Can Digital Transformation Contribute to the Sustainable Development of Logistics Enterprises? Evidence from China

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Abstract—**Digital transformation and sustainable development are major challenges in the logistics business. However, the effects and mechanisms of digital transformation on logistics enterprises' sustainable growth still need to be clarified. Based on the Resource-Based View and Dynamic Capability Theory, we construct a model that analyses the influence of digital transformation on the sustainable development of logistics companies, explicitly focusing on their ability to coordinate and integrate. Furthermore, we investigate the moderating influence of management capability. We conduct an empirical study utilizing panel data from 61 listed logistics companies in China between 2012 and 2021. The findings indicate that digital transformation plays a crucial role in enhancing the sustainable development performance of logistics firms through enhancing enterprises' coordination and integration capability. Additionally, there is a "U"-shaped moderating effect of management capability between digital transformation and sustainable development performance. According to heterogeneity analysis, compared with state-owned logistics enterprises, digital transformation more significantly promotes sustainable development performance in non-state-owned logistics enterprises. Moreover, this positive impact is particularly pronounced in large-scale and older enterprises. However, for smaller and younger logistics enterprises, the promoting effect is insignificant. This study provides empirical evidence and a decision-making guide for the sustainable development of logistics companies in the digitalization era.**

Index Terms—**digital transformation, logistics enterprises, mediating effect, sustainable development**

I. Introduction

THE logistics industry links production and sales, and is the artery of national economic development. In 2023, the total social logistics cost of China accounted for 14.4% of GDP, much higher than the 9.1% in the US during the same period. Currently, Chinese logistics enterprises are confronted with the dual challenge of reducing costs and improving service quality. In addition, the energy consumption of the logistics industry in China accounts for 8.35% of national total energy consumption [1]. The Chinese government has proposed to "promote logistics companies to strengthen green energy conservation and low-carbon management." Therefore, Chinese logistics firms need to shoulder social responsibility [2], improve their operations level in an environmentally friendly manner, and comprehensively elevate sustainable development.

The development of digital technologies such as information technology, big data, and artificial intelligence is rapidly injecting new vitality into the industry. These technologies have continuously exerted a multiplier effect on improving social production efficiency [3]. However, different studies have produced inconsistent results concerning the impact of digitalization on corporate growth. Zhao et al. [4] demonstrated how digital transformation can enhance a company's total factor productivity. Meanwhile, Zhang et al. [5] found that digital technology boosts production efficiency within enterprises, driving organizational growth by lowering costs, increasing productivity, and promoting innovation.

Regarding green development, Chen et al.'s [6] study suggests that digital transformation positively influences enterprise environmental performance by promoting green technology innovation, increasing disclosure of environmental information, and reinforcing environmental governance. Furthermore, implementing digital transformation helps enhance the performance of enterprise sustainable development by strengthening environmental governance [7] and promoting green technology innovation [8]. Nonetheless, Liu et al. [9] highlighted that digital transformation is prone to dynamic fluctuations, influenced by both internal and external factors within the enterprise, which consequently obstructs business growth. Overindulging in digital transformation may disrupt the balance between surplus digital aspects and traditional elements, impeding green innovation and development [10]. As cited by Yang et al. [11], digital transformation necessitates extensive migration of fixed assets and digital skill enhancement for the workforce. This might lead to an unfavorable situation where carbon emissions escalate, and achieving carbon reduction becomes a daunting task.

Digital technology serves a transformative function and opens up innovative possibilities for the sustainable expansion of logistics businesses. Take JD Logistics, for

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instance, which achieves zero carbon emissions and enhances operational efficiency through the adoption of photovoltaic power generation and digital technology. Wang [12] found that Transfar Zhilian, a Chinese logistics company, intensified its dynamic capability through the execution of digital transformation, ultimately generating value for the organization. Wang et al. [13] have illustrated how digital transformation enhances enterprise financial performance by improving both financial costs and managerial efficiency. Nevertheless, the research and development (R&D) investment of emerging and green technologies requires significant financial backing, but the immediate returns are often limited. Furthermore, heightened uncertainty deters logistics companies from realizing substantial benefits, yielding a minimal marginal contribution to sustainable growth. As mentioned above, the relationship between digital transformation and the sustainable development in logistics enterprises remains unclear.

Although the digital transformation of enterprises and its impact on sustainable development has garnered widespread attention, current research remains insufficient to satisfy the growing demand. While scholars have examined the digital transformation's effects on financial, innovation, and organizational value, there is a dearth of studies that integrate digital transformation, environmental performance, and total factor productivity [15]. Moreover, there exist no unanimity regarding the influence and mechanism of digital transformation on enterprise sustainability. Thus, further research is needed to guide business practice. Lastly, the logistics industry, deeply influenced by digital technology, has seen little exploration about sustainable development from the perspective of digital transformation, particularly empirical research.

This paper may make the following contributions: Firstly, this paper comprehensively evaluates the sustainable development performance of an enterprise by examining its production and environmental performance. The production performance here takes financial and human resources into account, which is a more comprehensive assessment of an enterprise's input-output efficiency than solely considering financial performance used by scholars in the past. Secondly, this paper introduces coordination and integration capability as a mediating factor in the relationship between logistics firms' digital transformation and sustainable development performance, which is a new research perspective. Thirdly, this empirical analysis is conducted based on the panel data from Chinese logistics listed companies, thereby providing empirical evidence for the strategic decision-making of logistics enterprises in China and similar developing countries amidst the wave of digital transformation.

The remainder of this paper is structured as follows: The second section reviews relevant literature and presents the research hypotheses. The third section outlines the research design, detailing the data, variables, and the corresponding econometric model. The fourth section presents empirical findings and engages in a comprehensive discussion of the research outcomes. The fifth part conducts heterogeneity testing and survival analysis. In conclusion, the sixth section encapsulates the research findings, presents pertinent strategic recommendations, acknowledges the study's constraints, and envisions potential avenues for future exploration.

II. Research Hypotheses

A. Digital Transformation and Sustainable Development Performance

Digital technology has gradually progressively emerged as a vital resource for boosting productivity, enabling enterprises to seamlessly incorporate these technologies into their operational and production processes. For instance, corporations can profoundly examine user behavioral preferences and consistently refine the correlation between supply and demand by effectively analyzing real-time data across various sectors [16]. By utilizing digital technology, enterprises can promptly comprehend R&D trends, optimize R&D structure, and enhance the innovation quality [17]. By leveraging digital technology, companies can swiftly understand R&D trends, optimize R&D structure, through innovation [4]. Digital transformation helps integrate digital resources and the real economy in enterprises. The Resource-Based View (RBV) emphasizes that digital technology, as an important heterogeneous resource, can help enterprises gain lasting influence [18]. Penrose's [19] groundbreaking research of RBV primarily focused on how a company's current resource configurations shape its future growth and progress. Barney [20] introduced RBV as a systematic approach. He highlighted that valuable, rare, inimitable, and non-substitutable (VRIN) strategic resources provide companies with distinctive competitive edges. From an economic rent perspective, Peteraf [21] proposed that a company can attain a competitive edge that rivals cannot replicate by capitalizing on its distinctive resources. Inside the organization, digital transformation enhances enterprises' total factor productivity by bolstering human resource acquisition [7], promoting technological progress, and boosting the effectiveness of management decision-making [22]. In terms of value generation from external sources, digital transformation can improve enterprises' operational performance by optimizing investment returns, reducing external transaction costs, and expanding the scope of consumer resources [23].

