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ENTERPRISE DIGITALIZATION AND INDUSTRY CHAIN EXTENSION: INSIGHT INTO BUSINESS SPECIALIZATION

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Abstract. The rapid advancement of technology and industrial transformation has made digital transformation imperative for enterprises. This study aimed to assess the micro-level digitalization of firms and empirically investigate its effects on labor division using machine learning, revealing significant enhancements in specialization among Chinese listed companies. Digital transformation fosters specialization mainly by improving supply chain efficiency, increasing business concentration, and strengthening workforce skills. Our findings clarify the pathways through which digital technologies extend value chains and also provide micro-level evidence for integrating digital and real economies, providing evidence for digitalization policies and high-quality economic development.

1. Introduction

With the continuous development of technology, digital transformation of enterprises has become a key driving force for sustainable competitive advantage, reshaping not only internal processes but also the structure and functions of entire industries. Studies indicate that integrating digital technologies can enhance organizational efficiency, foster innovation, and alter industry chain dynamics [4]. However, the specific ways digitalization impacts the specialization of tasks within these intricate supply chains remain largely unexplored. Investigating this area is vital for understanding how enterprises can achieve sustainable development, extend industry and value chains, and contribute to high-quality economic growth.

The specialization of tasks refers to the concentration of resources on specific business segments, thereby enhancing efficiency and market responsiveness. In today's economy, companies must adapt swiftly to market changes, and specialization is regarded as crucial for gaining a competitive advantage. Although research has examined the impact of digital transformation on economic efficiency and corporate performance, studies on how digitalization specifically facilitates specialization within enterprises remain scarce. Moreover, the impact of digitalization on business concentration is debated. Although some argue that it leads firms to focus on specific areas, thereby enhancing specialization, others propose that it prompts diversification, potentially undermining specialization trends. This divergence underscores the need for further empirical analysis and theoretical clarification.

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This study aimed to address this gap by examining how digitalization influences enterprise specialization and positions within industry chains. We used data from the management discussion and analysis (MD&A) sections of annual reports of publicly listed companies (2000–2022), employing machine learning to construct an index measuring corporate digitalization across five dimensions. Specialization levels were assessed using data on the top five suppliers and customers. A bidirectional fixed-effects model was used to control for individual, time, and industry-time co-trends.

The three main contributions of this study were as follows. First, it employed innovative machine learning methods to precisely measure digitalization levels, addressing the existing literature's shortcomings in quantifying digitalization. Second, it investigated the impact of digitalization on the changes in firms' positions within industry chains, exploring strategic adjustments during digital transformation. Finally, it identified three key pathways through which digitalization fosters enterprise specialization: enhancing supply chain efficiency, increasing business concentration, and strengthening workforce skills. These insights provide both theoretical and practical guidance for upgrading industry and value chains. These contributions enriched the relevant theoretical discourse and offer guidance for enterprises and policymakers to foster specialization, extend industry and value chains, and facilitate high-quality economic development.

2. Literature review and theoretical analysis

2.1. **Literature review.**

2.1.1. *Enterprise digitalization level.* Digitalization refers to the process by which enterprises leverage digital technologies at various levels to improve processes, customer experiences, and operational efficiency. Beyond technology adoption, it involves reforming organizational processes, culture, and business models. The level of corporate digitalization reflects an enterprise's ability to integrate information technology, digital tools, and data-driven decision-making. A large body of research has examined the effect of digitalization on firms, particularly in upstream and downstream supply chain relationships.

Corporate digitalization elevates organizational development and adaptability by optimizing resource allocation, reducing costs, driving innovation, and enhancing customer experience [8]. It not only drives internal changes but also transcends the external boundaries of firms, creating interconnected business networks and cross-industry operations within supply chains. Research has started investigating the effects of digitalization on both upstream and downstream entities within the supply chain. For instance, Hofmann et al. noted that digitalization enables suppliers to better respond to changing customer demands, enhancing product competitiveness [10]. Sanders et al. asserted that digitalization could optimize the geographical distribution of supply chains, improve trust relationships within supply chain finance networks, and elevate overall efficiency and performance [13]. Christopher et al. emphasized that digital transformation enhanced the flexibility and resilience of supply chains, enabling firms to swiftly adapt to market changes and bolster their overall competitiveness [5].

