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How Digital Transformation Enables Corporate Sustainability: Based on the Internal and External Efficiency Improvement Perspective

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Abstract: The promotion of the simultaneous advancement of digitalization and sustainability has emerged as a crucial concern for achieving high-quality economic growth within the framework of the ‘dual-carbon’ objective. Based on the micro data of Chinese A-share listed companies between 2009 and 2022, this paper systematically examines how digital transformation affects the ESG performance of enterprises in order to explore the effective path for digitalization to promote the sustainable development of enterprises. The results indicate that implementing digital transformation can enhance the ESG performance of enterprises, which in turn boosts their capacity for sustainable development. The test of the mechanism indicates that enhancing internal total factor productivity and optimizing external financial allocation efficiency are the key strategies for driving ESG performance improvement in companies through digital transformation. Further analysis reveals that the improvement effect of digital transformation on corporate ESG performance is more prominent in state-owned enterprises, non-heavily polluted industries, central and western, and low-marketization regions. In addition, while digital transformation enhances the ESG performance of enterprises themselves, it also creates beneficial ripple effects on the ESG metrics of their suppliers and customers, ultimately boosting the sustainable growth of the entire supply chain. The conclusions of this paper help to deepen the potential value of digital transformation and provide policy and practical insights for achieving sustainable economic development.

Keywords: digital technology; ESG performance; total factor productivity; financial allocative efficiency; spillover effects



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1. Introduction

Environmental emissions from production systems, particularly agriculture, livestock, and industrial sectors, are the main reason for the increase in global temperature [1–3]. In recent years, the rapid changes in global temperatures and the frequent occurrence of extreme weather events have posed serious challenges to economic and social development [4]. To address the significant effects of climate change and environmental degradation, the promotion of sustainable economic development has become a necessary means and method [5]. Serving as a key element in economic development, the sustainable development of enterprises is an important prerequisite and guarantee for the realization of the whole-economy sustainable development [6]. Meanwhile, as a novel approach, ESG practice evaluates the comprehensive performance of enterprises from three dimensions of environment, society, and governance, which cannot only encourage businesses to proactively engage in eco-friendly changes and advancements but also provide incentives for green transformations through market-driven governance methods [7]. Therefore, it helps enterprises practice sustainable development in an effective manner and is a necessary way for them to achieve high-quality development. However, at this stage, most enterprises still have weak ESG awareness [8], insufficient ESG information disclosure, and low ESG ratings [9,10],

which greatly hinders the sustainable growth of these enterprises. Consequently, how to effectively enhance the ESG performance of businesses and increase their development resilience is of great practical significance for coping with the global climate crisis and realizing green and sustainable development.

Accompanied by the continuous advancement of the new round of digital technological change, digital technology and the real economy have gradually achieved in-depth integration, constantly promoting digital industrialization and digital transformation of industries and serving as a crucial catalyst for enhancing the economy's high-quality growth [11]. As the important micro foundation for the real economy, enterprises carry the important function of digital transformation for the real economy, and digital transformation is gradually integrated into the specific changes in the production behavior of enterprises, making micro enterprises undergo subversive changes from the inside out [12]. Through the in-depth application of digital technology, the previous backward production methods and business models of enterprises have been re-structured and replaced by a production and operation system in which the flow of information is highly efficient, and innovation is fully stimulated, which helps to optimize resource allocation and release the potential of factors [13]. This fundamental reshaping of the information structure, management style, and operation mechanism will inevitably bring new resources and capabilities to enterprises [14]. So, can digital transformation help enterprises create integrated value covering the environment, economy, and society while bringing profound changes to enterprises and, thus, provide them with a continuous sustainable development capability? Although the existing literature has provided evidence support for the relationship between the two in terms of the level of green innovation [15], the quality of information disclosure [16], and external market concerns, respectively [17], there is a gap in the literature regarding the effects of digital transformation on both internal and external efficiency. This gap calls for a unified framework that considers the changes brought about by digital transformation to fully understand its role in enhancing the sustainable development of enterprises.

In view of this, after using the micro data from China's A-share listed companies between 2009 and 2022, this paper employed a panel fixed-effects model to systematically examine the impact and mechanism of digital transformation on corporate ESG performance on internal productivity enhancement and external financial support, respectively. The goal is to identify effective strategies for using digital technologies to drive green and sustainable growth in businesses. Compared with the previous literature, there are three aspects of marginal contributions that can be summed up as follows. Firstly, with the internal and external efficiency improvement brought by digital transformation as the main line, the internal total factor productivity and external financial allocation efficiency of enterprises are respectively included in a unified analytical framework to assess the role of digital transformation on corporate ESG performance, which helps to deepen the understanding of the ESG performance of enterprises driven by digital transformation. Thus, the research framework on the connection between digital transformation and corporate ESG performance is expanded. Secondly, the heterogeneous impact of digital transformation on corporate ESG performance will be explored from the levels of ownership attributes, industry attributes, and regional attributes. This will help to shed light on the impact of digital transformation on corporate ESG performance, which in turn provides directional guidance for promoting better ESG practices among corporations. Thirdly, on the basis of fully examining the impact of digital transformation on enterprises' own, this paper expands the scope of research to the upstream and downstream enterprises in the supply chain in order to examine how digital transformation impacts the ESG performance of these companies, which effectively expands the research boundaries of the economic consequences of digital transformation.

The rest of this document is organized as follows: a review of the research hypotheses is presented in Section 2, the research model and sample composition are described in Section 3, and the results of empirical tests are presented in Section 4. Afterwards, further

research is discussed in Section 5, and the relevant policy recommendations are presented in Section 6.

2. Research Hypotheses

2.1. The Impact of Digital Transformation on Corporate Sustainability

When entering the new stage of development, enterprises should not only improve the efficiency of operation and management in order to achieve profitability but also enhance the quality of their own development and maintain the long-term sustainability of their development [18]. ESG performance is a comprehensive evaluation of corporate development from the three dimensions of the environment (E), society (S), and governance (G), which is an important criterion for measuring corporate sustainability at present [19]. The digital economy has grown exponentially in recent years, and companies have witnessed profound changes in their production and operation processes due to digital transformation, which will effectively improve the financial performance of enterprises and at the same time lead to better ESG performance [20]. Overall, digital transformation mainly affects resource integration and information transfer and empowers the ESG performance of enterprises. Primarily, digital transformation promotes the integration of digital technology with various production processes of enterprises, promotes the optimization and reorganization of resources from design and R&D to product manufacturing, improves the efficiency of resource utilization of enterprises, and helps enterprises to achieve better outputs on the basis of existing resources, thus improving the innovation capability of enterprises [21]. At the same time, digitalization also accelerates the sharing and exchange of internal information resources with the outside world, generating information sharing and knowledge integration effects, which help enterprises and external enterprises to form an innovative knowledge co-creative network and further enhance the level of the enterprise's innovation capability [22]. As innovation ability is the core driving force for entrepreneurial sustainability, it can not only promote the transformation of the development mode of enterprises, thus improving the performance of enterprises in energy saving and emission reduction, but also promote the adjustment of production and operation management of enterprises in accordance with the needs of social development, thus improving the ability to fulfill the social responsibility of enterprises [23]. In addition, it can also reduce the marginal cost of production, increase the level of return on innovation, and further enhance the level of corporate governance of enterprises [24]. Conversely, digital transformation improves the efficiency of the use and delivery of corporate information, increasing its quality and availability [25]. High-quality information can effectively convey the objective performance of environmental, social, and governance aspects, which can accurately quantify the efforts made by enterprises to achieve sustainable development and reduce the information discrepancy between enterprises and the outside [26]. Reduced information asymmetry increases the attention of third parties to the enterprise, such as the media and the public [27], and the management will be pressured to take more proactive measures to avoid negative news on environmental and social responsibility to the enterprise's stock price and market value, which will lead to better energy conservation and emission reduction and fulfillment of social responsibility [28]. In addition, the reduction of information asymmetry will also increase the attention of stakeholders to the enterprise, making the external stakeholders obtain information on the enterprise's operation and development easier and more efficient, reducing irrational decision-making behavior of the management, thus achieving more effective supervision of the enterprise's operation and development, and effectively improving the enterprise's corporate governance capacity [29]. To summarize, digital transformation effectively improves the efficiency of enterprises in terms of the environment, social accountability, and corporate governance, and improves the sustainable development ability of enterprises. Therefore, we put forward Hypothesis 1.

