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The impact of supply chain digitization and logistics efficiency on the competitiveness of industrial enterprises

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ABSTRACT

This paper selects data from Chinese listed companies in the industrial sector from 2011 to 2022 as samples to explore the impact of supply chain digitization and logistics efficiency on the competitiveness of industrial enterprises. The study finds that the degree of supply chain digitization can enhance the competitiveness of industrial enterprises; logistics efficiency can help industrial enterprises improve their competitiveness; environmental regulation plays a positive moderating role in the relationship between logistics efficiency and the competitiveness of industrial enterprises; there is heterogeneity in the impact of supply chain digitization on the competitiveness of state-owned industrial enterprises and non-state-owned industrial enterprises, with a greater impact on the competitiveness of state-owned industrial enterprises than on non-state-owned ones. There is a significant difference in the impact of logistics efficiency on the competitiveness of state-owned industrial enterprises and non-state-owned industrial enterprises, with a noticeably greater impact on the competitiveness of non-state-owned industrial enterprises than on state-owned ones.

1. Introduction

Supply chain digitization refers to the informatization, digitization, and networking of each link in the supply chain to achieve intelligent management and collaboration in the whole process (Sun et al., 2022). With the development of information technology, more and more enterprises have begun to recognize the importance of digital transformation, of which supply chain digitalization is one of the critical aspects of digital transformation. China's supply chain finance business has achieved practical innovation and development, and the digitalization penetration rate has increased significantly (Degl'Innocenti et al., 2018). For example, in 2022, the digitalization scale of supply chain finance in China reached 11 trillion yuan, and the digitalization penetration rate was about 30%, which achieved a multi-fold increase compared with 2018. By 2027, the scale of supply chain finance digitization is expected to reach 30 trillion yuan, and the digitization penetration rate will also grow to about 50%. Meanwhile, financial institutions, core enterprises, and fintech companies have established supply chain finance digitization platforms. According to statistics, there are more than 200 operating platforms in the industry as of 2022, and the number is still growing at a high rate. In addition, some enterprises are also actively transforming the supply chain, optimizing it through digital technology to make it more efficient, collaborative, and intelligent. For example, Heineken Brewing Company has reduced the number of unique bottles and the use of secondary packaging through supply chain transformation; Schneider Electric has built a customer-centric supply chain through digitalization; and Walmart

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has invested heavily in its supply chain, omnichannel, and technology to respond to the trend of shoppers moving online (Remondino & Zanin, 2022). As technology advances and applications deepen, supply chain digitization will continue to increase, bringing enterprises more benefits and competitive advantages (Gupta et al., 2021).

Logistics efficiency is a comprehensive concept that involves the level of service provided by the logistics system in a certain period and the effect of various indicators reached while requiring the minimization of resources used in the process (Hallikas et al., 2021). In short, logistics efficiency ensures the level of service under the premise of reducing costs as much as possible and optimizing resource utilization (Moldabekova et al., 2021). The impact of logistics efficiency on industrial enterprises is reflected in several ways: Logistics is a significant cost component of industrial enterprise operations. Improving logistics efficiency means reducing unnecessary transportation, warehousing, and overall operating costs (Marmolejo-Saucedo & Hartmann, 2020). For example, companies can directly reduce transportation costs by optimizing transportation routes, increasing loading rates, and reducing losses in transit. In addition, efficient inventory management can reduce inventory backlogs and obsolescence, reducing inventory costs (Di & Varriale, 2020). These cost-control initiatives help improve the enterprise's economic efficiency and profit level; an efficient logistics system can ensure the timely supply of raw materials and components, reduce the waiting time in the production process, and thus improve productivity and production capacity (Liu & Chiu, 2021). In addition, improved logistics efficiency also helps to coordinate the interface between production and sales to ensure that products are delivered to customers on time. This synergy helps to reduce production delays and out-of-stock situations and improves the responsiveness and flexibility of the overall supply chain. In a competitive market environment, logistics efficiency is one of the critical factors for companies to win a competitive advantage. Efficient logistics services can ensure that products are delivered to customers quickly and accurately, enhancing customer satisfaction and loyalty (Wang et al., 2022). In addition, improving logistics efficiency also helps enterprises shorten the delivery cycle and enhance responsiveness to market changes to occupy a favorable position in the market competition.

The current development of industrial enterprises in China presents the following main features: First, industrial production has realized faster growth. The value-added of industries above the designated size in the first quarter grew significantly year-on-year, and critical industries such as electronics, chemicals, and automobiles were driven (Choudhury et al., 2021). This is mainly due to the support of national policies and the improvement of market demand. At the same time, market expectations are reasonable, industrial investment is proliferating, the number of industrial enterprises continues to increase, and the purchasing manager index of the manufacturing industry has risen back to the boom zone; secondly, new industrialization is accelerating. China's industrial enterprises are gradually realizing high-end and intelligent development (Özdağoğlu & Bahar, 2022). For example, some key core technology research projects have made breakthroughs, and innovative achievements continue to emerge. At the same time, the level of intelligence is also rising, and more and more enterprises have begun to adopt intelligent manufacturing technologies to improve production efficiency and product quality; in addition, the information and communication industry is developing steadily, with year-on-year growth in telecom business revenue. This reflects the rapid development and broad application of China's information and communication technology, which provides strong support for the digital transformation of industrial enterprises (Cacho et al., 2020). Meanwhile, the business environment continues to be optimized. The government has introduced a series of policies and measures to reduce the tax burden on enterprises, optimize the administrative examination and approval process, and strengthen the protection of intellectual property rights, creating a favorable environment for enterprise development. However, it should also be noted that the development of industrial enterprises in China still faces challenges, such as the uncertainty of the international trade environment and the intensification of resource and environmental constraints. Therefore, industrial enterprises must continue strengthening independent innovation and improving core competitiveness while actively addressing external risks and challenges (Khan et al., 2021).