Digital transformation is vital for enterprises seeking to elevate sustainable development, as it integrates seamlessly with core technology architectures like blockchain, cloud computing, artificial intelligence, and big data [16]. Cloud computing enables enterprises to access and manage computing resources with enhanced flexibility. Artificial intelligence enables machines to learn and make autonomous decisions, therefore improving enterprises' decision-making efficiency. Digital transformation promotes sustainable development by improving the quantity and quality of green innovation [24] and reducing carbon emissions and environmental contamination throughout the product lifecycle [25]. In addition, to a certain extent, a company's capacity to capitalize on market opportunities is contingent on its sensitivity to adapt to changes [26]. Digital transformation can enhance stakeholder oversight over corporate green development [14]. By employing digital technologies, enterprises can foster trust and collaboration more effectively by showcasing their environmental

protection strategies and outcomes to stakeholders. This transparent method not only aids companies in cultivating a superior corporate image but also encourages them to pursue sustainable practices.

Researchers have confirmed the significant influence of digital transformation on the sustainability performance of enterprises. Digital capabilities and strategies are essential for driving the evolution of novel processes and products. By enabling businesses to more effectively adapt to the ever-changing commercial landscape, they confer sustainable competitive advantages [27][28]. In a groundbreaking study, Wang et al. [29] demonstrated that digital transformation significantly enhances enterprises' sustainable development outcomes, primarily through fostering green product, process, and management innovation. Furthermore, the logistics sector, characterized by its labor-intensity, benefits from digital transformation by aiding companies in integrating human resources and boosting production efficiency. Drawing from the analysis presented above, we put forth the following hypothesis:

H_1: Digital transformation significantly enhances the sustainable development performance of logistics companies.

B. Mediating Effect of Coordination and Integration Capability

Enterprises enhance resource allocation by continuously redefining and redistributing novel knowledge and resources [30]. A key dynamic capability, coordination and integration capability, enables businesses to adapt to environmental shifts by effectively harmonizing and integrating various departments, processes, and systems [31]. This capability includes managing supply chains, information streams, and logistics services, and maintaining a firm grip on resources, data, processes, and customer requirements in logistics enterprises.

Coordination and integration are vital in driving sustainable development through digital transformation. Firstly, digital technology transcends traditional information barriers, empowering enterprises with tools for seamless internal and external connectivity. This enhances their perception of the external environment. Moreover, due to digital transformation, enterprises can more accurately assess the market value of various resources, enabling deeper exploration and utilization. This gives companies a competitive edge in sustainable development. Secondly, digital technology enhances the reintegration and allocation of internal and external resources. Enterprises can promote the sharing of corporate information through the efficient circulation of data [8]. Further, this enhanced ability to mobilize diverse resources aids in maximizing the overall synergy of internal resources and improving economic and social benefits [33]. Finally, low-carbon and sustainable-related technologies and innovations span numerous sectors. Digital technology promotes the convergence of knowledge across various disciplines, allowing for the creation of innovative products and services. As a result, it is emerging as a crucial driving force propelling businesses toward sustainable growth. Based on this, the following hypothesis is proposed:

H_2: Digital transformation improves sustainable development performance by enhancing coordination and integration capability.

C. Moderating Effect of Management Capability

An enterprise's management capability encompasses efficient operations through comprehensive planning, strategic organization, decisive command, and seamless coordination throughout its operational process. Digital technology's complexity has induced substantial transformations in corporate labor processes, production methodologies, management frameworks, and educational models [34]. To remain competitive, an enterprise's management capability must keep pace with digital technology. A high degree of alignment between technology and management can empower enterprises to extract greater value from their digital transformation. Take the integration of a big data platform, for instance, which necessitates complementing it with exceptional marketing decision-making capabilities. Similarly, a cloud computing platform should be seamlessly integrated with an enterprise's agile response mechanism.

In essence, businesses require a management framework that is deeply integrated with digital technology. Furthermore, they must integrate long-term sustainable development objectives into their management ideologies and practices. By harmonizing management expertise and digital innovations, companies can proficiently create economic, social, and environmental value throughout their operations. Clearly, during the digital transformation journey towards sustainable development, management prowess serves as a catalyst and holds the key to unlocking technological potential. Subsequently, we suggest the following hypothesis:

H_3: The greater an enterprise's management capability, the stronger its digital transformation's influence on sustainability development performance.

III. Research Design

This section initially presents the samples, details the data sources and explains the processing methods employed. Subsequently, it elucidates the measurement approaches for each variable, culminating in the design of a two-way fixed effects model that aptly fits the research context.

A. Sample and Data Source

The research sample is the enterprises that are classified as “transportation, warehousing, and postal industry” in the China Securities Regulatory Commission (2012 Revision). To ensure the integrity and credibility of the data, we implemented the following filtering criteria for the sample: (1) Companies listed with ST (Special Treatment) or ST* (Special Treatment and *ST, indicating potential delisting risk) from 2012 to 2021 were excluded; (2) Companies that underwent shell mergers to go public during the study period were identified and removed; (3) Companies with substantial data absences were eliminated. The primary sources for our dataset include financial data, keyword frequency data related to digital transformation, and regional economic development data, all drawn from reputable sources such as

China Stock Market & Accounting Research (CSMAR), RESSET, and corporate annual reports. To fill in the gaps, linear interpolation was employed for two employee educational data that were not publicly disclosed. ESG-related data were obtained from the East Money iFind Database. Ultimately, we assembled a balanced panel dataset consisting of 610 research samples, spanning 61 Chinese listed companies in the logistics industry from 2012 to 2021.