Hypothesis 1 (H1). *Digital transformation can effectively improve the ESG performance of companies and enhance their sustainability.*

2.2. Digital Transformation, Total Factor Productivity Improvement, and ESG Performance

The analysis above demonstrates that digital transformation enhances the ESG performance of businesses through resource integration and information transmission. However, it is worth noting that combining resources efficiently and promptly sharing information can bring about changes in the internal productivity and external financial allocation efficiency of enterprises, which in turn influences their ESG performance.

Specifically, for enterprises internally, digital transformation improves the mobility of data, improves the distribution structure of factors on production, and ultimately boosts total factor productivity, thus providing an important source of internal power for enterprises to carry out ESG practices. Driven by technologies such as big data, blockchain, artificial intelligence, and cloud computing, the data production factors are applied to the production process of enterprises, which can accelerate and promote the flow and integration of factors in all aspects of the enterprise, enhancing the overall allocation of production resources and ultimately boosting total factor productivity [30]. Furthermore, digital technology can facilitate the flow of data throughout the entire production process of a company, enabling seamless connectivity between upstream and downstream supply chain information. This allows for precise coordination and efficient alignment of supply and demand, leading to a significant enhancement in the speed of meeting market demands for the company [31]. Ultimately, this results in the establishment of a highly effective collaborative mechanism for allocating supply chain resources, thereby boosting operational efficiency and ultimately enhancing the total factor productivity of the enterprise [32]. Improving the overall efficiency of businesses can enhance their capacity for eco-friendly innovation and refine their approach to eco-friendly innovation [33,34]. This can prompt businesses to transition from the conventional high-input, high-energy consumption, and high-pollution production methods to a new model focused on high efficiency, low carbon emissions, and environmental preservation. Additionally, it can boost the environmental management performance of businesses, ultimately reducing their environmental footprint in terms of input, production, and emissions [35]. Simultaneously, the overall efficiency of businesses aids in minimizing resource wastage, thereby offering the necessary resources for meeting social obligations and encouraging businesses to actively engage in social responsibility initiatives [36]. In addition, the increase in total factor productivity can also inspire enterprises to take the initiative to change their business models and improve their cooperation with stakeholders, thus promoting the process of service-oriented transformation of enterprises and, in turn, encouraging enterprises to better fulfill their social responsibility [37]. Enhancements in overall factor productivity can lead to better financial outcomes for businesses, ultimately decreasing irrational decision-making by management, mitigating agency conflicts between management and shareholders, and enhancing corporate governance within companies [38]. In summary, digital transformation can enhance overall productivity, resulting in better environmental protection, fulfillment of social responsibilities, and improvement of corporate governance capabilities, ultimately serving as a sustainable driver for a company's ESG performance. In light of the aforementioned considerations, we put forth Hypothesis 2.

Hypothesis 2 (H2). *Digital transformation improves the ESG performance of companies by increasing internal total factor productivity, which indicates that the improvement of internal total factor productivity plays an important intermediate channel in the process of digital transformation affecting firms' ESG performance.*

2.3. Digital Transformation, Financial Allocation Efficiency Improvement, and ESG Performance

Digital transformation can enhance finance allocation efficiency at the enterprise level by decreasing information asymmetry, facilitating the flow of financial resources to more efficient enterprises, alleviating financing constraints, and ultimately offering external financial support for ESG performance, unlike the internal aspect of businesses. For a long time, the financing structure of Chinese enterprises has been dominated by indirect

financing based on bank credit, and the development of direct financing channels such as equity financing has been relatively insufficient, resulting in a subjective reliance on debt financing, while the over-reliance on the indirect financing model has also resulted in the structural problem of financial allocation, with a large amount of credit capital flowing into sectors or enterprises with low output efficiency [39]. On the contrary, sectors and enterprises with higher output efficiency are unable to obtain the financial support needed for development and face the difficulties of financing and expensive financing, resulting in the overall formation of financial allocation inefficiency and the emergence of a financial mismatch phenomenon [40]. As can be seen from the relevant theories on credit allocation, the failure to allocate finance in accordance with the principle of efficiency has seriously weakened the capacity to serve the real economy for financial services, resulting in a large number of enterprises with high investment opportunities and high growth opportunities facing serious financing constraints [41]. As capital is the lifeblood of an enterprise, when enterprises face financing constraints that result in tight capital flows, they will pay less attention to projects that require long-term investment to generate returns, such as green innovation, social responsibility, and corporate governance, thus hindering the improvement of their ESG performance [42]. However, with the advancement of digital transformation, the application of digital technology has greatly improved the internal and external information processing capabilities of enterprises, which can effectively break down the information barriers between enterprises and external investors, and external investors can easily obtain information about the operating conditions and risks, and assess the ability and willingness of repayment, so as to realize the accurate portrait of enterprise [43]. Thus, it can be observed that the information asymmetry between external financial institutions and enterprises has greatly improved through digital transformation and ultimately prompted more funds to flow into enterprises with higher efficiency [44]. As the efficiency of financial allocation improves, it can effectively address the issue of inadequate funds during enterprise development and then improve the motivation of enterprises to carry out green innovation [45]. At the same time, the increase in available capital will also encourage businesses to focus on enhancing operational efficiency and value. Enterprises will be more inclined to take on social responsibility and improve corporate governance in order to enhance their social image and reputation, ultimately boosting their overall ESG performance [46]. In summary, digital transformation can promote the allocation efficiency of finance for enterprises, improve the financing constraint dilemma faced by enterprises, effectively improve the ability of enterprises in environmental protection, social responsibility fulfillment, and corporate governance, and provide stable external financial security for their ESG performance. So, we highlight Hypothesis 3.

Hypothesis 3 (H3). *Digital transformation improves the ESG performance of companies by increasing the allocation efficiency of external finance, which indicates that the improvement of external financial allocation efficiency also plays an important intermediate channel in the process of digital transformation affecting firms' ESG performance.*

3. Research Design and Sample Selection

3.1. Samples and Data

In this paper, we use the annual data of all Chinese A-share listed enterprises from 2009 to 2022 for the research sample. At the same time, the original sample was screened and processed as follows: (1) the ST firms that had experienced two consecutive years of losses and PT firms that had experienced three consecutive years of losses in the sample were excluded; (2) all financial firms in the sample were excluded; (3) firms that had been delisted during the sample period were excluded; (4) firms that had been listed for less than five years were excluded; (5) sample observations with empty working capital were excluded; and (6) a 1% reduction was applied to both the upper and lower tails of all continuous variables to mitigate the impact of outliers. The data of listed firms used in the study came from the CSMAR and Wind databases.

3.2. Variables

3.2.1. Corporate Sustainability (ESG)

The ESG concept plays a crucial role in helping businesses attain high-quality sustainable development. Therefore, utilizing the research conducted by Li et al. [47], this paper adopts the CSI ESG rating index to measure the ESG performance of enterprises, which is classified into nine grades based on the performance of enterprises: C, CC, CCC, B, BB, BBB, A, AA, and AAA. Values ranging from one to nine were assigned, and their natural logarithm was taken to depict the ESG performance of businesses.