The influencing factors of industrial enterprise competitiveness are increasingly diversified. Internal factors such as technological innovation, management efficiency, brand building, and corporate culture are considered the core drivers of enterprise competitiveness (Shahadat et al., 2023). External factors such as market demand, policy environment, industry structure, and international competitive landscape also have a significant impact on enterprise competitiveness. In addition, green competitiveness has gradually become a research hotspot, emphasizing enterprises' capabilities in environmental protection and sustainable development(Saddique et al., 2023). With the global increase in environmental protection awareness, technological and management measures such as green production and energy conservation and emission reduction have become important ways to enhance enterprise competitiveness. According to the literature review results, currently, there is a lack of empirical research by scholars on the factors influencing the competitiveness of industrial enterprises(Damtew et al., 2021). No scholars have yet conducted empirical research on the relationship between the degree of supply chain digitalization, logistics efficiency, and the competitiveness of industrial enterprises. Therefore, the research results of this paper can enrich the research on the factors influencing the competitiveness of industrial enterprises.

2. Theoretical analysis and research hypotheses

Supply chain digitization has a multifaceted impact on the competitiveness of industrial enterprises.

First, supply chain digitization significantly improves industrial enterprises' operational efficiency. Through the digital platform, enterprises can obtain and analyze various data in the supply chain in real-time, including orders, inventory, logistics information, and so on. This real-time information sharing helps enterprises better grasp the market demand and supply situation to make quick decisions, optimize resource allocation, improve production efficiency, and reduce operating costs (Sharakhin et al., 2021).

Second, supply chain digitization helps enterprises realize customized production and services. With the support of digital technology, enterprises can quickly adjust and optimize the operation of each supply chain link according to market demand and customer requirements. This can not only meet the personalized needs of customers and improve customer satisfaction but also enhance the

market competitiveness of enterprises (Han et al., 2021).

In addition, supply chain digitization improves enterprises' risk management and forecasting capabilities. Through technologies such as extensive data analysis and model prediction, enterprises can manage and predict risks in the supply chain, identify and solve potential problems promptly, and reduce operational risks. This improved risk management capability helps enhance enterprises' stability and reliability and improves their competitiveness in the market (Sorkun, 2020).

Finally, supply chain digitization helps enterprises achieve business model innovation and transformation. Through digital technology, enterprises can explore new business models and growth points and open new market space (Yang et al., 2021). This improvement in innovation ability helps enterprises stand out in the fierce market competition and realize sustainable development (Zhao et al., 2023).

In summary, the impact of supply chain digitization on the competitiveness of industrial enterprises is mainly reflected in improving operational efficiency, realizing customized production and services, enhancing risk management and forecasting capabilities, and realizing business model innovation and transformation. With the continuous development and application of digitalization technology, this impact will become increasingly significant and essential for industrial enterprises to enhance their competitiveness (Bigliardi et al., 2022).

Based on the above analysis, this paper proposes the following hypotheses.

H1. The degree of supply chain digitization can enhance the competitiveness of industrial enterprises.

The impact of logistics efficiency on the competitiveness of industrial enterprises is significant. Enhancing logistics efficiency can reduce enterprise operating costs, meet market demand, optimize supply chain management, and promote enterprise innovation and development (Sarkis et al., 2021). Therefore, industrial enterprises should emphasize improving logistics efficiency by introducing advanced logistics technology and management concepts and constantly improving their logistics level to enhance competitiveness in the market (Song et al., 2022).

Improvements in logistics efficiency can significantly reduce industrial enterprises' operating costs. Enterprises can reduce transportation and storage costs by optimizing the logistics network and processes, improving overall economic efficiency (Alesiuniene et al., 2021). This can increase enterprises' profits, making them more competitive in price and attracting more consumers.

An efficient logistics system helps industrial enterprises better meet market demand. In a competitive market environment, responding quickly to customer needs is the key to gaining a competitive advantage (Ju et al., 2021). Improved logistics efficiency means that firms can fulfill order deliveries more quickly and shorten the time it takes for products to move from production to consumers, thus enhancing customer satisfaction and loyalty (Setiawan et al., 2023).

Logistics efficiency also affects industrial companies' supply chain management. An efficient logistics system ensures the stability and reliability of the supply chain and reduces production disruptions and supply chain risks caused by logistics problems. This helps enterprises manage supply chain resources, optimize inventory levels, reduce inventory backlogs and waste, and improve operational efficiency (Attaran, 2020).

Improving logistics efficiency also helps industrial enterprises realize innovation and development. With the continuous progress and application of logistics technology, enterprises can explore new logistics models and solutions and enhance the personalization and intelligence of logistics services. This will help enterprises establish a unique brand image and enhance their competitiveness and market share (Zhuckovskaya et al., 2020).