B. Variable Measurement

Dependent Variable

Sustainable development performance (Sdp). Sustainable development performance evaluates operational performance and enterprise's capacity to grow in an environmentally accountable manner. Drawing upon the studies of Jie et al. [35] and Wang et al. [29], this paper evaluates sustainable development performance as a composite of production and environmental outcomes [36]. The measurement method is constructed as equation (1):

$$\mathrm{Sdp} = [1 - |Env - Tfp|] \times \sqrt{Env \times Tfp}] / 1 \quad (1)$$

"Env" symbolizes an enterprise's environmental performance, assessed through the E-score data for each listed company developed by Sino-Securities Index Information Service. "Tfp" denotes production performance. This study employs the total factor productivity calculated through the Malmquist index method as the proxy variable for enterprise production performance [37][38]. The calculation procedure is as follows: first, set 2011 as the base year, assigning its total factor productivity to 1. Then, for each subsequent year, the Tfp is calculated by multiplying the Tfp of the previous year and the Malmquist index of that year [39].

TABLE I: CORRELATION ANALYSIS OF INPUT-OUTPUT INDICATORS IN THE MALMQUIST INDEX MODEL

Indicators	Total operating costs	Fixed assets	Employee compensation payable
Gross revenue	0.992***	0.916***	0.896***
Net profit	0.125***	0.143***	0.079**

Note: **, *** represent significance at the 5%, 1% levels, respectively.

This study selects indicators for the Malmquist index model from human and financial resources. The input indicators include the total operating costs, fixed asset investment, and employee compensation payable. The output indicators include the enterprise's total operating revenue and net profit. Drawing upon Zhang et al.'s [40] methodology, all data are divided by 10^9, and a power transformation is applied to the net profit using the base. The Pearson analysis result between input and output indicators is shown in Table I, aligning with the DEA model's requirement for a positive correlation between input and output indicators.

Core Explanatory Variable

Digital transformation (DT). Numerous scholars have employed various methodologies to quantify the enterprise's digital transformation. Some researchers utilize the ratio of digital-related intangible assets to gauge the degree of informatization within enterprises [41]. However, it is difficult to guarantee data integrity and may be influenced by conspicuous investments [42]. At present, a majority of researchers use the frequency of digital-related keywords in public reports as a measurement tool. Yuan et al. [43] initially identified related keywords from policy documents relevant to the digital economy. Zhao et al. [4] counted the keywords from four aspects: digital technology application, Internet business model, intelligent manufacturing, and modern information system, and developed a corporate digital transformation index using the expert rating method. Wu et al. [44] compiled an extensive list of keywords associated with digital transformation, encompassing aspects such as digital technology advancement and digital business scenarios. The assessment of digital transformation presented in this article is derived from CSMAR-sourced digitally-related data, where keywords are related to artificial intelligence, blockchain, big data technologies, and digital technology applications.

Mediator

Coordination and integration capability (CI). Exceptional coordination and integration capability significantly minimize inventory pileups, speed up the flow of goods and funds, and enhance information and logistics processes. The asset turnover rate not only serves as a crucial gauge for assessing asset management efficiency in logistics companies [45], but also reflects their resource integration capability and overall operational capability [46]. Aiming to accurately gauge the comprehensive efficiency in asset management and resource integration, this study employs the asset turnover rate as a proxy variable for logistics companies' coordination and integration capability [31].

Moderator

Management capability (MC). The management of an enterprise strengthens its grasp of the direction of technological development and the rational allocation of resources, which directly affects the efficiency of digital technology and the sustainable development. Adopting the perpetual inventory method proposed by Zhang et al. [47], organizational capital is employed to assess the management capabilities of a business, as detailed in the following calculation process:

$$MC_{it} = (1 - \delta_o) MC_{it-1} + \frac{SGA_{it}}{cpi_t} \quad (2)$$

In this method, i represents enterprise, t represents year. The initial organizational capital stock is calculated as follows:

$$MC_{i0} = \frac{SGA_{i1}}{g + \delta_o} \quad (3)$$

Where SG&A represents the cumulative sum of an enterprise's sales, general, and administrative expenses. cpi_t represents the consumer price index, with the data sources from the National Bureau of Statistics of China. Depreciation rate is represented by δ_o, while average real growth rate is denoted by g. According to Zhang et al., they are set at 15% and 10%, respectively.

Control Variables

The sustainable development of enterprises is influenced

TABLE II: VARIABLE SELECTION AND DEFINITION

Variable	Symbol	Measurement	Reference	Data Resource
Sustainable Development Performance	Sdp	Integrated Indicators of Environmental and Production Performance in Enterprises	Jie et al. [35]	---
Production Performance	Tfp	Calculated through the Malmquist index	Chen et al. [37]	CSMAR
Environmental Performance	Env	Environmental score in the Sino-Securities Index ESG Ratings	Wang et al. [29]	iFind
Enterprise Digital Transformation	DT	The frequency of keywords related to digital technology within annual reports.	Wu et al. [44]	CSMAR
Coordination and Integration Capability	CI	Asset turnover ratio	Li et al. [48]	CSMAR
Management Capability	MC	Capital stock measured through the Perpetual Inventory Method	Zhang et al. [47]	CSMAR
Employee Quality	Edu	The percentage of staff holding a bachelor's degree or higher.	Han et al. [49]	CSMAR
Government Subsidies	Gov	Government subsidies for the current period	Han et al. [49]	CSMAR
Region GDP	GDP	Regional GDP of the Enterprise	Gong [50]	CSMAR

by various pertinent factors. In this study, control variables include employee quality, government subsidies, and regional economic development level.

In summary, the proxy symbols, measurement methods, and data sources for each variable are shown in Table II.

C. Model Construction

The fixed effect model of the impact of digital transformation on enterprise sustainable development is constructed as Model (4):

$$Y_{it} = \alpha_0 + \alpha_1 X_{it} + \alpha_2 C_{it} + \sigma_{it} + \varepsilon \quad (4)$$

Where $Y_{it} = \{Sdp, Tfp, Env\}$ represents enterprise sustainable development performance, including sustainable development performance, total factor productivity, and environmental performance. $X_{it} = \{DT\}$ represents the dependent variable digital transformation. $C_{it} = \{Edu, Gov, GDP\}$ represents control variables, including employee quality, government subsidies, and regional GDP. α_0 is intercept term, α_1 and α_2 represents the regression coefficients of the core explanatory variables and control variables on the explained variables. σ_{it} represents the year and individual control effects, ε represents random disturbance terms.

In order to investigate the mechanism between digital transformation and the sustainable development performance of enterprises, this paper refers to the mediating effect testing method proposed by Wen et al. [51]. Model (5) shows the model of the mediating effect.

$$\begin{cases} Y_{it} = \alpha_0 + \alpha_1 X_{it} + \alpha_2 C_{it} + \sigma_{it} + \varepsilon \\ M_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 C_{it} + \sigma_{it} + \varepsilon \\ Y_{it} = \lambda_0 + \lambda_1 M_{it} + \lambda_2 X_{it} + \lambda_3 C_{it} + \sigma_{it} + \varepsilon \end{cases} \quad (5)$$

$M_{it} = \{CI\}$ represents the mediating variable, coordination and integration capability. α_0, β_0, and λ_0 are intercept terms. β_1 indicates the coefficient of the dependent variable on the mediator.