2.1.2. *Enterprise specialization level.* Enterprise specialization involves companies focusing on specific production segments or business areas within the industry chain, optimizing resource allocation, enhancing technological capabilities, and strengthening core competencies to achieve efficiency and value creation. In this process, firms outsource production stages to focus on core activities and achieve economies of scale [9].

Some studies have examined the factors influencing enterprise specialization, such as geography, price, cost, and policy. Most of these studies often analyze mechanisms through the lens of transaction cost theory, suggesting that when transaction costs are low, firms may prefer specialized collaboration over integrated production. Conversely, high transaction costs may drive firms toward integration to maintain stability in production and value chains.

Technological advancements also significantly impact specialization levels. Introducing digital and automation technologies allows firms to achieve efficient production processes and resource allocation. Hofmann et al. asserted that technological innovation enables enterprises to specialize in specific segments, thus enhancing overall production efficiency and competitiveness [10]. Digitalization not only boosts efficiency but also transforms specialization models within firms. For example, Nambisan et al. noted that companies could engage in cross-industry collaboration through digital platforms, adapting quickly to changing market demands during specialization [12].

External collaboration and supply chain management also play essential roles in enterprise specialization. Collaborating with other organizations enables firms to address non-core deficiencies while focusing on primary business activities. Afuah suggested that inter-firm collaboration enhanced specialization for all participants, promoting synergies throughout the industry chain [2].

2.1.3. *Literature summary.* Existing studies have extensively explored the impact of corporate digitalization on supply chain efficiency and resilience, emphasizing its role in operational efficiency, customer experience, and innovation. However, most studies have focused on single supply chain segments or upstream and downstream relationships, with limited analysis of the dynamic impact of digitalization on entire industry chains. A notable deficiency has been observed in systematic exploration regarding how digitalization reshapes corporate roles and positions within the industry chain. Furthermore, the current literature lacks a detailed analysis of the specific pathways through which corporate digitalization influences industry chain structures. It fails to comprehensively explain how digital transformation leverages the distinctions between data-driven and traditional elements to affect collaboration, resource allocation, and value creation mechanisms, thereby altering firms' positions within the industry. This study fills these gaps by exploring the dynamic effects of digitalization on firms' industry chain positioning and the pathways involved, providing valuable insights for strategic adjustments in the digital age.

2.2. **Theoretical analysis.** Companies adopt various organizational structures to maximize profits and enhance competitiveness in response to intense market competition. The firms increase specialization by allocating different production stages to other companies or individuals, whereas engaging in vertical integration can

help expand scale and competitiveness. As digitalization progresses, companies can leverage technologies such as Big Data, cloud computing, and artificial intelligence (AI) to better acquire, analyze, and process information, optimizing production and business decisions. For example, AI automates repetitive tasks and performs high-precision activities, finding widespread application across industries. Digital technologies increase automation, allowing firms to allocate resources and perform production activities efficiently, enabling them to focus on core competencies and increase productivity in competitive areas. Hence, digitalization also facilitates fine management within specific business domains and further enhances production efficiency and technological capabilities through data analysis and intelligent optimization, reducing resource dispersion in non-core businesses and allowing companies to focus more on core activities [9]. Through digital technologies, firms can gain deeper insights into market demands and core competencies, allowing them to adjust business structures and focus on high-value-added segments, laying the groundwork for specialized labor divisions. Based on this analysis, we propose Hypothesis 1:

H1: Enhancements in corporate digitalization can significantly increase the degree of enterprise specialization.