Building upon the preceding analysis, the following assumptions are advanced.

H2. Logistics efficiency can enhance the competitiveness of industrial enterprises.

Environmental regulation plays an essential moderating role in the relationship between logistics efficiency and industrial enterprise competitiveness. By guiding and restricting enterprises' behavior, environmental regulation aims to promote sustainable development and ecological civilization (Zhou & Wang, 2021).

Environmental regulation specifies logistics efficiency requirements. In order to reduce environmental pollution and ecological damage, environmental regulation usually requires companies to adopt more environmentally friendly logistics methods and technologies. This may include choosing clean energy-powered means of transportation, optimizing transportation routes, reducing unnecessary packaging and the number of shipments, etc. (Chauhan et al., 2022). Although these measures may increase firms' logistics costs to a certain extent, in the long run, they help improve logistics efficiency, reduce resource wastage, and help firms establish an excellent environmental image (Agrawal & Narain, 2023).

Environmental regulation has a positive impact on the competitiveness of industrial enterprises. Under environmental regulation, those firms that can actively respond to and meet environmental requirements tend to gain more market opportunities and competitive advantages (Haddud & Khare, 2020). This is because as consumers become more aware of environmental protection, more and more customers tend to choose those products and services with environmental certification and good environmental image. Therefore, by improving logistics efficiency to meet environmental regulation requirements, industrial enterprises can reduce operating costs and enhance their market competitiveness.

Environmental regulations also help promote technological innovation in the logistics industry and industrial enterprises. To meet environmental requirements, enterprises need to continuously develop and apply new environmental technologies and methods (Balcı, 2021). These technological innovations can improve logistics efficiency and bring enterprises more significant economic and social benefits. At the same time, technological innovation is also a necessary means for enterprises to enhance their competitiveness (Fatorachian & Kazemi, 2021).

However, it is essential to note that environmental regulation may also negatively impact logistics efficiency and the

competitiveness of industrial enterprises. Excessively high environmental standards and stringent regulatory measures may increase the operating costs of enterprises, reduce logistics efficiency, and even threaten their survival and development (Loske & Klumpp, 2022). Therefore, when formulating and implementing environmental regulations, it is necessary to fully consider enterprises' actual situation and affordability to ensure that environmental regulations are harmonized with economic development.Building upon the preceding analysis, the following assumptions are advanced.

H3. Environmental regulation regulates the relationship between logistics efficiency and industrial enterprise competitiveness.

There are differences in the impact of the degree of supply chain digitization on the competitiveness of state-owned and non-state-owned industrial enterprises (Shcherbakov & Silkina, 2021). For state-owned industrial enterprises, supply chain digitization further enhances their operational efficiency and cost control capacity due to their more stable policy support and richer resource reserves. State-owned industrial enterprises usually have a larger scale and more muscular financial strength, which enables them to better invest resources in the construction and optimization of supply chain digitization (Li et al., 2021). In addition, state-owned industrial enterprises focus more on long-term stable development and social benefits, and thus, supply chain digitization may have a more significant effect in enhancing their competitiveness and sustainability. However, for non-state-owned industrial enterprises, the effects of supply chain digitization on their competitiveness may be more complex and diverse (Pan et al., 2021). As non-state-owned industrial enterprises face more intense market competition, higher resource acquisition, and operational risks, supply chain digitization may become a critical means to enhance their competitiveness (Mohsen, 2023). Through supply chain digitization, non-state-owned industrial enterprises can more accurately grasp market demand and supply chain dynamics, optimize inventory management and logistics distribution, reduce operating costs, and improve response speed. At the same time, digitization technology also helps non-state-owned industrial enterprises to break the limitations of the traditional supply chain, realize the flexibility and synergy of the supply chain, and improve the overall operational efficiency (Ning & Yao, 2023).

Building upon the preceding analysis, the following assumptions are advanced:

H4. There is a difference in the impact of the degree of supply chain digitization on the competitiveness of state-owned industrial enterprises and non-state-owned industrial enterprises.

For state-owned industrial enterprises (SOEs), improving logistics efficiency may not significantly determine their competitiveness, as they tend to have more stable policy support and resource reserves (MacCarthy & Ivanov, 2022). State-owned industrial enterprises pay more attention to long-term strategic planning and social responsibility and, therefore, may be more inclined to robust and sustainable improvements in logistics efficiency.

However, logistics efficiency improvement often directly and significantly impacts non-state-owned industrial enterprises' competitiveness. Since these enterprises face more intense market competition and resource acquisition and cost control difficulties, logistics efficiency is directly related to their market competitiveness. Non-state-owned industrial enterprises usually pay more attention to flexibility and innovation to cope with rapid changes in the market, so they may be more proactive in logistics efficiency improvement and seek various innovative solutions (Wamba & Queiroz, 2022).

Building upon the preceding analysis, the following assumptions are advanced:

H5. There is a difference in the impact of logistics efficiency on the competitiveness of state-owned and non-state-owned industrial enterprises.