This paper constructs the model (6) for moderating effect. Where Z_{it} represents the enterprise management capability, and $Z_{it}X_{it}$ denotes the interaction between management capability and enterprise digital transformation.

$$\begin{cases} Y_{it} = \alpha_0 + \alpha_1 X_{it} + \alpha_2 Z_{it} + \alpha_3 C_{it} + \sigma_{it} + \varepsilon \\ Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 Z_{it} + \beta_3 Z_{it} X_{it} + \alpha_4 C_{it} + \sigma_{it} + \varepsilon \end{cases} \quad (6)$$

IV. Empirical Results Analysis

A. Descriptive Statistical Analysis

The equity structure, regional presence, and industry segmentation of 61 listed logistics companies demonstrate an uneven distribution. Table III provides detailed data on this aspect. Notably, state-owned enterprises dominate the sector, accounting for 90% of the total. Among the 61 companies, 41 of them are situated in China's eastern region. The road and water transportation sub-industries hold a significant stake, respectively, accounting for 41% and 33% of the total.

TABLE III: SAMPLE STATISTICS

Sub-industry	N	Regional Distribution	N	Equity Nature	N
warehousing	5	Eastern China	41	soe	55
road transportation	25	Central China	10	non-soe	6
aviation transportation	8	Western China	5		
maritime transportation	20	Northeast China	5		
railway transportation	3				

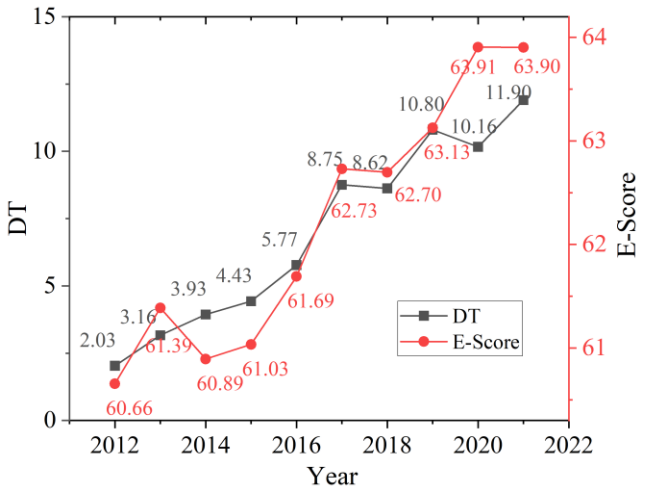

Fig. 1. Trend of digital transformation and E-score

As illustrated in Fig. 1, a comprehensive overview reveals that the average digital keyword count and E-score for sample enterprises have substantially increased from 2012 to 2021. Nonetheless, there have been minor declines in the digital transformation degree of logistics companies in 2018 and 2020, accompanied by a certain degree of E-score reduction in 2014, 2018, and 2021.

Fig.2 illustrates the distribution of the sample data, comprising 610 E-ratings. A significant 70% of the E-ratings, peaking at 10, consist of ratings 1 or 2. Among all ratings, the highest score of 5 appears only 15 times. This suggests a poor

environmental performance among logistics companies.

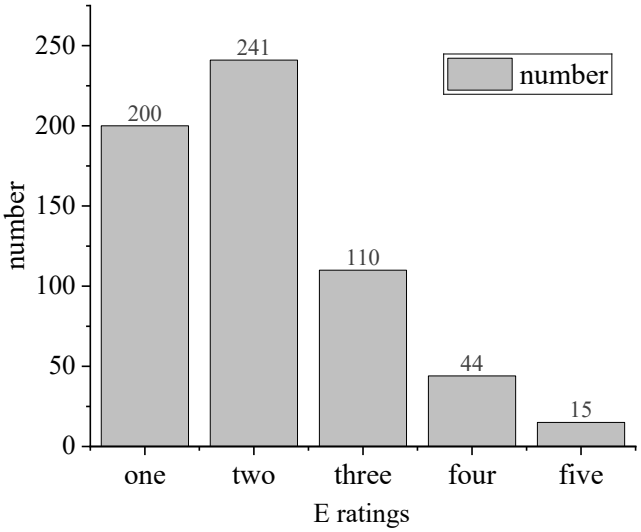

Fig.2. Distribution of Rating Data

Descriptive statistics were performed for each variable in Table IV. The mean of digital-related keywords frequency is 6.96, with a standard deviation of 13.5. This substantial variation indicates a wide disparity in digital transformation among logistics enterprises. 203 samples among the 610 had a word frequency 0 for digital-related words. The maximum frequency recorded is 145, achieved by Chutian Expressway in 2019.

TABLE IV: DESCRIPTIVE STATISTICS

Variable	Mean	Std. dev.	Min	Max
Sdp	0.16	0.05	0.00	0.59
Tfp	1.00	0.48	0.13	6.29
Env	62.20	5.76	46.35	79.30
DT	6.96	13.50	0.00	145.00
MC	3.24	8.56	0.03	53.24
Edu	27.28	16.13	1.42	94.44
CI	0.40	0.39	0.03	3.25
Gov	0.19	0.72	0.00	6.32
GDP	46755.69	30077.86	2855.54	124369.70

B. Basic Regression Results Analysis

A fixed-effect model is established to study the factors of the sustainable development performance in listed logistics enterprises. The regression findings are shown in Table V.

The digital transformation significantly promotes enterprises' sustainable development performance, with a statistical significance of 5%. This correlation is still statistically significant after the introduction of control variables. This finding is consistent with Wang et al. [29]. Thus, hypothesis H_1 is verified.

Employee quality is a key factor in a company's sustainable development performance, showing a statistical significance of 1%. Advanced knowledge structures can enhance production processes and boost overall productivity. On the other hand, government subsidies, at a 5% significance level, tend to hinder corporate sustainable development performance. Researchers like Han et al. [49] suggest that subsidies may exert a crowding-out effect on company R&D, potentially undermining internal motivations. This occurs because enterprises may prioritize securing government resources over allocating internal resources efficiently. Moreover, without government support, businesses may find it more difficult to address market fluctuations, industry changes, or other uncertainties.

TABLE V: RESULTS OF THE FIXED EFFECTS MODEL

Variables	Sdp	
DT	0.000473**	0.000405**
	(2.50)	(2.17)
Edu		0.000952***
		(4.18)
Gov		-0.0117**
		(-2.46)
GDP		-2.25e-7
		(-1.01)
year/individual FE	Yes	Yes
Cons	0.120***	0.109***
	(8.63)	(5.00)
R^2	0.479	0.478

Note: *, **, *** denote significance at the 10%, 5%, and 1% levels, respectively. T-values are given in parentheses, and the same convention applies throughout.