3.2.2. Digital Transformation (DT)

Existing research primarily uses three methods to assess the digital evolution of businesses: (1) analyzing the ratio of technology information employees [48] or the ratio of intangible assets linked to digitalization within the company [49]; (2) constructing a dummy variable based on whether the enterprise undertook digital transformation in that year [34]; and (3) constructing digital transformation indicators through text analysis, which involves tallying the occurrences of terms associated with digital transformation that are revealed in the yearly report [50]. Since the first two methods are one-sided, they cannot truly measure the actual application level of corporate digital. Thus, there are certain defects and shortcomings. In contrast, the annual report contains the enterprise's main business, operating conditions, management's business philosophy, and so on. It has important reference value and significance in grasping the enterprise's operation and development strategy and decision-making. Therefore, it can provide a more thorough depiction of the progress of digital evolution in businesses. Therefore, this paper utilized the research conducted by Verhoef et al. [50] and AlNuaimi et al. [51] and paper applied the Python text analysis technology to identify and analyze keywords in annual reports related to AI technology, Big Data technology, Cloud computing technology, Blockchain technology, and digital technology. Then, logarithmic processing on the total number of keywords after the summing up was used to eliminate the influence of outliers.

3.2.3. Control Variable (CT)

To avoid the omission of important variables that could lead to endogeneity problems, this paper will examine a range of firm characteristics and corporate governance level variables. Among them, the firm characteristic variables include the following: (1) size of the company (Size), which is calculated as the natural logarithm of the total assets; (2) age of the company (Age), which is expressed as the natural logarithm of the year the company was established; (3) return on assets (ROA), which is calculated by dividing the company's net profit by its total assets; (4) leverage of the company (Lev), which is calculated as the ratio of total liabilities to total assets; and (5) growth rate of sales revenue (Growth), which is measured by the annual growth rate of the company's sales revenue. Then the Corporate governance variables consist of four factors: (1) board size (Board), which is expressed as the natural logarithm of the number of board members; (2) the proportion of independent directors (Independent), which is calculated as the ratio of the number of independent directors to the number of board members; (3) the proportion of shares held by the first largest shareholder (First), which as the ratio of the number of shares held by the first largest shareholder of the enterprise to the total number of shares; and (4) the combination of general manager and chairman positions (Combination), which is measured by the situation in which the general manager and the chairman of the board are concurrently employed. It takes the value of one when the general manager and chairman of the board are the same individual; otherwise, it takes the value of zero.

3.3. Models

This paper introduces a panel fixed-effects model to analyze how digital transformation affects companies' ESG performance.

$$ESG_{i,t} = \alpha_0 + \alpha_1 DT_{i,t} + \delta_1 X_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (1)$$

where the i and t denote firm and time, respectively; the firm's ESG performance is denoted by ESG, the firm's degree of digital transformation is denoted by DT; and X represents the control variables. The model also incorporates both firm fixed effects μ_i and time fixed effects ν_t . $\varepsilon_{i,t}$ is a random error term. α_1 is the coefficient that is the focus of this paper, and its significance and sign reflect the impact and direction of digital transformation on firms' ESG performance.

4. Empirical Results

4.1. Descriptive Statistics

Table 1 reports the descriptive statistics of the main variables. The average ESG rating of the sample companies is 4.063, which corresponds to a B-level performance. This finding indicates that, overall, companies generally have a low ESG performance. At the same time, the ESG has a standard deviation of 1.050, suggesting notable variations in ESG performance across different companies. In addition, the standard deviation of the digital transformation variable is 1.397, and the difference between its maximum and minimum values after logarithmic processing is 6.304, indicating that the firms' digital transformation processes vary greatly.

Table 1. Descriptive statistics.

Variable	Meaning	Mean	Std.	Min	Max	P25	P50	P75
ESG	ESG performance	4.063	1.050	1.000	8.000	3.500	4.000	5.000
DT	digital transformation	1.881	1.397	0.000	6.304	0.693	1.792	2.833
Size	corporate size	3.761	1.376	0.640	7.743	2.811	3.611	4.561
Age	corporate age	2.259	0.819	0.000	3.367	1.792	2.485	2.890
ROA	return on firm's assets	0.033	0.072	−0.341	0.209	0.012	0.035	0.065
Lev	corporate leverage	0.441	0.216	0.054	1.081	0.271	0.432	0.595
Growth	corporate sales revenue growth rate	0.175	0.471	−0.641	3.194	−0.033	0.103	0.265
Board	board size	2.134	0.198	1.609	2.708	1.946	2.197	2.197
Independent	the proportion of independent directors	0.375	0.054	0.273	0.571	0.333	0.357	0.429
First	the proportion of shares held by the first largest shareholder	34.140	15.100	8.440	74.660	22.370	31.850	44.520
combination	the situation of combining the two positions	0.260	0.439	0.000	1.000	0.000	0.000	1.000

4.2. Empirical Results: Digital Transformation on Corporate ESG Performance

In Table 2, the baseline regression findings regarding the influence of digital transformation on corporate ESG performance are presented. Columns (1)–(3) display the outcomes when no control variables are included, when firm characteristics control variables are added, and when both firm characteristics and corporate governance control variables are included, respectively. Additionally, the model incorporates city-level clustering effects to adjust standard errors in each column. The results indicate that the coefficients exhibit statistically significant positive values, at a minimum significance level of 5%. This finding suggests that digital transformation can effectively contribute to the ESG performance of firms. In other words, digital transformation has the potential to enhance the overall efficiency of businesses in relation to environmental, social responsibility, and corporate governance. This, in turn, can contribute to the sustainability of enterprises, which confirms the correctness of Hypothesis 1's conclusion. Meanwhile, the results in column (3) demonstrate that a 1% increase in digital transformation is associated with a 0.0181% increase

in firms' ESG performance. The rationale for the aforementioned conclusion is that the resource integration capacity and information transfer impact of digital transformation not only facilitates the transformation of enterprise development models but also enhances enterprise management standards, prompting them to prioritize long-term and sustainable development, thereby enhancing the overall ESG performance of enterprises. The findings also provide direction and policy guidance on how to enhance the sustainable development capacity of enterprises.

Table 2. Main regression results.

	(1) ESG	(2) ESG	(3) ESG
DT	0.0302 *** (0.0080)	0.0159 ** (0.0080)	0.0181 ** (0.0080)
Size		0.3632 *** (0.0237)	0.3626 *** (0.0237)
Age		−0.3226 *** (0.0369)	−0.2915 *** (0.0389)
ROA		0.3340 ** (0.1314)	0.3252 ** (0.1327)
Lev		−0.9408 *** (0.0858)	−0.9428 *** (0.0848)
Growth		−0.0546 *** (0.0157)	−0.0569 *** (0.0156)
Board			0.0604 (0.0880)
Independ			1.1744 *** (0.2709)
First			0.0059 *** (0.0014)
Cons	4.0727 *** (0.0156)	3.8137 *** (0.1276)	2.9910 *** (0.3010)
Enterprise	Yes	Yes	Yes
Time	Yes	Yes	Yes
N	20,065	20,053	19,703
R ²	0.5907	0.6189	0.6196

Note: ***, ** represent significance at the 1%, 5% levels, respectively; robust standard errors are in parentheses; the same applies below.

4.3. Robustness Tests

4.3.1. Dynamic Panel Model Estimation

Due to the dynamic continuity of firms' ESG practices, current ESG performance is easily influenced by the past. Therefore, to address the estimation bias issue stemming from the inertial nature of corporate ESG performance, this paper incorporates the lagged one-period value of corporate ESG performance ($ESG_{i,t-1}$) into the baseline model (1) to construct the following dynamic panel model:

$$ESG_{i,t} = \alpha_0 + \rho ESG_{i,t-1} + \alpha_1 DT_{i,t} + \delta_1 X_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (2)$$

In this context, ρ is the coefficient of the lagged one-period value of firms' ESG performance, whose value is between 0 and 1, indicating the extent to which the current ESG performance is affected by the previous period. The definitions of the remaining variables in model (2) are identical to those in model (1). In this paper, the differential GMM

(DIF-GMM) method and the systematic GMM (SYS-GMM) method are used to estimate model (2) at the same time to overcome the one-sidedness of the estimation results of a single method, and with the outcomes presented in columns (1)–(2) of Table 3. It can be observed that the delayed factors of companies' ESG achievements show a strong positive correlation at the 1% significance level, suggesting that the current ESG performance of companies is greatly influenced by the preceding period. Meanwhile, the coefficients of digital transformation are all significantly positive at the 1% level, indicating that after controlling for the dynamic continuity characteristics of firms' ESG performance, digital transformation still promotes firms' ESG performance, and the conclusion of the benchmark model is robust.