3. Study design

3.1. Sample selection

In this paper, the data of listed companies in the industrial sector of Shanghai and Shenzhen A-shares from 2011 to 2022 are selected as samples, and the data sources are mainly CSMAR and CNRDS databases. Moreover, the following treatments are done: the samples of delisted companies are excluded; the samples of ST*, ST, and PT companies in that year are excluded; and the samples with missing data are excluded. In order to avoid the impact of missing values and outliers on the study, the explanatory variables, control variables, and control variables were subjected to 1% shrinkage treatment, and some of the control variables with large values were subjected to the treatment of taking the natural logarithm. After data processing, the final valid samples were obtained as 9251.In terms of indicators such as the scale and nature of the sample enterprises, the selected enterprises in this paper can well represent various types of industrial enterprises, demonstrating strong representativeness.

3.2. Definition of variables

3.2.1. Dependent variable

Enterprise Competitiveness (*IC*): Regarding measuring enterprise competitiveness, most of the existing literature selects a single indicator or a multi-dimensional evaluation index system. In this paper, eight indicators are selected to measure the competitiveness of industrial enterprises in terms of the research results of scholars, and the weights of sub-indicators are set concerning the research results of scholars. Eventually, the standardized indicators are weighted to obtain the enterprise competitiveness score of the observation sample. The specific evaluation index system is shown in Table 1.

Table 1
Enterprise competitiveness evaluation index system.

factor	Indicator name	Indicator weights
Scale subfactor	revenues	20
	net assets	11
	net profit	16
Growth subfactor	Growth rate of operating income in the last 3 years	17
	Net profit growth rate in the last 3 years	14
Efficiency subfactor	Net asset margin	8
	Total assets contribution ratio	14

Table 2
Definition of variables.

Variable type	Variable name	Variable symbol	Variable definition
Dependent variable	Enterprise Competitiveness	IC	Eight indicators were selected to measure the competitiveness of industrial enterprises
Independent variables	Supply Chain Digitization Degree	SCD	When the enterprise is a pilot enterprise of supply chain innovation and application, the value is assigned to 1, otherwise the value is assigned to 0
	Logistics efficiency	LE	The selected indicators were measured using the BCC-DEA model
Moderator variables	Environmental regulation	ERI	Completed investment in industrial pollution control/industrial output value
Control variables	firm age	age	Ln (time of establishment of the enterprise)
	firm size	size	Ln (total business assets)
	growth	Growth	Enterprise sales revenue growth rate
	gearing	Lev	Total liabilities/total assets
	dual	Dual	If the chairman of the board of directors and general manager is not the same person, assigned a value of 1, otherwise take 0
	firm nature	state	State-owned enterprises take the value of 1, otherwise 0

3.2.2. Independent variables

Supply Chain Digitization Degree (*SCD*): When the enterprise is a pilot enterprise of supply chain innovation and application, the value is assigned as 1. Otherwise, the value is assigned as 0.

Logistics efficiency (*LE*): The logistics efficiency indicator system is constructed from the input-output perspective to measure logistics efficiency better. The logistics efficiency evaluation index system includes two dimensions: input variables and output variables. Input variables include capital input, financial expenditure, infrastructure investment, number of employees, and policy support. The output variables include development scale, contribution level, and transportation capacity, and the BCC-DEA model is used to measure the logistics efficiency of the cities where industrial enterprises are located.

3.2.3. Moderator variables

Environmental regulation (*ERI*) is measured using the ratio of completed investment in industrial pollution control to industrial output value for industrial industries in the region where the enterprise is located.

3.2.4. Control variables

The control variables in this paper include firm age (*lnage*), firm size (*size*), growth (*Growth*), gearing (*Lev*), dual (*Dual*), and firm nature (*state*). All variable definitions are shown in Table 2.

3.3. Model construction

This paper develops the following model to test the hypotheses of the previous paper. The paper uses a fixed effects model and controls for yearly effects.

$$IC_{i,t} = \alpha_0 + \alpha_1 SCDi_{i,t} + \sum_{k=1}^{n} \alpha_k control_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$IC_{i,t} = \lambda_0 + \lambda_1 LE_{i,t} + \sum_{k=1}^{n} \lambda_k control_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$IC_{i,t} = \eta_0 + \eta_1 IE_{i,t} + \eta_2 IE_{i,t} * ERI_{i,t} + \sum_{k=1}^{n} \eta_k control_{i,t} + \varepsilon_{i,t} \quad (3)$$

Table 3
Descriptive statistical analysis.

VarName	Obs	Mean	SD	Min	Max
IC	9251	0.9871	0.1732	0.473	1.281
SCD	9251	0.143	0.138	0.000	1.000
LE	9251	0.724	0.252	0.174	0.997
ERI	9251	11.071	0.872	7.948	12.451
age	9251	2.779	0.518	0.131	4.258
size	9251	20.372	1.405	19.472	24.715
Growth	9251	0.151	0.324	−0.271	1.724
Lev	9251	0.475	0.714	0.052	0.916
Dual	9251	0.712	0.458	0.000	1.000
state	9251	0.492	0.372	0.000	1.000

Table 4
Results of the main regression test(*SCD*).

	(1)	(2)
	IC	IC
SCD	0.1452*** (4.4827)	0.1511*** (5.1422)
Age		0.1326*** (3.3251)
size		0.2156*** (9.7813)
Dual		−0.1103 (−1.0357)
Lev		−0.1744*** (−7.3158)
state		0.1542*** (5.2418)
Growth		0.1613*** (6.0458)
_cons	0.4724*** (15.1324)	0.7139*** (17.2026)
Year	Yes	Yes
N	9251	9251
r^2	0.3258	0.3314

Table 5
Results of the main regression test(*LE*).

