt distinct supply chain management strategies and practices. Furthermore, considering the regional disparities in the development of the digital economy, different regions could potentially possess distinct technological and market advantages. For example, the large-scale market and consumer demand in certain local areas could be transmitted to the focal enterprises through the upstream and downstream enterprises of the supply chain in different regions, thereby influencing the process of its digital transformation. In light of this, the sample was divided into two groups, the same region, and different regions, based on whether the focal enterprise and the upstream and downstream enterprises are located within the same provincial administrative region. The regression results as shown in columns (3) - (4) of Tab. 9 indicate that in the same region group, the regression coefficient of the digital transformation of the same group of enterprises is not significant. In the different region groups, the regression coefficient is 0.0663, which is significant at the 1% level. This suggests that when the focal enterprise and the same group of enterprises are located in different provincial administrative regions, the degree of digital transformation of the focal enterprise is higher.

6.3.3 Property Right

For enterprises characterized by disparate property rights, the impetus and strategies for digital transformation are divergent. The affiliation of state-owned enterprises with governmental entities influences their capacity to procure requisite resources, and they are more inclined to proactively respond to governmental policies and endorse long-term visionary objectives during the digital transformation trajectory. Conversely, non-state-owned enterprises often face more significant impacts from market competition and resource constraints. They tend to seek essential information from external markets and various entities within the supply chain, both upstream and downstream, to support their digital transformation efforts. This study executed a subsample regression analysis on state-owned and non-state-owned enterprises. The outcomes delineated in columns (5) - (6) of Tab. 9 reveal that when the focal enterprise is a state-owned entity, the regression coefficient is not statistically significant. However, when the focal enterprise is a non-state-owned entity, the regression coefficient is 0.0593, which is statistically significant at the 5% level. This insinuates that non-state-owned enterprises are more conspicuously influenced by the digital transformation of enterprises within the same cluster.

6.3.4 Interlocking Director

The phenomenon of digital transformation homophily, apart from the upstream and downstream supply chains, industries, and regions discussed in this study, is also prevalent within the context of social network linkages. Interlocking directors can further promote the process of digital transformation of enterprises by promoting the exchange and sharing of knowledge and information resources among enterprises. This study constructs a directorial network of listed companies, categorizing them into connected and unconnected cohorts based on whether the directors of the focal enterprise hold concurrent directorships in other listed companies. The regression outcomes delineated in columns (7) - (8) of Tab. 9 reveal that when the directors of the focal enterprise hold concurrent directorships in other listed companies, the regression coefficient is 0.367, statistically significant at

the 10% level. In the cohort of the focal enterprise that is unconnected, the regression outcome is not statistically significant. This insinuates that when the focal enterprise has a linkage wherein the director holds concurrent positions, the influence of digital transformation's peer effect is more pronounced.

6.3.5 Common Institutional Ownership

Research has confirmed that common institutional investors can effectively enact both regulatory governance and synergistic governance effects. Based on the peer enterprises' connection between industries established by common institutional ownership, the information and knowledge of enterprise digital transformation will be effectively migrated to focus enterprises, so as to maximize the overall portfolio value of investors. Referring to the standard of existing literature [46], if institutional investors hold 5% or more of the shares of two or more listed companies in the same industry at the same time, they are judged to be joint institutional ownership. Then this study divides the sample into the connected group and the unconnected group, and the regression results are shown in column (9) (10) of Tab. 9. When there is a common institutional investor connection in the focal enterprises, the regression coefficient is 0.0855, which is significant at the 10% level. When there is no common institutional investor connection, the regression coefficient is 0.0323, which is significant at the 10% level. Therefore, when there is a common institutional investor in focus enterprises, the peer enterprises have a greater impact on the digital transformation of focal enterprises.

6.3.6 Executive Team Stability

In contrast to the stable network of concurrent directorships, the volatility of personnel among corporate executives is typically more pronounced. Enterprises possessing a stable executive team are predisposed to achieving consensus in decision-making and implementing congruent actions to buttress the enterprise's digital transformation process. However, an excessively stable executive team may engender certain ethical hazards (Crutchley et al., 2002), potentially escalating the enterprise's agency costs or engendering latent conflicts of interest with shareholders. Additionally, a consistently stable executive team may lead to conservative decision-making and a lack of innovative drive within the organization. This can hinder the digital transformation process not only for the focal enterprise but also for other enterprises within the same cluster. This study, drawing upon the methodology of Crutchley et al. (2002), constructs a model of team stability. The sample is bifurcated into stable and volatile cohorts based on the median stability of the executive team. The regression outcomes, as delineated in columns (9) - (10) of Tab. 9, reveal that when the executive team exhibits substantial volatility, i.e., the stability is inferior to the median level of the focal enterprise within the same sample, the digital transformation of peer enterprises exerts a more conspicuous impact on the digital transformation of the focal enterprise.