Table 3. Dynamic panel estimation and instrumental variable method results.

	DIF-GMM	SYS-GMM	IV	
	(1) ESG	(2) ESG	(3) DT	(4) ESG
L.ESG	0.7585 *** (0.0260)	0.8172 *** (0.0124)		
DT	0.0977 *** (0.0351)	0.0450 *** (0.0127)		0.6594 ** (0.2743)
IV			0.0045 *** (0.0013)	
AR(1)-P	0.0000	0.0000		
AR(2)-P	0.8265	0.8494		
LM				16.3020 (0.0001)
KP-F				16.2980
Enterprise	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
N	14,161	17,991	19,792	19,552
R ²			0.7234	0.0165

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

4.3.2. Instrumental Variable

In order to better address the issue of endogeneity, we rely on the findings of Audretsch et al. [52], which use the number of landline phones per 10,000 residents and the number of Internet users in the city where the business is situated in the previous year of 1984 as a proxy variable. On the one hand, the communication method used in the past is the basis for the enterprise to carry out digital transformation, which can influence the acceptance and application of emerging technology from the technical level and social preference. On the other hand, the landline telephones used in the location of the enterprise mainly provide communication services for the people. As the infrastructure of the society, it does not directly affect ESG performance. So, the instrumental variable selected satisfies both the relevance condition and the exclusivity requirement. Columns (3)–(4) of Table 3 show the results of the instrumental variable method, which uses the two-stage least squares regression. It can be found that the estimated coefficient of the instrumental variable in column (3) is significantly positive at the 1% level, which indicates that the instrumental variable has a significant positive impact on the digital transformation variable. The coefficient of the core explanatory variable in column (4) is still significantly positive at the 5% level, with the Cragg–Donald Wald F-statistic exceeding 10, indicating that the weak instrumental variable hypothesis is rejected. The above results further suggest that the conclusion that digital transformation improves corporate ESG performance is robust.

4.3.3. Replacing the Metrics of Variable

To prevent the baseline model's conclusions from being influenced by measurement bias in the core variables, this study also substitutes the measurements of the dependent and independent variables. Firstly, since different industries are supported by different national policies and the degree of digital transformation carried out varies tremendously, failing to consider industry distinctions may introduce significant bias in the digital transformation variable. So, we modify the digital transformation factor based on the industry average in order to remove the impact of industry variations on the regression outcomes. Second, drawing on Müller [53], we replace the digital transformation variable using the percentage of the digital technology-related portion of intangible assets. Finally, the ESG performance is re-measured using Bloomberg ESG rating metrics. Columns (1)–(3) of Table 4 show the regression results of the substitution variable measurement approach. In column (1), the impact coefficient of the digital transformation variable, which is adjusted by the industry mean, is significantly positive at the 5% level. The coefficient of the new digital transformation variable, which is replaced using the percentage of the digital technology-related portion of intangible assets, is still significantly positive at the 1% level in column (2). Furthermore, the coefficient of the effect of digital transformation remains positive and significant at the 5% level after changing the ESG performance measure in column (3). Therefore, all the above results suggest that the findings of the baseline regression are robust.

Table 4. Variable and sample adjustment results.

	Industry Adjustment for Digital Transformation	Replacement of Digital Transformation	Replacement of ESG Performance	Sample Adjustments	
	(1) ESG	(2) ESG	(3) ESG	(4) ESG	(5) ESG
DT_adj	0.0181 ** (0.0080)				
DT_2		0.0589 *** (0.0072)			
DT			0.2962 ** (0.1141)	0.0135 * (0.0073)	0.0339 *** (0.0091)
Enterprise	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes
N	19,703	25,803	7071	17,651	12,906
R ²	0.6196	0.5654	0.8033	0.6287	0.5948

Note: ***, **, * represent significance at the 1%, 5%, and 10% levels, respectively.

4.3.4. Adjustment of Sample Size

As the business scope of enterprises in the digitalization industry includes digital technology-related businesses, the key information on digitalization in their annual reports is only an external reflection of their business scope rather than an internal representation of their digital transformation decisions. Thus, they are susceptible to interference from such enterprises when constructing digital transformation indicators. In view of this, we continue to make the following adjustments to the sample scope to exclude the above sample effects. Firstly, we exclude sample companies that fall under the categories of computer, communications, and electronic equipment manufacturing, telecommunications and satellite services, and Internet services, as per the 2012 Revised Guidelines for Industry Classification of Listed Companies. Then, the regression analyses are reconducted on the remaining samples, and the outcomes are displayed in column (4) of Table 4. Secondly, we analyzed the regression by only relying on the sample of traditional industries in the broad categories of mining, manufacturing, electricity, heat, gas, and water production and supply, and the results are shown in column (5) of Table 4. The results clearly show that

the impact coefficients of digital transformation are consistently positive and statistically significant, further confirming the reliability of the findings.

4.4. Mechanism Tests

After combining the theoretical analysis in the previous sections, it is evident that digital transformation affects the ESG performance of firms by improving internal total factor productivity and external financial allocation efficiency. Therefore, in order to open the “black box” of the impact of digital transformation, this paper constructs the following mediation effect models to examine the intrinsic mechanism of digital transformation to affect the sustainability of enterprises from the perspective of internal and external efficiency enhancement, respectively:

$$M_{i,t} = \alpha_0 + \alpha_1 DT_{i,t} + \delta_1 X_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (3)$$

$$ESG_{i,t} = \beta_0 + \beta_1 DT_{i,t} + \beta_2 M_{i,t} + \delta_1 X_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (4)$$

where the M is the mediating variable in terms of internal and external efficiency. Model (3) is used to test the effect of digital transformation on the mediating variable, and model (4) is used to test the mediating role of the mediating variable in the relationship between digital transformation and firms’ ESG performance. The meanings of the other variables in models (3)–(4) are the same as in model (1). When the coefficients α_1 and β_2 are significant, and the significance or absolute value of the coefficients β_1 decreases relative to model (1), it can be inferred that the mediating variables play a partial mediating role in the relationship between digital transformation and corporate ESG performance.

4.4.1. Mechanism Test Based on Internal Total Factor Productivity

For total factor productivity, existing studies mainly use the OP method and LP method to measure. Since the OP method fails to achieve the estimation of the sample with zero investment, which leads to problems such as missing a large number of valid samples, so drawing on the research of Levinsohn and Petrin [54], this paper adopts the LP method to measure the total factor productivity of enterprises. This method assumes that the firm’s production function adheres to the Cobb–Douglas functional form and incorporates the firm’s intermediate goods inputs as unobservable productivity shocks into the production function. The firm’s production function takes the form as follows:

$$\ln Y_{i,t} = \lambda + \alpha \ln L_{i,t} + \beta \ln K_{i,t} + \gamma \ln M_{i,t} + \varepsilon_{i,t}$$

where the variable Y denotes the total outputs, the variable L is the labor inputs, the variable K is the capital inputs, and the variable M is the intermediate goods inputs.