	(1)	(2)
	IC	IC
LE	0.2125*** (12.3016)	0.2132*** (12.4215)
Age		0.1451*** (4.4892)
size		0.2172*** (11.0324)
Dual		−0.1106 (−1.0451)
Lev		−0.1752*** (−7.4215)
state		0.1553*** (5.4729)
Growth		0.1625*** (6.1531)
_cons	0.3571*** (12.6249)	0.7145*** (18.3052)
Year	Yes	Yes
N	9251	9251
r^2	0.3277	0.3324

4. Empirical analysis

4.1. Descriptive statistical analysis

As displayed in Table 3, the highest measure of corporate competitiveness (*IC*) reaches 1.281, while the lowest stands at 0.473, reflecting significant disparities among the competitive strengths of various industrial firms. The mean score for the Supply Chain Development (*SCD*) indicator is 0.143, suggesting that the entities participating in the supply chain innovation and application pilot project constitute 14.3% of the sample. Regarding logistics effectiveness (*LE*), a peak value of 0.997 is observed, with a nadir of 0.174, thus evidencing substantial variations in the logistical efficiency across the cities where these industrial companies are situated. Further descriptive statistics for other variables are presented in Table 3.

4.2. Main test regression results

In Table 4, the contrast of the two outcome columns reveals the regression outputs with and without control factors. For column (1), when no control variables are incorporated, the coefficient for Supply Chain Digitization (*SCD*) stands at 0.1452, significantly

Table 6
Moderating effect results.

	(1)	(2)
	IC	IC
LE	0.2132*** (12.4215)	0.1982*** (9.0472)
*ERC*LE*		0.1537*** (5.3918)
Age	0.1326*** (3.3251)	0.1322*** (3.2848)
size	0.2156*** (9.7813)	0.2032*** (9.7249)
Dual	−0.1103 (−1.0357)	−0.1107 (−1.0362)
Lev	−0.1744*** (−7.3158)	−0.1736*** (−7.2518)
state	0.1542*** (5.2418)	0.1536*** (5.1942)
Growth	0.1613*** (6.0458)	0.1584*** (5.9317)
_cons	0.3571*** (13.6249)	0.7128*** (19.1453)
Year	Yes	Yes
N	9251	9251
r^2	0.3281	0.3296

Table 7
Results of heterogeneity test(*SCD*).

	(1)	(2)
	state-owned enterprises	non-state-owned enterprises
SCD	0.1973*** (4.4827)	0.1146 (1.4257)
Age	0.1421*** (4.0127)	0.1278*** (2.8035)
size	0.2341*** (12.7259)	0.2044*** (10.1457)
Dual	−0.1157 (−1.5429)	−0.1073 (−1.0248)
Lev	−0.1781*** (−7.8035)	−0.1703*** (−7.0218)
Growth	0.1724*** (7.0613)	0.1592*** (5.9807)
_cons	0.6714*** (16.6832)	0.6258*** (15.5941)
Year	Yes	Yes
N	4551	4700
r^2	0.3271	0.3315

pertinent at the 1% level, suggesting a substantial contribution of SCD to industrial firms' competitiveness. Upon inclusion of control variables in column (2), the coefficient for SCD rises to 0.1511, remaining statistically significant at the 1% level, thereby demonstrating that SCD continues to enhance industrial enterprise competitiveness. This substantiates Hypothesis 1 further.

Table 5's Column (1) reveals regression outcomes sans control variables, revealing a logistics efficiency (*LE*) coefficient of 0.2125, statistically noteworthy at the 1% level. This suggests that supply chain digitalization substantially influences industrial firm competitiveness. In Column (2), upon incorporating control variables, the LE coefficient remains significant at 0.2132, confirming that logistics efficiency positively affects industrial enterprise competitiveness (*IC*) significantly, substantiating Hypothesis 2.

4.3. Analysis of moderating effect

Table 6 presents the outcomes of the moderated effects analysis. In column (2), corresponding to model 3's regression outputs, the logistics efficiency (*LE*) coefficient stands at 0.1982, which is significant at the 1% significance level. The interaction term coefficient between logistics efficiency (*LE*) and environmental regulation (*ERC*) is 0.1537, which is also statistically significant at the 1% level. This suggests that environmental regulation (*ERC*) has a positively moderating influence on the relationship between logistics efficiency (*LE*) and the competitive strength (*IC*) of industrial firms, thereby validating Hypothesis 3.

4.4. Heterogeneity analysis

Separate subsample regressions are performed to examine variations in the influence of supply chain digitalization on competitiveness between state-owned and non-state-owned industrial firms. For state-owned enterprises, the coefficient related to supply chain digitalization (*SCD*) measures 0.1973, statistically significant at the 1% level, suggesting a substantial reinforcing impact of SCD on these firms' competitiveness (*IC*). Conversely, in the non-state-owned enterprise sample, the coefficient for SCD stands at 0.1146. It fails to attain statistical significance, implying that the positive effect of SCD on the competitiveness (*IC*) of non-state-owned industrial firms is negligible, thereby substantiating Hypothesis 4 (see Table 7).