Digital technologies have introduced informational and intelligent management methods, enabling companies to enhance the responsiveness and transparency of their supply chains through real-time data monitoring, precise demand forecasting, and supply chain visualization. Using technologies such as Big Data analytics, the Internet of Things, and cloud computing, firms can more efficiently coordinate production planning and resource allocation, reducing inventory buildup and logistics costs, thus achieving full-process optimization of the supply chain [11]. This enhancement in supply chain efficiency allows companies to concentrate on core business segments while outsourcing non-core activities to more specialized partners, promoting further focus on high-value-added areas. Additionally, digital technologies can simplify collaboration processes between firms and their suppliers and customers, lower communication costs and uncertainties, and enhance upstream and downstream synergies within the supply chain, thereby advancing the specialization of division of labor across various segments [5]. Based on this analysis, we propose Hypothesis 2.

H2: Corporate digitalization promotes enterprise specialization by improving supply chain efficiency.

The application of digital technologies enables companies to clearly identify their core competencies in the market using precise market analysis and data-driven decision-making tools, allowing for targeted resource allocation and business adjustments. First, an increase in business focus means that firms allocate more resources, management capacity, and technology toward their core business areas, thus enhancing their competitive advantage. According to the resource-based view (RBV), firms have limited resources, and concentrating them on critical business segments can improve specialization. This allows firms to better exploit their potential in specific areas, accumulating unique knowledge, experience, and technological advantages, thereby developing specialized capabilities. Second, increased business focus promotes firms' ability to innovate and improve products in specific fields. Firms can focus more on market demands and technological advancements

by concentrating on fewer business areas, thereby enhancing their innovation capacity in these areas. Moreover, highly focused business operations allow firms to establish closer collaboration with other specialized firms in the supply chain, integrating external resources and information to improve supply chain efficiency and synergy [5]. At the same time, the increase in digitalization enables firms to better leverage external resources and collaborate with other specialized firms, thus further driving specialization within the industry value chain [7]. In summary, increased business focus allows firms to establish clearer core competencies and differentiated advantages in the context of global competition, positioning themselves more professionally within complex value chains. Based on the aforementioned analysis, we propose Hypothesis 3.

H3: Digital transformation enhances firm's specialization by increasing business focus.

The application of digital technologies allows firms to more effectively allocate tasks and manage resources, reducing the demand for low-skilled labor engaged in repetitive, routine tasks while increasing their reliance on high-skilled labor. High-skilled workers, who are more adaptable to digital environments, are better equipped to handle complex technical tasks and optimize processes, further driving specialization in core business areas [6]. Firms can achieve a higher degree of specialization in key areas such as research and development, design, and product innovation by improving workforce skills. Moreover, digital transformation has profoundly changed supply chain management and decision-making models. Firms require more decentralized decision-making and flat organizational structures to respond more flexibly to market changes by optimizing information management and production control, reducing inventory and costs [1]. High-skilled workers play a crucial role in such flat structures, they take on more decision-making and management responsibilities, promoting a more efficient and flexible form of specialization. The growing number of high-skilled workers allows firms to achieve a higher level of specialization in both core businesses and emerging services, strengthening their competitiveness in global markets. In conclusion, digital transformation enhances a firm's specialization by improving workforce skills. Based on the aforementioned analysis, we propose the following hypothesis:

H4: Digital transformation enhances firm's specialization by strengthening workforce skills.

3. Methodology and data

3.1. **Model settings.** Fixed-effects models are widely used in panel data estimation to mitigate estimation bias from omitted variables by controlling for individual and time effects. This study constructed a panel fixed-effects model to determine the impact of corporate digitalization on enterprise division of labor:

$$Spe_{ijt} = \beta_0 + \beta_1 Digital_{ijt} + \beta_2 X_{ijt} + \alpha_i + \delta_t + \eta_{jt} + \varepsilon_{ijt} \tag{3.1}$$

where Spe_{ijt} represents the enterprise specialization level. Digital means the digital transformation. The estimation coefficient β_1 depicts how digital transformation affects enterprise enterprise specialization. X_{ijt} denotes control variables, whereas

ϵ_{ijt} represents the error term. The model accounts for individual fixed effects α_i, time fixed effects δ_t, and industry-year fixed effects η_{jt}.