It then measures the level of total factor productivity through the residuals of the production function. Columns (1)–(2) of Table 5 report the results of the mechanism test using models (3)–(4) and based on internal total factor productivity (TFP), in which the impact coefficient of digital transformation on firms’ TFP in column (1) is 0.0276 and is significant at the 1% level, which indicates that digital transformation is effective in increasing the level of firms’ TFP, and thus enhancing the firms’ business performance. In column (2), by simultaneously incorporating digital transformation and total factor productivity variables into the model for regression, the impact coefficient of total factor productivity (TFP) is 0.0491 and is significant at the 10% level. At the same time, the impact coefficient of digital transformation is still significant and positive, but its significance and absolute value have declined relative to the baseline model, indicating that total factor productivity plays a partially mediating role in the relationship between digital transformation and firms’ ESG performance. The result suggests that digital transformation contributes to firms’ ESG performance and sustainability by increasing internal total factor productivity, so Hypothesis 2 was tested. The above findings further illustrate that digital transformation improves the mobility of data within companies and optimizes the allocation efficiency

of production factor resources, which in turn leads to the improvement of companies' environmental protection, social responsibility performance, and corporate governance capabilities, and then provides a sustainable source of motivation for companies to engage in ESG practices.

Table 5. Mechanism test results based on internal and external efficiency perspectives.

	(1) TFP	(2) ESG	(3) FM	(4) ESG
DT	0.0276 *** (0.0048)	0.0176 * (0.0100)	−0.0165 ** (0.0073)	0.0434 * (0.0259)
TFP		0.0491 * (0.0281)		
FM				−0.1194 *** (0.0312)
Enterprise	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
N	19,227	18,995	18,364	18,180
R ²	0.9148	0.6247	0.2630	0.2414

Note: ***, **, * represent significance at the 1%, 5%, and 10% levels, respectively.

4.4.2. Mechanism Test Based on the Efficiency of External Financial Allocation

According to the theory of resource allocation, only by allocating more resources to more efficient sectors can be the optimal overall allocation of resources. Accordingly, it can be inferred that the level of financial allocation efficiency reflects whether the flow of financial resources is reasonable. When a large number of financial resources are allocated to more efficient departments or enterprises, a high-efficiency allocation of finance will be formed, and this can have a positive impact on the whole economy. On the contrary, when a large number of financial resources are allocated to less efficient departments or enterprises, it will form a financial mismatch phenomenon and can have a huge negative impact on the whole economy. Therefore, this paper adopts the degree of financial mismatch at the enterprise level to represent the level of external financial allocation efficiency. The distortion of capital price ultimately reflects the fact that capital factors are not optimally allocated in accordance with the principle of efficiency, which in turn can effectively reflect the degree of financial mismatch. As an important aspect of the factor price distortion method, the extent of the discrepancy between the cost of funds as measured by the cost of funds deviation method can effectively reflect the actual level of financial mismatch burden borne by enterprises, which is a direct representation of the results of the allocation of financial resources at the enterprise level. So, drawing on the research of Wu [55] and Whited and Zhao [56], we adopt the degree of distortion of capital price as a proxy for the financial mismatch, which is measured by the deviation of enterprises' actual cost of funds from the industry's average cost of funds, in order to reflect the level of the financial mismatch burden actually borne by the enterprises. When the level of financial mismatch burden borne by enterprises is heavier, it indicates that the allocation of external finance at the enterprise level is less efficient, while the opposite indicates that the allocation of external finance at the enterprise level is more efficient.

Columns (3)–(4) of Table 5 report the results of the mechanism test for the efficiency of external financial allocation, in which the coefficient of the impact of digital transformation on the degree of financial mismatch is −0.0165 and is significant at the 5% level in column (3). Digital transformation is able to significantly reduce financial mismatch at the firm level, thus significantly improving the efficiency of external financial allocation at the firm level. In column (4), by simultaneously incorporating digital transformation and financial mismatch variables into the model for regression, the impact coefficient of the financial mismatch variable is −0.1194 and is significant at the 1% level. At the same time, the impact coefficient of digital transformation is still significantly positive, but its significance

decreases in relation to the baseline model, indicating that financial mismatch also plays a partially mediating role in the relationship between digital transformation and firms' ESG performance. The results suggest that digital transformation contributes to firms' ESG performance by improving the allocation efficiency of external finance, which in turn improves firms' sustainability, and Hypothesis 3 was tested. The above results also further suggest that the mitigation of information asymmetry by digital transformation effectively improves the allocation efficiency of finance at the firm level, facilitates the flow of more financial resources to more efficient firms, and suppresses firms' financing constraints, thus providing strong external financial support for firms to implement ESG practices.

5. Further Research: Heterogeneity and Spillover Analysis

As different types of enterprises have differentiated characteristics, they also exhibit different behavioral characteristics in different external environments, which may result in heterogeneity in the impact of digital transformation on the sustainable development of enterprises. In addition, given the interconnectedness of enterprises, it remains to be seen whether digital transformation has a spillover effect on the sustainable development of enterprises. In this regard, this paper will further analyze the heterogeneity and spillover effects of digital transformation on the sustainable development of enterprises in order to examine the impact of digital transformation on the sustainable development of enterprises from a deeper perspective.

5.1. Heterogeneity Analysis

5.1.1. Heterogeneity Analysis Based on the Nature of Property Rights

The dual attributes are economic and political; therefore, state-owned enterprises often undertake major missions entrusted by the state and play an important role in promoting the high-quality development of the economy. Therefore, compared with non-state-owned enterprises, state-owned enterprises not only have richer digital technology resources but also have a stronger willingness to implement green and sustainable development. Accordingly, it can be inferred that the effect of digital transformation on an enterprise's sustainable development may be greater in state-owned enterprises. So, according to the nature of property rights for enterprises, the sample of enterprises was divided into state-owned enterprises and non-state-owned enterprises, and then the regression analysis was carried out, respectively. The results of grouped regression are shown in columns (1)–(2) of Table 6. It can be seen that the coefficient of digital transformation on the ESG performance of state-owned enterprises is significantly positive at the 5% level, while the coefficient of non-state-owned enterprises is insignificant and smaller than that of state-owned enterprises. This indicates that the effect of digital transformation on the ESG performance of state-owned enterprises is more significant than that of non-state-owned enterprises, i.e., promoting the digital transformation of state-owned enterprises can better promote their sustainable development.

Table 6. Results of heterogeneity analysis based on property rights and industry attributes.

	State-Owned Enterprises	Non-State-Owned Enterprises	Heavily Polluting Enterprises	Non-Heavily Polluting Enterprises
	(1) ESG	(2) ESG	(3) ESG	(4) ESG
DT	0.0338 ** (0.0160)	0.0088 (0.0134)	0.0326 *** (0.0089)	0.0717 *** (0.0189)
Enterprise	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
N	7113	10,726	13,338	6315
R ²	0.6709	0.6009	0.5995	0.6400

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

5.1.2. Heterogeneity Analysis Based on Industry Attributes

Given that sustainable development is a comprehensive performance for enterprises that can reflect environmental protection, the environmental regulatory pressures on enterprises in different industries will vary greatly. Specifically, compared with the heavy pollution industry, enterprises in the non-heavy pollution industry face less environmental regulation and economic pressure, and these enterprises are more concerned about and willing to accept digital transformation and will apply digital technology to their production and operation more actively. In addition, non-polluting enterprises usually have asset-light characteristics, so the technical barriers to digital transformation are relatively low, and the same level of digital transformation will bring about a greater increase in green innovation efficiency. As a result, the effect of digital transformation on the sustainable development of enterprises in non-heavy polluting industries is likely to be greater. For this reason, this paper divides the sample enterprises into heavily polluted industries and non-heavily polluted industries and conducts regression analyses separately (According to the Guidelines for Disclosure of Environmental Information by Listed Companies, 16 categories of industries are treated as heavy polluters: iron and steel, metallurgy, thermal power, cement, coal, chemicals, petrochemicals, building materials, paper, brewing, pharmaceuticals, fermentation, tannery, electrolytic aluminum, textile, and mining. The remaining industries are treated as non-heavily polluting industries). The results are shown in columns (3)–(4) of Table 6. It can be found that, although the coefficient of the impact of digital transformation is significantly positive at the 1% level in both heavily polluted industries and non-heavily polluted industries, the effect on enterprises in non-heavily polluted industries is greater, indicating that advancing the level of digital transformation of enterprises in non-heavily polluted industries has a more significant role in the promotion of their sustainable development capability.