Separate sub-sample regressions are conducted to examine the disparity in the influence of logistics efficiency on the competitiveness of state-owned and non-state-owned industrial firms. For state-owned firms, the logistics efficiency (*LE*) coefficient stands at 0.1724, statistically significant at the 1% level, demonstrating that LE significantly enhances the competitiveness (IC) of these firms. Conversely, in the non-state-owned firm sample, the LE coefficient is 0.2451, notably higher than that of state-owned firms, suggesting a significantly more pronounced effect of LE on the competitiveness of non-state-owned industrial enterprises compared to state-

Table 8
Results of heterogeneity test(*LE*).

	(1)	(2)
	state-owned enterprises	non-state-owned enterprises
LE	0.1724*** (7.4037)	0.2451*** (14.0327)
Age	0.1322*** (3.3148)	0.1334*** (3.4521)
size	0.2104*** (10.0724)	0.2259*** (12.5736)
Dual	−0.1024 (−1.0247)	−0.1145 (−1.1452)
Lev	−0.1631*** (−6.3047)	−0.1781*** (−7.8523)
Growth	0.1525*** (5.0537)	0.1581*** (5.8321)
_cons	0.4548*** (14.5731)	0.5031*** (15.2918)
Year	Yes	Yes
N	4551	4700
r^2	0.3282	0.3304

Table 9
Robustness test.

	(1)	(2)
	IC	IC
SCD	0.1527*** (5.2031)	
LE		0.2173*** (12.7045)
Age	0.1331*** (3.3472)	0.1327*** (3.3125)
size	0.2147*** (9.7625)	0.2104*** (10.3834)
Dual	−0.1108 (−1.0362)	−0.1114 (−1.0925)
Lev	−0.1751*** (−7.4203)	−0.1747*** (−7.3629)
state	0.1547*** (5.3128)	0.1539*** (5.2148)
Growth	0.1618*** (6.1427)	0.1593*** (5.9821)
Ta	0.1524*** (5.2128)	0.1573*** (5.7329)
Indep	0.1328*** (3.2922)	0.1341*** (3.4561)
_cons	0.4629*** (4.5138)	0.8215*** (8.0327)
Year	Yes	Yes
N	9251	9251
r^2	0.3281	0.3294

Table 10
Endogeneity test results.

	(1)	(2)
	IC	IC
SCD	0.1487***	
	(4.9032)	
LE		0.2054***
		(11.2931)
Control variable	Yes	Yes
_cons	0.4702***	0.4819***
	(4.7125)	(4.9024)
Year	Yes	Yes
r^2	0.3258	0.3307

owned ones, thereby validating Hypothesis 5 (see Table 8) .The greater impact of logistics efficiency (*LE*) on the competitiveness of non-state-owned industrial enterprises compared to state-owned ones may stem from factors such as policy support, resource allocation, and market access. Non-state-owned enterprises, often facing more market competition, rely more on efficient logistics to enhance competitiveness.

4.5. Robustness tests

In this paper, we add control variables to conduct robustness tests. In industrial enterprises, fixed assets account for a relatively high proportion, which may have a particular impact on the competitiveness of enterprises. Meanwhile, independent directors play an essential supervisory role in the operation of enterprises. Therefore, this paper supplements the two control variables of fixed assets to total assets ratio (*Ta*) and independent directors to board of directors ratio (*Indep*) for the robustness test. The robustness test results are shown in Table 9; the coefficients of Supply Chain Digitization Degree (*SCD*) and Logistics Efficiency (*LE*) are positive and pass the significance test, indicating that this paper's regression results are stable.

4.6. Endogeneity test

In order to solve the endogeneity problem caused by sample self-selection, this paper adopts the propensity score matching method (PSM) to alleviate this problem. First, the samples with high supply chain digitization (supply chain digitization assigned a value of 1) are used as the experimental group, and the control variables in this paper are used as the matching variables to obtain the samples with low supply chain digitization according to the one-to-one pairing. Table 10 shows the regression results obtained based on the PSM method. Supply Chain Digitization Degree (*SCD*) and Logistics Efficiency (*LE*) coefficients are positive and pass the significance test. The regression results are consistent with those of the previous paper, indicating that the findings of the previous paper are not affected by endogeneity.

5. Conclusions

There are few empirical studies by scholars on the factors affecting the competitiveness of industrial enterprises. Scholars have yet to conduct empirical research on the relationship between the degree of supply chain digitization, logistics efficiency, and the competitiveness of industrial enterprises. Therefore, this paper selects the data of listed companies in the industrial sector from 2011 to 2022 as a sample to explore the relationship between the degree of supply chain digitization, logistics efficiency, and the competitiveness of industrial enterprises. The study found that the degree of supply chain digitization can improve the competitiveness of industrial enterprises; logistics efficiency can improve the competitiveness of industrial enterprises; environmental regulations play a moderating role in the relationship between logistics efficiency and competitiveness of industrial enterprises; the influence of supply chain digitization on the competitiveness of state-owned industrial enterprises and non-state-owned industrial enterprises varies, and supply chain digitization has a more pronounced influence on the competitiveness of state-owned industrial enterprises. There are differences in the impact of logistics efficiency on the competitiveness of state-owned industrial enterprises and non-state-owned industrial enterprises, and the impact of logistics efficiency on the competitiveness of non-state-owned industrial enterprises is more prominent. The results can enrich the research on the factors affecting the competitiveness of industrial enterprises and provide references for regions to formulate measures to strengthen industrial competitiveness.