A significant relationship does not exist between regional economic development and the sustainable performance of a company. Success in sustainable development primarily depends on the strategies and actions implemented by businesses rather than being influenced by the economic status of the region in which they operate. Additionally, some studies indicate that digitalization exerts a spatial spillover effect on sustainable development, and that the regional mobility of logistics is robust [32]. This further reinforces the negligible impact of regional economic development on a company's sustainable development performance.

C. Robustness Check

The following steps are taken to assess the robustness of the regression results. Firstly, we remove specific data points. The A-share market collapse in 2015 potentially affected the operations and digital transformation of listed companies. As such, we exclude 2015 data for robustness testing, as shown in Table VI, column (1). Secondly, we modify the environmental performance indicator. Considering companies' value from an environmental, social, and governance perspective, ESG scores partially represent their sustainable development capabilities. Hence, we utilize ESG scores as a proxy for environmental performance in robustness testing, presented in Table VI, column (2). Finally, we separately regress production performance and environmental performance as dependent variables for further robustness testing. The results are presented in Table VI, columns (3) and (4). The above regression results outcomes align largely with the baseline analysis, indicating a reasonable degree of robustness in empirical discoveries.

By examining the regression analysis, we uncover that an elevated employee quality significantly enhances the enterprise's sustainable growth and operational efficiency. Nonetheless, it also negatively affects its environmental performance. This outcome can be attributed to the uneven distribution of highly educated talent across internal production and environmental sectors. With these talents being more densely concentrated in production-related areas, the proportion of these invaluable resources allocated to the environmental sector is proportionally reduced.

Government subsidies inhibit the sustainable development performance of logistics enterprises by a significant level of

5%. However, they are positive on environmental performance. One possible explanation is that most government subsidies for enterprises are invested in environmental protection and low-carbon activities. This investment inevitably occupies a certain portion of resources that could have been used for productivity growth, thereby inhabiting production performance.

TABLE VI: RESULTS OF THE ROBUSTNESS CHECK

Variables	(1) Sdp	(2) Sdp	(3) Tfp	(4) Env
DT	0.000535** (2.36)	0.000391** (1.97)	0.00440** (2.53)	0.0352** (2.34)
Edu	0.00129* (4.68)	0.00102*** (4.04)	0.00825*** (3.89)	-0.0418** (-2.27)
Gov	-0.00991* (-1.73)	-0.0114** (-2.33)	-0.0562 (-1.28)	0.940** (2.46)
GDP	-3.15e-07 (-1.16)	-2.57e-07 (-1.09)	-1.09e-6 (-0.52)	-6.53e-06 (-0.36)
year/individual FE	Yes	Yes	Yes	Yes
Cons	0.0862 (3.26)	0.109*** (4.65)	0.455** (2.24)	62.596 (35.59)
R^2	0.480	0.515	0.467	0.719

D. Mediating and Moderating Effects Testing

We investigate the mediating effect of coordination and integration ability between digital transformation in enterprises and sustainable development performance. Table VII, column (1) shows that digital transformation enhances enterprises' ability to coordinate and integrate. Column (2) reports the result of the mediating effect of coordination and integration capability. The results implies that asset turnover plays a positively promoting role in the impact of digital transformation on sustainable development performance. Hypothesis H_2 is confirmed. Digitalization empowers enterprises to enhance their adaptability and versatility in external environments by refining resource allocation and strategic decisions. Through efficiently consolidating internal resources and deeply absorbing cutting-edge knowledge, digital transformation can encourage eco-friendly innovation and sustainable restructuring, ultimately leading to improved sustainable development performance.

TABLE VII: RESULTS OF MEDIATING AND MODERATING EFFECTS TESTING

Variables	(1) CI	(2) Sdp	(3) Sdp	(4) Sdp
DT	0.00249*** (3.08)	0.0170* (1.71)	0.000059 (0.3)	-0.000418* （-1.92）
CI		0.000363* (1.93)		
MC			0.000110 (0.13)	0.00524* (1.74)
MC×DT			0.000173*** (4.86)	0.000562*** (5.76)
MC^2				-0.0000558 (-1.20)
MC^2×DT				-0.0000132*** (-5.02)
Cons	0.117 (1.24)	0.107*** (4.91)	0.107*** (5.03)	0.0966*** (4.65)
Control	Yes	Yes	Yes	Yes
year/individual FE	Yes	Yes	Yes	Yes
R^2	0.823	0.502	0.521	0.554

The moderating effect test result for enterprise management capability is shown in column (3) of Table VII. The interaction between management capability and digital transformation positively enhances sustainable development performance at the 1% significance level. Hypothesis H_3 is confirmed. Management capability serves as a catalyst between digital investment and high sustainable development performance. In essence, management capability fosters a seamless integration of digital technology and high sustainable development performance.

This study employs the slope analysis method to visualize the moderating effect. As depicted in Fig. 3, the moderating effect of management capability exists between digital transformation and sustainable development performance. Low management capability hinders sustainable development success during the digital transition, but high management capability enhances it.

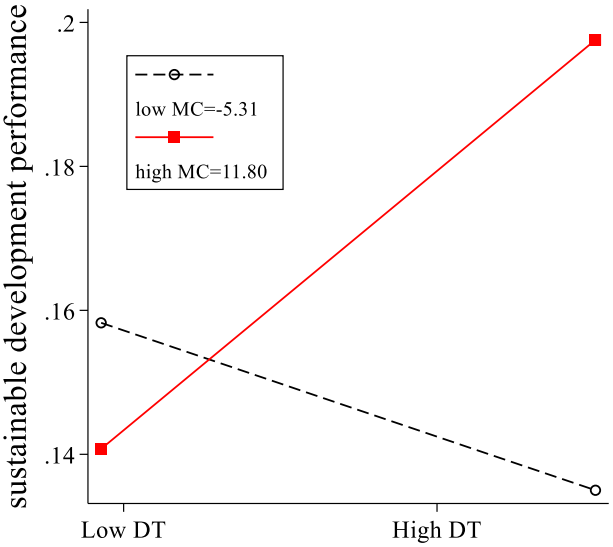

Fig. 3. Diagram of the moderating effect

This paper delves deeper into the nonlinear moderating effect of management capability. Based on the original moderating effect testing, the interaction term between the core explanatory variable and the square term of the moderator is introduced. Finally, a corresponding moderating effect test model is constructed, as shown in model (7).