Table 9 Heterogeneity analysis results

Variables	same industry	different industries	same area	Different areas	state-owned enterprises	Non-state-owned enterprises
	Digfocus	*Digfocus*	*Digfocus*	*Digfocus*	*Digfocus*	*Digfocus*
	(1)	(2)	(3)	(4)	(5)	(6)
Digchain	0.0555**	0.0613**	–0.0031	0.0663***	0.0337	0.0593**
	(0.0251)	(0.0257)	(0.0394)	(0.0200)	(0.0271)	(0.0232)
Constant	–23.9087***	–5.0092	–19.6392*	–11.2023*	12.2498	–35.5092***
	(8.7946)	(7.1796)	(11.7774)	(6.1161)	(7.6505)	(9.5553)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry& Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,165	1,765	649	2,274	1,074	1,856
R-squared	0.3122	0.3734	0.4608	0.3456	0.3208	0.3755
Variables	Interlocking director		Mutual institutional investors		Executive team	
	connected	unconnected	connected	unconnected	stable	volatile
	Digfocus	*Digfocus*	*Digfocus*	*Digfocus*	*Digfocus*	*Digfocus*
	(7)	(8)	(9)	(10)	(11)	(12)
Digchain	0.0367*	0.0260	0.0855*	0.0323*	0.0302	0.0858***
	(0.0221)	(0.0328)	(0.0488)	(0.0196)	(0.0251)	(0.0260)
Constant	–12.1474	–0.8966	–34.7466***	–10.0571	-25.5185***	–1.3694
	(7.3855)	(11.1012)	(12.6473)	(6.3958)	(8.4193)	(7.2765)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry& Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,929	784	277	2,448	1,394	1,394
R-squared	0.3465	0.4228	0.5209	0.3450	0.3754	0.3777

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

7 CONCLUSIONS

7.1 Findings

This study reveals significant advantages of digital transformation within supply chain networks and its association with peer effects. It offers empirical evidence to explain the motivation behind corporate digital transformation and the micro mechanisms of spillover effects within supply chain networks.

This study broadens the research horizons of digital transformation peer effects from the standpoint of supply chain networks, elucidating the transmission mechanisms of enterprise digital transformation within the supply chain. The research discerns that the digital transformation peer

effect of enterprises within the supply chain network is propelled by both internal and external factors, primarily manifested as follows: (1) The digital transformation peer effect intensifies with escalating environmental uncertainty and heightened enterprise perception of uncertainty. (2) To understand the reasons for learning and imitation among peer enterprises, this study examines differences in the influence of upstream and downstream enterprises in supply chain discourse power, as well as variations in the extent of digital transformation compared to the focal enterprise. Group tests are conducted to explore these aspects. The findings indicate that the peer effect of digital transformation is stronger when there are greater disparities in supply chain power and digital transformation levels among enterprises.(3) The manifestation of enterprise digital transformation peer effects diverges based on different scenarios. Specifically, the degree of enterprise digitalization is superior when the supply chain is stable. (4) Further economic consequence tests also discern a spillover effect between peer enterprises within the supply chain network, manifested as the promotion of the productivity of the focal enterprise by the digitalization of peer enterprises. (5) Heterogeneity analysis results indicate that regional and industry differences, property rights characteristics, directorial connections in social networks, common institutional ownership, and the stability of the executive team all exert an influence on the peer effect of enterprise digital transformation.

7.2 Discussion

Firstly, the digital transformation of enterprises not only augments their intrinsic efficiency and benefits but also stimulates the digitalization and productivity enhancement of upstream and downstream enterprises within the supply chain, thereby actualizing the comprehensive optimization and synergistic evolution of the supply chain. The discovery of the peer effect of digital transformation within supply chain networks suggests that as the degree of digital transformation of peer companies increases, focal companies within the supply chain networks also demonstrate a growth trend in digital transformation. This is consistent with the view of social learning theory which states imitation behaviors and synergistic effects exist among organizations and members [27]. Therefore, it is essential for the government to enact specialized plans and policies regarding supply chain management from a macroscopic viewpoint.

Secondly, environmental uncertainty and enterprise uncertainty perception act as both internal and external drivers prompting companies to engage in digital transformation. The regression results indicate that when enterprises perceive higher levels of uncertainty, the digital transformation of peer enterprises within the supply chain network has a stronger influence on driving the digital transformation process of focal enterprises. Amid heightened uncertainty, enterprise managers should carefully evaluate their own and similar enterprises' levels and trends of digitalization, adjust their digital transformation strategies and actions accordingly, and align their objectives and trajectories with their specific circumstances. Seeking synergy and complementarity with customers and suppliers can facilitate mutual prosperity and the collective evolution of the supply chain.

Thirdly, the efficacy of the digital transformation of peer enterprises is contingent upon the industry and region they are situated in, as well as the network characteristics of executives, directors, and common institutional ownership. Previous literature suggests that digital transformation promotes collaboration between supply chain enterprises [22]; the findings of this paper further investigate the mechanism behind the trend. The regression analysis suggests that when there is a common institutional investor in focus enterprises, the peer enterprises have a greater impact on the digital transformation of focal enterprises.

Fourthly, there exists a structural issue of uneven development of enterprise digital transformation at the level of the entire supply chain, primarily manifested in the associated effects engendered by supply chain risks of upstream and downstream enterprises. Supply-demand matching and supply-demand equilibrium form the bedrock for ensuring the resilience and stable security of the supply chain. Enterprises require advancing internal control system reforms, strengthening supply chain management and partner relationships, and establishing a comprehensive financial supply and risk assessment system. This ensures a secure and reliable environment for constructing a digital supply chain.

7.3 Limitation

This paper should be considered in the context of its limitations. Firstly, there may be limitations in the research perspective. Corporate digital transformation is not an individual behavior, and existing studies have mainly analyzed it from the perspectives of shared production areas, industries, and supply chains. Yet, analysis of analyst tracking networks and social networks among enterprises is rarely mentioned, and further clarification and analysis are needed on resource acquisition and learning imitation mechanisms among peer enterprises. Secondly, there may be insufficient data sources. Due to the specific investments and information processing costs of listed companies, they may selectively disclose information about supply chain relationships, making it difficult to depict the full picture of supply chain networks. Therefore, this study focuses on listed companies that disclose information.

This paper encourages future researchers to cover specific industries or focus on the peer effects of digital transformation among small and medium-sized enterprises.

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