3.2. **Variable descriptions.**

3.2.1. *Independent variable.* The explanatory variable is the level of corporate digitalization. Most existing studies measure corporate digitalization through the frequency of digital-related terms, overlooking the significance of individual words and some omitted terms. This study employed neural network word embedding models to assess corporate digitalization levels using texts from the MD&A section of Chinese public firms. Word embedding models map words to a continuous low-dimensional vector space, capturing semantic features and contextual relationships among words. We manually defined five seed words reflecting corporate digitalization across different dimensions: digital device manufacturing, digital information transmission, digital technology services, digital content and media, and Internet applications and related services, selecting four to five words for each dimension. We generated an extended word list using the seed words and a trained Word2Vec model by analyzing the MD&A text of listed companies. Table 1 presents the seed words for each dimension of corporate digitalization, along with the top 10 extended words, arranged in descending order of similarity to the representative vector for each dimension.

TABLE 1. Seed words and top 10 extended words for each dimension

Dimension	Seed words	Top 10 extended words
Digital device manufacturing	Radar, Robotics, Computers, Electronic components, Instruments and meters	Instruments and meters, Computers, Electronic components, Radio communications, Telecommunications equipment, Electronic devices, Digital information systems, Wireless communications, Semiconductor devices
Digital information transmission	Satellite communications, Cable television, Wireless networks, Telecommunications, Broadband	Broadband access, Access networks, Cable broadband, Cable television, Digital television, Core networks, Communication networks, Metropolitan area networks, Wireless networks
Digital technology services	Information systems, Cybersecurity, Software development, Network resources, Information technology	Information systems, Network systems, Cybersecurity, Information technology, Data security, Infrastructure, Disaster recovery, Application software, Information security, Network equipment
Digital content and media	E-books, Online games, Streaming media, Animation, TV programming	Online games, Animation, TV programming, Video games, television, Cartoon production, Audiovisual content, Mobile gaming, Online gaming, Web-based content
Internet applications and related services	Food delivery, Alipay, E-commerce, Financial information, Online education	Online shopping, Alipay, Social commerce, E-commerce, Micro-stores, E-commerce platforms, Internet services, Online education, Merchant acquiring, Online-to-offline services

Following the approach of Lori Qingyuan Yue (2021), we calculated the intensity of each dimension in the MD&A reports by dividing the weighted count of words from the extended vocabulary list by the total word count in the MD&A reports. We employed a term frequency–inverse document frequency (TFIDF) weighting scheme to adjust the importance of words in the calculations, assigning greater weight to words that are frequent in a document but have lower coverage in the overall corpus. Formally, given an MD&A report and a set of selected words reflecting the subdimensions of corporate digitalization $[word_1, \ldots, word_n]$, we have:

$$\text{Score} = \frac{\sum_i^n TF_i * IDF_i}{D} * 100, \tag{3.2}$$

where TF_i is the count of $word_i$ in the MD&A; IDF_i is the natural logarithm of one plus the ratio of the total number of MD&As in the corpus divided by the number of MD&As and containing $word_i$: $\log\left(1+\frac{\text{Number of all MD\&As and CSRs}}{\text{Number of MD\&As and CSRs containing word } i}\right)$; D is the total word count in the MD&A; and the multiplier 100 is used to represent the frequency score as a percentage.