The results of Model (7) are displayed in Table VII, column (4). At a significance level of 1%, the coefficient of the first-order interaction term is positive, while the coefficient of the second-order interaction term is negative. Which means the relationship between digital transformation and sustainable development performance follows an inverted “U”-shaped curve, with management capability serving as the regulatory factor.

$$\begin{cases} Y_{it} = \alpha_0 + \alpha_1 X_{it} + \alpha_2 Z_{it} + \alpha_3 C_{it} + \sigma_{it} + \varepsilon \\ Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 Z_{it} + \beta_3 Z_{it} X_{it} \\ \quad + \beta_2 {Z_{it}}^2 + \beta_3 {Z_{it}}^2 X_{it} + \alpha_4 C_{it} + \sigma_{it} + \varepsilon \end{cases} \tag{7}$$

That is, the regulatory effect does not always increase with the rise in resource input, but there is an inflection point. Within a specific range, management capability's moderating effect increases with the rise in management capability. The regulatory effect weakens once it reaches a specific threshold with increasing management capability. Overinvesting in management could result in imbalanced capital allocation and restrict enterprises' resource allocation for digital

transformation. High management capability may generate a "crowding-out effect," which can impede digitalization progress and the enhancement of sustainable development performance. Therefore, it is crucial to maintain a balanced management capability within an enterprise.

V. Further Analysis

A. Heterogeneity Testing

This study conducts a comprehensive analysis of enterprises based on their varying equity nature, size, and age. Firstly, the sample companies are categorized into state-owned enterprises and non-state-owned enterprises. Comparing the results in Table VIII, columns (1) and (2), respectively, the promotional effect of non-state-owned logistics enterprises is higher than that of state-owned logistics enterprises. The primary reason is that state-owned enterprises typically encounter numerous administrative approvals and inspections when implementing digital technologies. Moreover, their operations are heavily governed by the government, resulting in limited flexibility in resource allocation. This ultimately leads to decreased decision-making efficiency and constrains the potential of digital technology. In contrast, non-state-owned enterprises possess adaptable and responsive operational frameworks, enabling them to fully leverage their strengths in digital transformation.

Based on the median value of corporate total assets, the samples are categorized into large-size companies and small-scale enterprises, which are subsequently analyzed using the fixed-effects model. The heteroscedasticity testing results are shown in Table VIII, columns (3) and (4). Digital transformation positively promotes the sustainable development performance of large-size logistics enterprises at a 1% significance level, while its impact on smaller logistics enterprises is insignificant. The overriding factor is that as enterprises expand, they control increasingly more resources and specific assets, resulting in a richer data resource pool. This equips them with superior conditions for executing digital and environmental projects systematically. Moreover, large enterprises possess abundant human capital, complex operations, and broad management scope. Digital technology can effectively integrate data and enterprise resources, significantly enhancing efficiency. This collective impact makes it simpler for large enterprises to accomplish environmental and sustainable development objectives through digital transformation.

The samples are also divided into older enterprises and younger enterprises by comparing them with the median value. The results are shown in Table VIII, columns (5) and (6). The results of the heterogeneity test indicate that digital transformation has a significant positive effect in older logistics enterprises at the 5% significance level. However, this effect is not significant in younger companies. One possible explanation is that, in contrast to younger counterparts, older logistics enterprises have accumulated rich market and industry experience and formed their own relatively stable business model and management system that allows them to adapt more effectively to changing market trends. As a result, under the low-carbon strategy, older logistics companies are better positioned to take the lead to improve their sustainability performance by using digital resources. Younger companies, who are still in the development stage, are more likely to focus on improving financial performance.

B. Survival Analysis

Regression analysis mainly explores the relationship between dependent variables and independent variables. It focuses on the magnitude and orientation of each factor's impact on the results. This paper conducted a comprehensive examination of influence mechanism, temporal differences still deserve further exploration. How do logistics companies at varying digital transformation stages differ in their time taken to achieve a specific level of sustainable development performance? Additionally, what are the disparities in the duration required for companies of different types to reach a similar level of sustainable performance? Survival analysis provides a time-based perspective, examining the duration differences for various logistics companies to reach a certain level of sustainable performance. Subsequently, this paper will investigate this issue by employing the survival analysis model.

First, the survival time of an enterprise is defined as the duration from the beginning to the point at which it reaches a certain level of performance. The virtual variable "dead" is constructed. If the performance exceeds the predetermined threshold level in the period t, the value of "dead" is set to "1". Otherwise, "0" is adopted.

TABLE VIII: RESULTS OF HETEROSCEDASTICITY TESTING

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	soe	non-soe	large-size	small-size	older	younger
DT	0.000440**	0.000454**	0.00302***	0.000200	0.000733**	7.87e-06
	(1.96)	(2.12)	(3.15)	(1.34)	(2.3)	(0.04)
Edu	0.000947***	-0.00211	0.00111*	0.0000995***	0.00156***	0.000155
	(3.98)	(-1.39)	(1.77)	(4.87)	(4.1)	(0.6)
Gov	-0.01200**	0.0353	-0.0150**	-0.0369	-0.0174**	-0.00237
	(-2.45)	(0.31)	(-1.97)	(-1.04)	(-2.57)	(-0.37)
GDP	-2.12e-07	-1.35e-07	-5.81e-07	-2.62e-07	-2.75e-07	-2.57e-07
	(-0.85)	(-0.39)	(-0.72)	(-1.35)	(-0.79)	(-0.95)
Cons	0.106***	0.167***	0.0929*	0.0110***	0.0929***	0.117***
	(4.52)	(10.11)	(1.84)	(6.30)	(2.92)	(5.04)
year/ individual FE	Yes	Yes	Yes	Yes	Yes	Yes
sample size	550	60	160	450	300	310
R^2	0.484	0.795	0.510	0.594	0.494	0.518

Next, the survival function is constructed to describe the distribution characteristics of enterprises' survival time. It is defined as the probability that the survival duration exceeds t years. This can be mathematically stated as:

$$S_i(t) = \Pr(T_i > t) = \prod_{l=1}^{t}(1 - h_{il}) \quad (7)$$

Formula (7) represents the duration it takes for an enterprise i to reach a certain level of performance. h_{il} indicates the probability that the enterprise does not attain the performance level in period $l-1$, but does achieve it in period l.

$$\hat{S_i}(t) = \prod_{l=1}^{t}(N_l - D_l)/N_l \quad (8)$$

The survival function non-parametric estimator obtained by Kaplan-Meier product term, which can be expressed as Formula (8).

N_l represents the number of enterprises that are at risk during period l. D_l represents the number of enterprises that reach the set performance level in period l.