Although this study has revealed the impact of supply chain digitalization and logistics efficiency on the competitiveness of industrial enterprises, as well as the moderating role of environmental regulation, there are still limitations. Firstly, the dynamic relationship and long-term effects between supply chain digitalization and logistics efficiency have not been thoroughly explored. Secondly, the research sample is limited to listed companies in the industrial sector in China, which may lack universality. Future research should expand the time span, adopt dynamic models to analyze the interactive mechanisms and long-term impacts of these factors, and simultaneously broaden the sample scope to include different countries and industries, thereby enhancing the generality and applicability of the research conclusions.

Author statement

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Declaration of interest statement

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled.

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Data availability

The authors do not have permission to share data.

References

Agrawal, P., & Narain, R. (2023). Analysis of enablers for the digitalization of supply chain using an interpretive structural modelling approach. *International Journal of Productivity and Performance Management, 72*(2), 410–439.

Alesiuniene, K. S., Simanaviciene, Z., Bickauske, D., Mosiiuk, S., & Belova, I. (2021). Increasing the effectiveness of food supply chain logistics through digital transformation. *Independent Journal of Management & Production, 12*(6), 677–701.
Attaran, M. (2020). Digital technology enablers and their implications for supply chain management. *Supply Chain Forum: International Journal, 21*(3), 158–172. Taylor & Francis.
Balcı, G. (2021). Digitalization in container shipping services: Critical resources for competitive advantage. *Journal of ETA Maritime Science, 9*(1).
Bigliardi, B., Filippelli, S., Petroni, A., & Tagliente, L. (2022). The digitalization of supply chain: A review. *Procedia Computer Science, 200*, 1806–1815.
Cacho, J. L., Marques, L., & Nascimento, Á. (2020). Customer-oriented global supply chains: Port logistics in the era of globalization and digitization. In *Anthropological approaches to understanding consumption patterns and consumer behavior* (pp. 82–103). IGI Global.
Chauhan, S., Singh, R., Gehlot, A., Akram, S. V., Twala, B., & Priyadarshi, N. (2022). Digitalization of supply chain management with industry 4.0 enabling technologies: A sustainable perspective. *Processes, 11*(1), 96.
Choudhury, A., Behl, A., Sheorey, P. A., & Pal, A. (2021). Digital supply chain to unlock new agility: A TISM approach. *Benchmarking: An International Journal, 28*(6), 2075–2109.
Damtew, A. W., Borena, T., & Yilma, Y. (2021). The roles of cloud-based supply chain integration on firm performances and competitiveness. *International Journal of Industrial and Manufacturing Systems Engineering, 6*(3), 49–58.
Degl'Innocenti, M., Grant, K., Šević, A., & Tzeremes, N. G. (2018). Financial stability, competitiveness and banks' innovation capacity: Evidence from the Global Financial Crisis. *International Review of Financial Analysis, 59*, 35–46.
Di Vaio, A., & Varriale, L. (2020). Digitalization in the sea-land supply chain: Experiences from Italy in rethinking the port operations within inter-organizational relationships. *Production Planning & Control, 31*(2–3), 220–232.
Fatorachian, H., & Kazemi, H. (2021). Impact of Industry 4.0 on supply chain performance. *Production Planning & Control, 32*(1), 63–81.
Gupta, H., Kumar, S., Kusi-Sarpong, S., Jabbour, C. J. C., & Agyemang, M. (2021). Enablers to supply chain performance on the basis of digitization technologies. *Industrial Management & Data Systems, 121*(9), 1915–1938.
Haddud, A., & Khare, A. (2020). Digitalizing supply chains potential benefits and impact on lean operations. *International Journal of Lean Six Sigma, 11*(4), 731–765.
Hallikas, J., Immonen, M., & Brax, S. (2021). Digitalizing procurement: The impact of data analytics on supply chain performance. *Supply Chain Management: International Journal, 26*(5), 629–646.
Han, L., Hou, H., Bi, Z. M., Yang, J., & Zheng, X. (2021). Functional requirements and supply chain digitalization in industry 4.0. *Information Systems Frontiers*, 1–13.
Ju, Y., Hou, H., & Yang, J. (2021). Integration quality, value co-creation and resilience in logistics service supply chains: Moderating role of digital technology. *Industrial Management and Data Systems, 121*(2), 364–380.
Khan, S. A., Kusi-Sarpong, S., Gupta, H., Arhin, F. K., Lawal, J. N., & Hassan, S. M. (2021). Critical factors of digital supply chains for organizational performance improvement. *IEEE Transactions on Engineering Management, 71*, 13727–13741.
Li, Z. P., Ceong, H. T., & Lee, S. J. (2021). The effect of blockchain operation capabilities on competitive performance in supply chain management. *Sustainability, 13*(21), Article 12078.
Liu, K. P., & Chiu, W. (2021). Supply chain 4.0: The impact of supply chain digitalization and integration on firm performance. *Asian Journal of Business Ethics, 10*(2), 371–389.