3.2.2. *Dependent variable.* The dependent variable is the level of enterprise specialization, measured by the weighted average difference in industry upstreamness between a firm's top five suppliers and top five customers. We referenced Antràs et al. to calculate the industry upstreamness u_j for 135 industries using the 2007 Input–Output Table of China [3]:

$$U_j = 1\cdot\frac{F_j}{r_j} + 2\cdot\frac{\sum_{i=1}^{N} d_{ji}F_i}{r_j} + 3\cdot\frac{\sum_{i=1}^{N}\sum_{k=1}^{N} d_{jk}d_{ki}F_i}{r_j} + \cdots, \tag{3.3}$$

where Y_j is the gross output in industry j and F_j is the value of the output that goes directly to final uses (i.e., consumption or investment). d_{ij} is the direct requirements coefficient in the 2007 Input–Output Table of China, this being the value of i used as an input to produce one yuan worth of industry i output.

We manually matched the departments in the Input–Output Table with the industry classifications of the firm's suppliers (customers) and computed the weighted average upstreamness u_j of the suppliers according to the output of the departments in the table. The weighted average industry upstreamness u_j^s for the firm's top five suppliers and u_j^c for the top five customers were calculated, with the difference between them serving as a measure of enterprise specialization. The industry upstreamness reflects the position of products or industries within the value chain; a smaller difference $u_j^s - u_j^c$ indicates that the suppliers and customers of the listed company are positioned more closely in the value chain, signifying a higher level of enterprise specialization.

3.2.3. *Control variables.* Several firm-level control variables were included based on prior relevant research: (1) firm size (*Size*), measured using the natural logarithm of a firm's total annual assets, which is an appropriate proxy to capture the firm's overall scale; (2) asset liability ratio (*Lev*), described by the ratio of total liabilities to total assets; (3) return on assets (*Roa*), represented by the ratio of net profit and average balance of total assets; (4) the top 10 majority shareholding ratio (*Top 10*), measured by the ratio of the number of shares held by the top 10 shareholders to the total number of shares held; (5) cash flow ratio (*Cashflow*), described by the ratio of net cash flows generated from operating activities to total assets; and (6) state-owned enterprise (*Soe*), represented by 01 dummy variable, in which the state-owned enterprise is assigned to 1, otherwise is 0.

3.3. **Data sources.** This study focused on A-share listed companies from 2001 to 2022. The data on corporate digitalization levels were obtained through analyzing the companies' annual reports. The information regarding the companies and their top five suppliers and customers, as well as other financial data, was sourced from China Stock Market & Accounting Research Database (CSMAR), whereas Input–Output Table data were obtained from the National Bureau of Statistics. The

sample selection criteria were as follows. (1) Companies with significant missing data for suppliers and customers were excluded, including companies that had not disclosed their suppliers and customers, samples lacking specific names of suppliers and customers, which prevented matching with other company characteristic data, and unreasonable samples where incomplete disclosure of supplier and customer data resulted in a negative difference in the calculated weighted average upstreamness between suppliers and customers. (2) Companies with significantly incomplete financial data were excluded. (3) Financial sector samples were excluded. A 1% winsorization process was applied to continuous variables to minimize the influence of outliers. Following the aforementioned criteria, the final sample included 1809 observations. Specific definitions and descriptions of the key variables in the model are provided in Table 2.

Table 2. Descriptive statistics

Variables	Definition	N	Mean	SD	Min	Max
Spe	Specialization level	1809	1.129	0.804	0.021	3.334
Digital	Digitalization level	1809	3.646	6.017	0.000	34.655
Size	Firm size	1809	22.058	1.145	19.267	26.631
Lev	Asset liability ratio	1809	0.452	0.213	0.052	1.016
Roa	Return on assets	1809	0.029	0.068	-0.287	0.231
*Top*10	the top ten majority shareholding ratio	1809	54.980	15.170	23.192	91.043
Cashflow	Cash flow ratio	1809	0.041	0.070	-0.197	0.257
Age	Firm age	1809	2.912	0.347	1.386	3.526
Soe	State owned enterprise	1809	0.420	0.494	0.000	1.000