This paper calculates the average digital transformation of each enterprise from 2012 to 2021. Samples are divided into two groups based on their level of digital transformation by comparing them to the median: the high digital transformation group (DT=1) and the low digital transformation group (DT=0). The Kaplan-Meier survival curve that plots the survival time of the two groups is shown in Fig. 4. A notable observation is that the Kaplan-Meier survival curve for enterprises with higher digital transformation tends to be lower than that of those with lower digital transformation. This revelation suggests that enterprises with a more advanced digital transformation are capable of reaching a specific performance level in a shorter duration. Logistics enterprises, for instance, leverage cutting-edge digital technologies to swiftly enhance operational efficiency and minimize environmental impact. This expedites the organization's sustainable development process, enabling the achievement of anticipated sustainable development performance within a truncated timeframe.

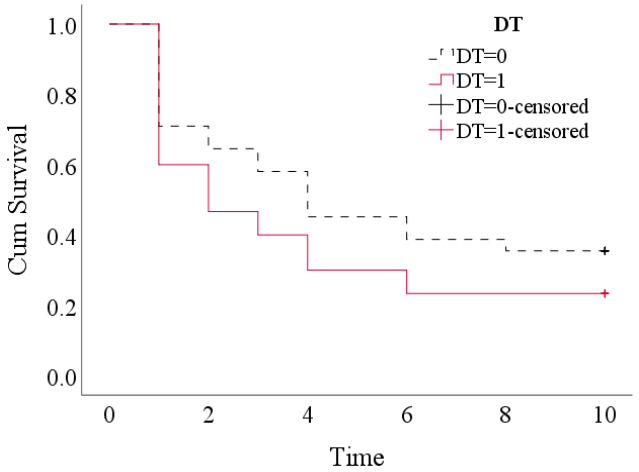

Fig. 4. Kaplan-Meier curves of different digital transformation

The logistics companies examined in this research are categorized into state-owned (soe=1) and non-state-owned (soe=0). As illustrated by the Kaplan-Meier curve in Fig. 5, state-owned logistics enterprises achieve a specific level of sustainable development performance in a shorter timeframe compared to their non-state-owned counterparts. This is primarily due to their substantial advantages in internal and external resources, coupled with more stringent monitoring and evaluation of sustainability-focused projects. This enables state-owned logistics enterprises to enhance their sustainability performance at a faster pace. Conversely, while non-state-owned logistics enterprises enjoy greater flexibility and innovation, they might confront limitations in internal and external resources, as well as heightened corporate survival challenges. These factors contribute to a longer duration for achieving the desired sustainable development performance.

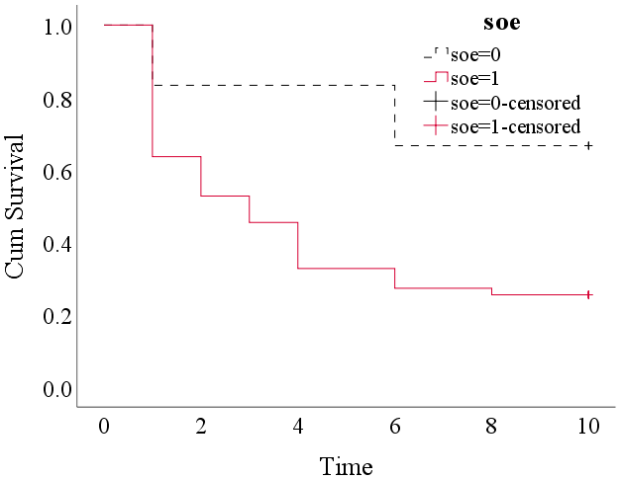

Fig. 5. Kaplan-Meier curves of different ownership

VI. Discussion And Implications

A. Discussion

Digital transformation serves as a crucial resource for logistics enterprises. This research affirms the contribution of digital transformation to enhancing sustainable development performance, aligning with the findings of Wang et al. [29]. By applying the RBV to the digital transformation field, this paper provides additional theoretical support for digital transformation to promote the sustainable development performance of logistics enterprises.

We explored the value of coordination and integration capability and constructed a theoretical framework of "digital transformation—coordination and integration capabilities—sustainable development performance", which is a useful extension of dynamic capability theory within the framework of digitalization. The flow of materials, goods, and information constitutes critical components in the operations of logistics enterprises. With the ongoing development of the industry, logistics enterprises have progressively evolved from mere transporters of goods to entities that create value within the supply chain [52]. Consequently, there is a growing need for enterprises to coordinate and integrate diverse information and resources. As a key production factor, digital technology is essential in realizing the advantages of integration. [53]. The broad sharing of logistics information between enterprises guarantees that materials or products are delivered to

customers promptly and accurately. [54]. The coordination of logistics activities enhances the production planning process, thereby reducing inventory costs and increasing customer satisfaction [55]. Furthermore, integrating cargo supply chain information significantly enhances the flexibility of the supply chain, which is crucial for enterprises to manage uncertainties arising from environmental factors [56]. Additionally, logistics companies can integrate green supply chains. They achieve minimize environmental impact and promote environmental sustainability by real-time tracking, data-informed decision-making, and flawless coordination among partners [57].

Using organizational capital as a proxy variable for enterprise management capabilities in this paper is highly significant. The importance of organizational capital permeates the entire process of enterprise production and operation. Scholars generally agree that organizational capital positively impacts enterprise production efficiency [58] and sustainable development performance [59]. However, this paper presents a novel finding regarding the role of management capabilities: during the digital transformation that enhances the sustainable development of logistics companies, management capabilities exhibit an inverted “U”-shaped moderating effect. On the one hand, investing in organizational capital enables logistics companies to foster stronger relationships with employees, customers, and suppliers [60], thereby alleviating corporate information asymmetry and promoting performance growth [61]. However, logistics companies must recognize the limitations of their assets and resources. An overabundance of organizational capital can impede digital transformation efforts and limit the sustainable development of the company. The findings expand the theoretical framework of digital transformation and offer a novel perspective on how enterprises can achieve sustainable development through digital transformation.

Both the production performance and environmental performance are critical metrics for corporate development. However, a potential conflict or "trade-off" may exist between the two, as enhancing production could overlook environmental impacts, while emphasizing environmental protection might adversely affect production efficiency [62]. This issue has seldom been addressed in existing literatures. Some scholars have directly analyzed the various impactors on environmental and financial performance [63]. In order to achieve more thorough and detailed research results, this paper explores not only the influencing factors of the composite variable but also disaggregates it into two dimensions—production performance and environmental performance, for separate analysis. We found that factors such as employee quality and government subsidies have distinct effects on production and environmental performance, this approach offers new perspectives for researching the sustainable development of enterprises.