5.1.3. Heterogeneity Analysis Based on Regional Distribution

From the point of geographic spatial distribution, due to different resource endowments, there are huge differences in the level of economic development of various regions, which further leads to differences in the intensity of environmental regulation and the level of development for the digital economy. For the relatively good level of economic development in the eastern region, the high foundation of economic development leads to the speed of development of the digital economy, and the strength of environmental regulation is relatively strong, so the role of digital technology for the sustainable development of local enterprises is relatively limited. However, for the central and western regions where the level of economic development is relatively backward, the pace of development of the digital economy is slower, and the strength of environmental regulation is weaker due to the lag in economic development. Therefore, the application of digital technology has a relatively stronger role in enhancing the efficiency of environmental, social responsibility, and corporate governance of local enterprises, which is more likely to promote the sustainable development of enterprises in these regions. To this end, this paper divided the sample enterprises into the eastern and central-western regions according to the provinces where the enterprises' addresses belong and analyzed the impact of digital transformation separately (The China Statistical Yearbook categorizes China into four distinct regions: eastern, central, western, and northeastern. The northeastern and central regions exhibit comparable levels of economic development and are supported by two distinct national policies: the revitalization of the old northeastern industrial bases and the rise of central China, respectively. It is evident that both of them can be considered as a single zone. Therefore, this paper categorizes the sample into three regions: eastern, central, and western). The results are shown in columns (1)–(2) of Table 7. As can be seen from the results, the coefficients of the impact of digital transformation in the central and western regions are significantly larger than those in the eastern region, suggesting that digital transformation has a greater impact on the sustainability of the enterprises in regions with poorer levels of economic development than those in the eastern region with a better level of economic development.

Table 7. Results of heterogeneity analysis based on regional distribution and degree of marketization.

	Eastern Region	Central and Western Region	High Marketization	Low Marketisation
	(1) ESG	(2) ESG	(3) ESG	(4) ESG
DT	0.0154 * (0.0090)	0.0295 * (0.0168)	0.0096 (0.0110)	0.0345 *** (0.0125)
Enterprise	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
N	14,158	5521	11,557	7982
R ²	0.6206	0.6220	0.6212	0.6349

Note: ***, * represent significance at the 1%, 10% levels, respectively.

5.1.4. Heterogeneity Analysis Based on Degree of Marketisation

From the perspective of the institutional environment, the degree of marketization varies from region to region, and the legal environment, social responsibility, and regulation of enterprises may also differ, which results in the impact of digital transformation on the ESG performance of enterprises varying with the degree of marketization. Compared to regions with better institutional environments, regions with poorer institutional environments have higher levels of information asymmetry, which hinders stakeholders from evaluating, incentivizing, and governing corporate performance, and the development of digitalization will effectively change this situation. Therefore, it can be surmised that the impact effect of digital transformation on firms' sustainability may be greater in regions with lower marketization. In view of this, this paper divides the regions in which the sample firms belong into two samples of high and low marketization according to the mean value of the marketization index compiled by Fan Gang and examines the heterogeneity of the impact of digital transformation on firms' ESG performance, respectively. The results are shown in columns (3)–(4) of Table 7. It is not difficult to find that the absolute value and significance of the coefficients of digital transformation are larger in those of low-marketization regions, indicating that the impact effect of digital transformation on firms' sustainability is larger in low-marketization regions.

5.2. Analysis of Spillover Effects

With the globalization of the economy and the development of information technology, enterprises are no longer isolated individuals but are complex affiliations through transactions, guarantees, and shareholdings, which has led to the formation of an intricate credit chain. As a community of interest in the credit chain, once the operating conditions of a node enterprise change, the impact will quickly ripple through the credit relationship to other affiliates, resulting in a spillover effect on other affiliates [57]. However, whether the impact of digital transformation on firms' ESG performance has spillover effects on their affiliates has not been systematically discussed in the existing literature. In view of this, this paper selects the supply chain relationships among enterprises as the research object; the relationship involves not only the enterprise itself but also the suppliers and customers associated with the enterprise [58]. Using the data of the top five suppliers and customers disclosed by the listed enterprises, we construct the upstream supplier and downstream customer relationship subsamples corresponding to the sample enterprises and examine the impact of the digital transformation on the ESG performance of their upstream suppliers and downstream customers, in order to explore whether the digital transformation has a spillover effect on the enhancement of the enterprise's sustainable development capability. The constructed panel regression model is shown below:

$$ESG_{i,t}^{S/C} = \alpha_0 + \alpha_1 DT_{i,t} + \delta_1 X_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (5)$$

Among them, the core independent variable is the degree of digital transformation of the sample firms, which is also constructed by adopting the text analysis method to count the frequency of words related to digital transformation disclosed in the annual reports of the firms. The dependent variables ESG^S and ESG^C are the ESG performance of the upstream suppliers and downstream customers corresponding to the sample firms, which are still measured by the CSI ESG rating index. The meanings of the other variables in the model (3) are the same as those in the model (1).

Columns (1)–(2) of Table 8 report the spillover results of the impact of digital transformation on firms' ESG performance. As can be seen from the results, the coefficient of the impact of digital transformation on the ESG performance of their upstream suppliers is significantly positive at the 5% level in column (1). Meanwhile, the coefficient of the impact of digital transformation on the ESG performance of their downstream customers is also significantly positive at the 5% level. It indicates that firms' digital transformation not only promotes their own ESG performance but also brings about an improvement in the ESG performance of their upstream suppliers and downstream customers. The result also further suggests that while digital transformation promotes the sustainable development of the enterprise itself, the effect also has a positive spillover effect. Therefore, promoting digital transformation has great value and significance to the sustainable development of enterprises.

Table 8. Spillover results of digital transformation.

	Upstream Supplier	Downstream Customers
	(1) ESG^S	(2) ESG^C
DT	0.0832 ** (0.0376)	0.0803 ** (0.0385)
Enterprise	Yes	Yes
Time	Yes	Yes
<i>N</i>	482	446
R^2	0.2584	0.3605

Note: ** represents significance at the 5% levels; S , C represents the upstream suppliers and the downstream customers, respectively.

6. Research Conclusions and Policy Recommendations

Whether digitalization can promote the green transformation of enterprises has become an important issue for high-quality development under the “dual-carbon” target. Based on the microdata of Chinese A-share listed companies from 2009 to 2022, this paper systematically examines the impact of digital transformation on corporate ESG performance and its functioning mechanism in order to explore the effective path of synergistic development between digitalization and greening. Firstly, the results of the study show that digital transformation effectively promotes corporate ESG performance, which in turn enhances corporate sustainability. The finding remains robust after controlling for endogeneity issues, replacing the measures of the core variables and adjusting the sample capacity, suggesting that Hypothesis 1 is supported. Secondly, the mechanism test finds that digital transformation affects ESG performance mainly by enhancing firms' internal and external efficiency. Within firms, digital transformation improves the total factor productivity of enterprises, which further validates the conclusion of Hypothesis 2. While outside firms, digital transformation improves firms' efficiency in allocating external finance, which in turn further validates the conclusion of Hypothesis 3. Thirdly, further analysis shows that the effect of digital transformation on firms' ESG performance is more prominent in SOEs, non-heavily polluted industries, central and western regions in China, and low-marketization regions. In addition, digital transformation not only improves the ESG performance of firms themselves but also brings about a simultaneous improvement

in the ESG performance of their upstream and downstream firms, which in turn has a positive external spillover effect.