Loske, D., & Klumpp, M. (2022). Verifying the effects of digitalisation in retail logistics: An efficiency-centred approach. *International Journal of Logistics Research and Applications, 25*(2), 203–227.
MacCarthy, B. L., & Ivanov, D. (2022). The Digital Supply Chain—emergence, concepts, definitions, and technologies. In *The digital supply chain* (pp. 3–24). Elsevier.
Marmolejo-Saucedo, J. A., & Hartmann, S. (2020). Trends in digitization of the supply chain: A brief literature review. *EAI Endorsed Transactions on Energy Web, 7*(29). e8-e8.
Mohsen, B. M. (2023). Developments of digital technologies related to supply chain management. *Procedia Computer Science, 220*, 788–795.
Moldabekova, A., Philipp, R., Satybaldin, A. A., & Prause, G. (2021). Technological readiness and innovation as drivers for logistics 4.0. *The Journal of Asian Finance, Economics and Business, 8*(1), 145–156.
Ning, L., & Yao, D. (2023). The Impact of digital transformation on supply chain capabilities and supply chain competitive performance. *Sustainability, 15*(13), Article 10107.
Özdağoğlu, A., & Bahar, S. (2022). Logistics 4.0 and smart supply chain management. In *Industry 4.0 and global businesses: A multidisciplinary investigation* (pp. 163–183). Emerald Publishing Limited.
Pan, S., Trentesaux, D., McFarlane, D., Montreuil, B., Ballot, E., & Huang, G. Q. (2021). Digital interoperability in logistics and supply chain management: State-of-the-art and research avenues towards physical internet. *Computers in Industry, 128*, Article 103435.
Remondino, M., & Zanin, A. (2022). Logistics and agri-food: Digitization to increase competitive advantage and sustainability. Literature review and the case of Italy. *Sustainability, 14*(2), 787.
Saddique, F., Nwagwu, U., Mushtaq, N., Lamiaa, B., & Ali, A. (2023). Implementation of digitalization supply chain helps in gaining of competitive advantages as mediating role in the supply chain performance in construction organization in Pakistan. *Traditional Journal of Humanities, Management, and Linguistics, 2*(1), 14–27.
Sarkis, J., Kouhizadeh, M., & Zhu, Q. S. (2021). Digitalization and the greening of supply chains. *Industrial Management & Data Systems, 121*(1), 65–85.
Setiawan, H., Tarigan, Z., & Siagian, H. (2023). Digitalization and green supply chain integration to build supply chain resilience toward better firm competitive advantage. *Uncertain Supply Chain Management, 11*(2), 683–696.
Shahadat, M. H., Chowdhury, A. H. M. Y., Nathan, R. J., & Fekete-Farkas, M. (2023). Digital technologies for firms' competitive advantage and improved supply chain performance. *Journal of Risk and Financial Management, 16*(2), 94.
Sharakhin, P. S., Levchenko, A. V., & Renzhin, D. A. (2021). Comparing efficiency of outsourcing or insourcing digital logistics in supply chain management. In *2021 international conference on quality management, transport and information security, information technologies (IT&QM&IS)* (pp. 716–718). IEEE.
Shcherbakov, V., & Silkina, G. (2021). Supply chain management open innovation: Virtual integration in the network logistics system. *Journal of Open Innovation: Technology, Market, and Complexity, 7*(1), 54.
Song, M., Ma, X., Zhao, X., & Zhang, L. (2022). How to enhance supply chain resilience: A logistics approach. *International Journal of Logistics Management, 33*(4), 1408–1436.
Sorkun, M. F. (2020). Digitalization in logistics operations and industry 4.0: Understanding the linkages with buzzwords. *Digital business strategies in blockchain ecosystems: Transformational design and future of global business* (pp. 177–199).
Sun, Y., Zeng, X., Zhao, H., Simkins, B., & Cui, X. (2022). The impact of COVID-19 on SMEs in China: Textual analysis and empirical evidence. *Finance Research Letters, 45*, Article 102211.
Wamba, S. F., & Queiroz, M. M. (2022). Industry 4.0 and the supply chain digitalisation: A blockchain diffusion perspective. *Production Planning & Control, 33*(2–3), 193–210.
Wang, X., Kumar, V., Kumari, A., & Kuzmin, E. (2022). Impact of digital technology on supply chain efficiency in manufacturing industry. In *Digital transformation in industry: Digital twins and new business models* (pp. 347–371). Cham: Springer International Publishing.
Yang, M., Fu, M., & Zhang, Z. (2021). The adoption of digital technologies in supply chains: Drivers, process and impact. *Technological Forecasting and Social Change, 169*, Article 120795.
Zhao, N., Hong, J., & Lau, K. H. (2023). Impact of supply chain digitalization on supply chain resilience and performance: A multi-mediation model. *International Journal of Production Economics, 259*, Article 108817.
Zhou, Q., & Wang, S. (2021). Study on the relations of supply chain digitization, flexibility and sustainable development—a moderated multiple mediation model. *Sustainability, 13*(18), Article 10043.
Zhuckovskaya, I. F., Panshin, I. V., & Markhaichuk, M. M. (2020). Digitalization of labor as a key factor in the development of logistic activities in the conditions of COVID-19. In *Proceedings of the international conference digital age: Traditions, modernity and innovations (ICDATMI 2020)* (pp. 274–281). Atlantis Press.