B. Practical Insights

The main focus of this paper is to investigate how digital transformation in logistics enterprises affects their sustainable development performance and the mechanisms underlying this influence. Furthermore, it performs moderating effect and heterogeneity assessments. The following practical insights are derived from our findings:

First of all, logistics companies should clarify the digital transformation goals and formulate detailed transformation strategies. By actively promoting the digital platforms construction and technological innovation, they can ensure that the digital foundation is reliable for transformation. To ensure the successful implementation of the digital transformation strategy, logistics companies should also strengthen digital knowledge training and management for employees. Such as actively formulate digital talent training plans, clarify training goals and content. They should also offer employees opportunities for training and learning, while encouraging them to explore new methods and technologies.

Second, logistics enterprises must dynamically adopt diversified digital transformation strategies. State-owned logistics companies, typically equipped with abundant human resources and financial backing, would benefit from optimizing these resources to facilitate comprehensive digital transformation. Simultaneously, these enterprises should prioritize streamlining decision-making processes to swiftly respond to market demands. Non-state-owned logistics enterprises should harness their flexibility and ingenuity relentlessly. They can dynamically address customer requirements and enhance service excellence by embracing innovative technologies and digital solutions. Mature logistics enterprises usually have complex internal systems and processes. They can establish a unified information platform that integrates data and processes from various departments, enabling information sharing and collaborative efforts. Correspondingly, to enhance operational efficiency and customer satisfaction, developing logistics enterprises should focus on addressing key pain points and challenges that affect core businesses. They can choose digital solutions that are more adaptable and cost-effective, such as cloud computing and Software as a Service (SaaS). It is also a wise choice to cooperate and share resources with other organizations or technology providers to reduce the cost and risk of digital transformation. Meanwhile, it is crucial to note that digital technology is an ever-evolving field. To stay ahead of the curve, logistics companies must continually update their digital strategies in response to technological advancements and industry fluctuations.

Third, logistics enterprises should strengthen the construction of coordination and integration capability. Achieving sustainable development in these enterprises depends not solely on the adoption of digital technologies, but also on the intensification of internal coordination and integration. In the first place, logistics firms should leverage digital transformation to enhance the utilization of existing data resources, thereby optimizing internal management and improving service quality. Furthermore, logistics companies can carry out specialized division of labor and cooperation with partners such as professional logistics service providers or technology companies. This allows them to fully leverage external expertise and resources, thereby enhancing their competitiveness. Ultimately, logistics enterprises should improve resource allocation, management systems, and technological implementations to augment their company's capacity for sustainable development.

Fourth, logistics enterprises should operate resources in a

rational and efficient manner while optimizing their management systems. Digital transformation and competent business management are two vital strategies that modern enterprises employ to enhance their competitive edge. Digital transformation enables enterprises to operate and innovate more efficiently. Simultaneously, proficient business management promotes optimal resource allocation and improved organizational functioning. Logistics companies can establish a feedback mechanism to continuously improve and adjust resource allocation strategies in a timely manner based on performance. By implementing contemporary management tools and techniques, enterprises can assess their current management processes. This enables them to adjust their management systems accordingly and amplify their economic and environmental advantages.

Fifth, it is crucial for the government to enhance the policy framework and develop relevant infrastructure to drive digital progression. Digital transformation represents a high-barrier investment project, serving as a significant impediment for numerous logistics enterprises seeking to undergo this transition. To address this, the government can take twofold measures. First, it can bolster legal protection and institute relevant incentive policies. For instance, enhancing data privacy protection measures, minimizing enterprise data breach risks, and establishing a favorable policy backdrop for corporate digital transformation. Second, the government can construct an efficient data-sharing platform that collects social production, retail, logistics, transportation, and other industry data. The platform can provide data query and support services for logistics enterprises in accordance with policy requirements, so as to reduce enterprise data acquisition costs.

C. Research Conclusions

This study focuses on an in-depth analysis of 61 listed logistics companies over the period from 2012 to 2021. It employs the DEA-Malmquist and fixed effect models to investigate how digital transformation influences the sustainable development of logistics enterprises. The key findings of this study can be encapsulated as follows:

First, digital transformation significantly enhances the sustainable development performance of logistics companies. This correlation remains strong even after considering control variables and enduring robustness tests. Enterprise digital transformation fuels long-term growth and progress. Furthermore, the caliber of employees positively contributes to production performance, but negatively impacts environmental performance. Government subsidies significantly promote environmental performance but do not significantly impact production performance.

Second, the mediating effect test found that the ability to coordinate and integrate is an essential path to improve enterprises' sustainable development performance through digital means. Management capability moderates the impact of digital transformation on enterprise sustainable development performance in an inverted "U"-shape. When an enterprise's management capability reaches a certain level, digital transformation can unlock its full potential in boosting sustainable development performance.

Third, according to the heterogeneity testing, digital transformation exerts a greater positive impact on non-state-owned logistics enterprises compared to state-owned ones. The role of digital transformation in promoting sustainable development performance is significant in larger-scale enterprises and older enterprises, while it is not significant in small-scale logistics and younger enterprises. Survival analysis found that compared with logistics enterprises with low levels of digital transformation and non-state-owned logistics enterprises, respectively, high levels of digital transformation and state-owned logistics enterprises can achieve sustainable development performance goals in a shorter time.

D. Limitations and Further Research

This study has conducted an insightful investigation into how digital transformation enhances the sustainable development performance of logistics enterprises. However, there are still certain deficiencies that require further improvement and refinement in future research.

Firstly, this research delves into the mediating influence of coordination and integration capability on the link between digital transformation and sustainable development performance. Nonetheless, other potential impact pathways may exist between these two factors. Future studies could aim to reveal the mechanisms of influence from the angles of dynamic capability, technological innovation, and industrial upgrading, thereby providing more comprehensive strategic guidance for logistics enterprises.

Secondly, this study meticulously identifies a comprehensive set of control variables spanning employee quality, government subsidies, and regional economic conditions. The sustainability performance of logistics enterprises is determined by numerous intricate factors during their transformation process. Future investigations can delve into the effects of additional control variables, including industry competition, industry concentration, and corporate equity concentration, to offer more targeted guidance for enterprises navigating digital transformation under varying circumstances.

Thirdly, this paper identifies the differing impacts of various influencing factors on production performance and environmental performance, and subsequently analyzes the obstacles faced by logistics companies in achieving sustainable development. Future research is suggested to identify additional internal and external influencing factors and thoroughly examine their distinct effects on sustainable development performance, environmental performance, and production performance. This will facilitate the exploration of strategies and methods to enhance the sustainable development of enterprises.

Finally, the sample data in this article is derived from logistics firms that are publicly listed in China. Expanding the sample source in the future will enhance studies in the logistics business. For example, non-listed logistics enterprises can be included to improve the robustness of this study further. Additionally, the research scope could also be broadened to a global level. By using sample data from logistics enterprises in different countries and regions, we can conduct further tests of the model to investigate regional variations.

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