Combined with the above empirical results, the findings of this paper strongly support the correctness of the hypotheses and provide a wealth of evidence in support of the hypotheses. It can be seen that while digital transformation brings profound changes to the production and operation process of enterprises, it also effectively improves the performance of enterprises in terms of the environment, social responsibility, and corporate governance. This, in turn, plays an important role in the sustainable development of enterprises. On the one hand, digital transformation allows for the full exploitation of the benefits of resource integration. The promotion of technologies such as big data, blockchain, artificial intelligence, and cloud computing has enabled enterprises to optimally allocate their overall production factor resources, thereby improving their total factor productivity. The enhancement of enterprise total factor productivity not only improves their environmental governance performance but also enhances their fulfillment of corporate social responsibility and corporate governance capabilities. Conversely, digital transformation also allows for the full exploitation of the information transfer effect. The extensive utilization of digital technology has significantly reduced the information asymmetry between enterprises and external financial institutions, thereby facilitating the flow of financial resources to enterprises with superior benefits in accordance with the principle of efficiency. This, in turn, effectively alleviates the financing constraints faced by enterprises, thereby providing them with greater incentives to engage in green innovation, fulfill their social responsibility, and invest in corporate governance. Furthermore, the enhancement of ESG performance through digital transformation can serve as a model for upstream suppliers and downstream customers. This, in turn, leads to the simultaneous improvement of ESG performance for upstream and downstream enterprises and synergistically promotes the sustainable development of enterprises in the entire supply chain.

Based on the above analysis results, this paper offers the following policy insight: (1) Local governments, on the one hand, should increase the construction of digital economic infrastructure, especially the digital input in the backward regions of central and western regions, so as to reduce the digital development gap between different regions, and at the same time, to provide a good external environment for the realization of the digital transformation of enterprises. On the other hand, the support of special funds should also be promoted to give full play to the incentive effect of financial support policies in order to effectively support the focus on the development of digital technologies related to green sustainable development and stimulate the vitality of enterprises to carry out digital transformation, so as to promote the in-depth fusion of digital technology and green innovation and development and provide a lasting impetus for the sustainable development of enterprises. (2) Enterprises should actively comply with the wave of digital economy development, fully grasp the opportunities of digital transformation, continuously consolidate the foundation of digital transformation, and apply information technology such as big data, blockchain, cloud computing, and artificial intelligence to the whole process of production and operation of enterprises, so as to realize the in-depth fusion of digital transformation with production and operation. Through the introduction of cutting-edge digital technology to drive the green transformation of products, processes, and organizational structure, they should give full play to the positive impact of digital transformation on the green and sustainable development of enterprises. (3) The market-oriented reform of the financial system should be deepened, not only to steadily increase the proportion of direct financing, especially equity financing but also to continue to promote the construction of a multi-level, wide-coverage, and differentiated banking system, effectively alleviate the credit bias and discrimination of large commercial banks, guide the flow of funds from inefficient to efficient sectors, then enhance the ability of the financial services of the real economy. Therefore, we should give full play to the synergy between financial allocation and digital transformation, then promote corporate ESG investment efforts so as to effectively improve the ability of enterprises to develop sustainably. (4) The government should

also introduce a comprehensive policy framework, establish a cross-sectoral coordination mechanism, promote data sharing and cooperation between the government and enterprises, break down information silos, guide enterprises to carry out digital transformation in accordance with local conditions, and make full use of the function of optimizing the allocation of resources in digital technology to enhance the green innovation capacity of enterprises. This process will, in turn, promote in-depth integration between the innovation chain and the industrial chain, thereby effectively enhancing the synergy between digital transformation and green innovation and providing a significant impetus for the sustainable development of the economy and society.

Although the research sample of this paper is limited to Chinese-listed enterprises, the resource integration and information transfer brought about by digital transformation based on emerging technologies are somewhat universal. Consequently, the findings of this paper can provide a reference point for enterprises in different countries to seek sustainable development paths. In the future, the overall effect of digital transformation on corporate sustainability can be further refined by targeting specific technologies, such as big data, artificial intelligence, cloud computing, blockchain, and so forth. This will involve exploring the unique contribution of each segmented technology to enhance corporate sustainability and exploring how the combination strategies of different segmented technologies can work synergistically. Furthermore, longitudinal studies and international comparisons can be conducted to track the dynamic changes in the digitalization process and ESG performance of enterprises and to explore the differences in the effects of digital transformation on the empowerment of corporate sustainability in different contexts in different countries and regions in the context of globalization. Expanding the above research directions will not only help deepen the mechanism between digital transformation and corporate ESG performance but also provide more precise strategies for effectively promoting sustainable economic development.

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References

1. Abbas, A.; Waseem, M.; Ahmad, R.; Khan, K.A.; Zhao, C.; Zhu, J. Sensitivity analysis of greenhouse gas emissions at farm level: Case study of grain and cash crops. *Environ. Sci. Pollut. Res.* **2022**, *29*, 82559–82573. [\[CrossRef\]](#)
2. Abam, F.I.; Inah, O.I.; Ekwe, E.B.; Igbong, D.I.; Effiom, S.O.; Ovat, F.A.; Nyong, O.E.; Ikem, I.A. CO2 Emissions Decoupling from Added Value Growth in the Chemical and Pharmaceutical (CHPH) Industry in Nigeria. *Green Low-Carbon Econ.* **2023**, *1*, 52–59. [\[CrossRef\]](#)
3. Elahi, E.; Li, G.; Han, X.; Zhu, W.; Liu, Y.; Cheng, A.; Yang, Y. Decoupling livestock and poultry pollution emissions from industrial development: A step towards reducing environmental emissions. *J. Environ. Manag.* **2024**, *350*, 119654. [\[CrossRef\]](#) [\[PubMed\]](#)
4. Kalkuhl, M.; Wenz, L. The impact of climate conditions on economic production. Evidence from a global panel of regions. *J. Ecol. Environ. Manag.* **2020**, *103*, 102360. [\[CrossRef\]](#)
5. Avramov, D.; Cheng, S.; Lioui, A. Sustainable investing with ESG rating uncertainty. *J. Financ. Econ.* **2022**, *145*, 642–664. [\[CrossRef\]](#)
6. Chowdhury, S.; Dey, P.K.; Rodríguez-Espíndola, O. Impact of organisational factors on the circular economy practices and sustainable performance of small and medium-sized enterprises in Vietnam. *J. Bus. Res.* **2022**, *147*, 362–378. [\[CrossRef\]](#)
7. Houston, J.F.; Shan, H. Corporate ESG profiles and banking relationships. *Rev. Financ. Stud.* **2022**, *35*, 3373–3417. [\[CrossRef\]](#)