4. Empirical results

4.1. **Benchmark regression results.** For the benchmark model, this study employed regression analysis by sequentially adding and changing variables to enhance reliability. Table 3 reports the regression results regarding the impact of corporate digitalization on enterprise specialization. Column (1) controls only for fixed effects, showing that digitalization has a positive impact on specialization. The estimation suggests that each unit increase in digitalization produces a 0.025 unit increase in the level of specialization. Columns (2) and (3) gradually add control variables, with the digitalization coefficient remaining statistically significant. In Column (4), the independent variable is replaced with a lagged digitalization level, and the results remain significant. These findings indicate that an increase in corporate digitalization levels promotes specialization, supporting Hypothesis 1.

4.2. **Robustness test.**

4.2.1. *Replacing the independent variables.* We re-evaluated corporate digitalization (*Digitalization2*) by summing sub-indices from "Digital Information Transmission," "Digital Technology Services," and "Internet Applications and Related Services" using the word embedding method. The regression results in Table 4, Column (1) confirm consistency with the benchmark conclusions, indicating that digitalization promotes specialization.

TABLE 3. Benchmark regression results

	(1)	(2)	(3)	(4)
Digitalization	-0.025**	-0.029**	-0.029**	
	(0.012)	(0.012)	(0.012)	
L.Digitalization				-0.027**
				(0.011)
Size		0.014	0.017	0.019
		(0.079)	(0.080)	(0.080)
Lev		0.340	0.291	0.310
		(0.238)	(0.244)	(0.244)
Roa		-0.228	-0.313	-0.288
		(0.444)	(0.457)	(0.455)
*Top*10		-0.001	-0.001	-0.000
		c(0.004)	(0.004)	(0.004)
Cashflow			-0.304	-0.395
			(0.397)	(0.398)
FirmAge			0.023	0.017
			(0.509)	(0.513)
Soe			0.206	0.212
			(0.157)	(0.158)
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Industry-Year FE	YES	YES	YES	YES
Observations	1975	1823	1809	1810
R-squared	0.651	0.650	0.652	0.653

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors in parentheses.

4.2.2. *Increasing control variables.* We added the control variable "Inventory Ratio" to the benchmark regression model to further validate the robustness of the regression results regarding corporate digitalization's impact on specialization. As a significant component of firm assets, inventory ratio reflects the efficiency of inventory management in operations, potentially influencing production strategies and business structure. Thus, including this variable helps control for its potential impact on enterprise specialization levels. The regression results in Table 4, Column (2) demonstrate that the results remained robust after adding control variables.

4.2.3. *Adjusting sample interval.* We adjusted the sample interval based on the temporal characteristics of corporate digital transformation to further verify the robustness of the regression results. Given that the period after 2010 marked a critical phase of accelerated corporate digital transformation globally, the application and popularization of digital technologies profoundly impacted business models and structures. Consequently, we restricted the sample interval to 2010–2022 and conducted regression analysis again to assess whether the impact of digitalization levels on enterprise specialization remained robust. The regression results are shown in Table 4, Column (3), confirming that the findings of this study still hold.

4.2.4. *Controlling for joint fixed effect of time and region.* Recognizing that corporate digital transformation may undergo systematic changes due to varying regional economic development levels and temporal trends, we introduced interaction terms of province and year for control. This robustness test effectively captured regional

differences arising from varying digital development processes, avoiding potential bias from neglecting regional temporal characteristics. The final results aligned with previous findings, indicating that the findings of this study remain valid even after controlling for regional temporal trend effects.

Table 4. Robustness test

	(1)	(2)	(3)	(4)
*Digitalization*2	-0.048***			
	(0.018)			
Digitalization		-0.030**	-0.031**	-0.034*
		(0.012)	(0.012)	(0.018)
Control Variables	YES	YES	YES	YES
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Industry-Year FE	YES	YES	YES	YES
Region-Year-FE	NO	NO	NO	YES
Observations	1,809	1,772	1,767	1,687
R-squared	0.652	0.657	0.657	0.744

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors in parentheses.

5. Mechanism analysis

5.1. **Supply chain efficiency.** We employed inventory turnover days (*Itd*) as a measure of supply chain efficiency, calculated as ln(365/inventory turnover rate), to explore whether corporate digitalization impacts specialization by influencing supply chain efficiency. This metric was chosen for two reasons: first, it effectively mitigates measurement errors in supply chain efficiency caused by safety stock holdings; second, it reflects the frequency of interaction and trade between upstream and downstream supply chain entities, indicating flexibility and responsiveness within the supply chain, resonating with overcapacity issues. The results in Table 5, Column (1), show a significant negative coefficient for digitalization related to Itd, indicating improved supply chain efficiency. This supports Hypothesis 2, which posits that digitalization enhances specialization through better supply chain efficiency.

5.2. **Product diversification.** This study measured business concentration (*Con*) as the ratio of primary business income to total revenue. The mechanism analysis results are shown in Table 5, Column (2). The regression coefficient is significantly positive, indicating that improved digitalization levels indeed contribute to higher business concentration, thereby affecting the level of specialization development.

5.3. **Workforce skills.** We used two methods to measure the skill level of a firm's labor force to empirically test the mechanism by which digital transformation enhanced firm specialization through improving labor skills. First, we categorized technical and research and development (R&D) personnel as high-skilled employees and measured the ratio of high-skilled employees to the total number of employees (*Hski*). This metric reflects the proportion of employees engaged in specialized and complex tasks. Second, we categorized employees with a bachelor's degree or higher as highly educated employees, whereas the rest were classified as low-skilled employees. We then used the ratio of highly educated employees to the total number

of employees (*Hedu*) to capture the proportion of employees with advanced educational backgrounds, reflecting the overall educational level and skill reserves of the workforce. Together, these two metrics serve as proxies for measuring the skill level of a firm's labor force. Column (3) results indicate that digital transformation significantly increases the proportion of high-skilled employees within firms. Similarly, the results in Column (4) show a significant positive effect of digital transformation on the proportion of highly educated employees. The results from both measures are significant, indicating that digital transformation, by improving labor skills, significantly promotes firm specialization, which supports Hypothesis 4.

Table 5. Mechanism analysis

	(1) Itd	(2) Con	(3) Hski	(4) Hedu
Digitalization	-0.006***	0.027***	0.002***	0.002***
	(0.002)	(0.000)	(0.000)	(0.000)
Control Variables	YES	YES	YES	YES
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Industry-Year FE	YES	YES	YES	YES
Observations	44,453	43,786	40,273	38,823
R-squared	0.772	0.399	0.700	0.801

Note: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors in parentheses.

6. Conclusions

This study examines the efficiency enhancement effects of digital transformation at the micro-level of enterprises and explores its internal mechanisms. The main conclusions are: (1) An increase in digitalization levels facilitates a specialized division of labor in enterprises, thereby extending the industry and value chains. (2) The mechanisms through which enhanced digitalization promotes enterprise specialization include improved supply chain efficiency, business concentration, and workforce skills. This study presents four policy recommendations.

First, companies should prioritize optimizing supply chain management to enhance efficiency. Using digital tools such as the Internet of Things, blockchain technology, automation technologies and Big Data analytics, companies can monitor various aspects of the supply chain in real time, effectively controls inventory levels and minimizes waste.

Second, companies need to focus resources on core business areas to further enhance their specialization and competitiveness. Adopting enterprise resource planning systems enables companies to effectively integrate different business functions, such as finance, procurement, and sales, achieving efficient resource allocation.

Finally, companies must emphasize the enhancement of labor skills. Companies should invest in workforce skill training. Through internal training and external collaborations, companies can help employees master new digital tools and technologies. Moreover, Companies should foster cross-departmental collaboration to enhance employee capabilities, helping them adapt to a changing market and improving information transfer within the organization.

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