8. Baid, V.; Jayaraman, V. Amplifying and promoting the “S” in ESG investing: The case for social responsibility in supply chain financing. *Manag. Financ.* **2022**, *48*, 1279–1297. [\[CrossRef\]](#)
9. Liang, L.; Li, Y. The double-edged sword effect of organizational resilience on ESG performance. *Corp. Soc. Responsib. Environ. Manag.* **2023**, *30*, 2852–2872. [\[CrossRef\]](#)
10. Pinheiro, A.B.; dos Santos, J.I.A.S.; Cherobim, A.P.M.S. What drives environmental, social and governance (ESG) performance? The role of institutional quality. *Manag. Environ. Qual. Int. J.* **2024**, *35*, 427–444. [\[CrossRef\]](#)
11. Perano, M.; Cammarano, A.; Varriale, V. Embracing supply chain digitalization and unphysicalization to enhance supply chain performance: A conceptual framework. *Int. J. Phys. Distrib. Logist. Manag.* **2023**, *53*, 628–659. [\[CrossRef\]](#)
12. Zhai, H.; Yang, M.; Chan, K.C. Does digital transformation enhance a firm’s performance? Evidence from China. *Technol. Soc.* **2022**, *68*, 101841. [\[CrossRef\]](#)
13. Chen, W.; Zhang, L.; Jiang, P. Can digital transformation improve the information environment of the capital market? Evidence from the analysts’ prediction behavior. *Account. Financ.* **2022**, *62*, 2543–2578. [\[CrossRef\]](#)
14. Wielgos, D.M.; Homburg, C.; Kuehn, C. Digital business capability: Its impact on firm and customer performance. *J. Acad. Mark. Sci.* **2021**, *49*, 762–789. [\[CrossRef\]](#)
15. Zhang, W.; Zhao, J. Digital transformation, environmental disclosure, and environmental performance: An examination based on listed companies in heavy-pollution industries in China. *Int. Rev. Econ. Financ.* **2023**, *87*, 505–518. [\[CrossRef\]](#)
16. Yonghong, L.; Jie, S.; Ge, Z. The impact of enterprise digital transformation on financial performance—Evidence from Mainland China manufacturing firms. *Manag. Decis. Econ.* **2023**, *44*, 2110–2124. [\[CrossRef\]](#)
17. Cai, C.; Tu, Y.; Li, Z. Enterprise digital transformation and ESG performance. *Financ. Res. Lett.* **2023**, *58*, 104692. [\[CrossRef\]](#)
18. Hadi, S.; Baskaran, S. Examining sustainable business performance determinants in Malaysia upstream petroleum industry. *J. Clean. Prod.* **2021**, *294*, 126231. [\[CrossRef\]](#)
19. Baker, E.D.; Boulton, T.J.; Braga-Alves, M.V. ESG government risk and international IPO underpricing. *J. Corp. Financ.* **2021**, *67*, 101913. [\[CrossRef\]](#)
20. Loske, D.; Klumpp, M. Verifying the effects of digitalisation in retail logistics: An efficiency-centred approach. *Int. J. Logist. Res. Appl.* **2022**, *25*, 203–227. [\[CrossRef\]](#)
21. Loebbecke, C.; Picot, A. Reflections on societal and business model transformation arising from digitization and big data analytics: A research agenda. *J. Strateg. Inf. Syst.* **2015**, *24*, 149–157. [\[CrossRef\]](#)
22. Subramaniam, M.; Youndt, M.A. The influence of intellectual capital on the types of innovative capabilities. *Acad. Manag. J.* **2005**, *48*, 450–463. [\[CrossRef\]](#)
23. Battisti, E.; Nirino, N.; Leonidou, E. Corporate venture capital and CSR performance: An extended resource based view’s perspective. *J. Bus. Res.* **2022**, *139*, 1058–1066. [\[CrossRef\]](#)
24. Hanelt, A.; Bohnsack, R.; Marz, D.; Antunes, M.C. A Systematic Review of the Literature on Digital Transformation: Insights and Implications for Strategy and Organizational Change. *J. Manag. Stud.* **2021**, *58*, 1159–1197. [\[CrossRef\]](#)
25. Ferreira, J.J.M.; Fernandes, C.I.; Ferreira, F.A.F. To Be or Not to Be Digital, That is the Question: Firm innovation and Performance. *J. Bus. Res.* **2019**, *101*, 583–590. [\[CrossRef\]](#)
26. Vollero, A.; Siano, A.; Palazzo, M. Hoftsede’s cultural dimensions and corporate social responsibility in online communication: Are they independent constructs. *Corp. Soc. Responsib. Environ. Manag.* **2020**, *27*, 53–64. [\[CrossRef\]](#)
27. Muller, A.; Kolk, A. Extrinsic and intrinsic drivers of corporate social performance: Evidence from foreign and domestic firms in Mexico. *J. Manag. Stud.* **2010**, *47*, 1–26. [\[CrossRef\]](#)
28. Anthony, C.; Zabihollah, R. Business sustainability performance and cost of equity capital. *J. Corp. Financ.* **2015**, *34*, 128–149.
29. Atan, R.; Alam, M.M.; Said, J. The impacts of environmental, social, and governance factors on firm performance: Panel study of Malaysian companies. *Manag. Environ. Qual. Int. J.* **2018**, *29*, 182–194. [\[CrossRef\]](#)
30. Zhang, H.; Dong, S. Digital transformation and firms’ total factor productivity: The role of internal control quality. *Financ. Res. Lett.* **2023**, *57*, 104231. [\[CrossRef\]](#)
31. Fantazy, K.; Tipu, S.A.A. Linking Big Data Analytics Capability and Sustainable Supply Chain Performance: Mediating Role of Knowledge Development. *Manag. Res. Rev.* **2024**, *47*, 512–536. [\[CrossRef\]](#)
32. Urbinati, A.; Chiaroni, D.; Chiesa, V. The role of digital technologies in open innovation processes: An exploratory multiple case study analysis. *R. Manag.* **2020**, *50*, 136–160. [\[CrossRef\]](#)
33. El-Kassar, A.N.; Singh, S.K. Green innovation and organizational performance: The influence of big data and the moderating role of management commitment and HR practices. *Technol. Forecast. Soc. Chang.* **2019**, *144*, 483–498. [\[CrossRef\]](#)
34. Goldfarb, A.; Tucker, C. Digital economics. *J. Econ. Lit.* **2019**, *57*, 3–43. [\[CrossRef\]](#)
35. Mubarak, M.F.; Tiwari, S.; Petraite, M. How Industry 4.0 technologies and open innovation can improve green innovation performance. *Manag. Environ. Qual. Int. J.* **2021**, *32*, 1007–1022. [\[CrossRef\]](#)
36. Mukhuty, S.; Upadhyay, A.; Rothwell, H. Strategic sustainable development of Industry 4.0 through the lens of social responsibility: The role of human resource practices. *Bus. Strategy Environ.* **2022**, *31*, 2068–2081. [\[CrossRef\]](#)
37. Kraus, S.; Rehman, S.U.; García, F.J.S. Corporate social responsibility and environmental performance: The mediating role of environmental strategy and green innovation. *Technol. Forecast. Soc. Chang.* **2020**, *160*, 120262. [\[CrossRef\]](#)
38. Albulescu, C.T.; Turcu, C. Total factor productivity, financial performances and corporate governance: An analysis of the R&D sector in Romania. *INF Work. Pap.* **2018**, *9*, 1–28.

39. Wei, X.; Chen, Y.; Zhou, M. SOE preference and credit misallocation: A model and some evidence from China. *Ecol. Lett.* **2016**, *138*, 38–41. [\[CrossRef\]](#)
40. Wu, G.L. Capital misallocation in China: Financial frictions or policy distortions. *J. Dev. Econ.* **2018**, *130*, 203–223. [\[CrossRef\]](#)
41. Naeem, K.; Li, M.C. Corporate investment efficiency: The role of financial development in firms with financing constraints and agency issues in OECD non-financial firms. *Int. Rev. Financ. Anal.* **2019**, *62*, 53–68. [\[CrossRef\]](#)
42. Manso, G. Motivating Innovation. *J. Financ.* **2011**, *66*, 1823–1860. [\[CrossRef\]](#)
43. Aben, T.A.E.; Van-der, V.W.; Roehrich, J.K. Managing information asymmetry in public–private relationships undergoing a digital transformation: The role of contractual and relational governance. *Int. J. Oper. Prod. Manag.* **2021**, *41*, 1145–1191. [\[CrossRef\]](#)
44. Liberti, J.M.; Petersen, M.A. Information: Hard and Soft. *Rev. Financ. Stud.* **2019**, *8*, 1–41. [\[CrossRef\]](#)
45. Gomber, P.; Kauffman, R.J.; Parker, C. On the fintech revolution: Interpreting the forces of innovation, disruption, and transformation in financial services. *J. Manag. Inf. Syst.* **2018**, *35*, 220–265. [\[CrossRef\]](#)
46. Yin, Z.; Li, X.; Si, D. China stock market liberalization and company ESG performance: The mediating effect of investor attention. *Econ. Anal. Policy* **2023**, *80*, 1396–1414. [\[CrossRef\]](#)
47. Li, X.; Xu, F.; Jing, K. Robust enhanced indexation with ESG: An empirical study in the Chinese Stock Market. *Econ. Model.* **2022**, *107*, 105711. [\[CrossRef\]](#)
48. Hajli, M.; Sims, J.; Ibragimov, V. Information Technology (IT) Productivity Paradox in the 21st Century. *Int. J. Product. Perform. Manag.* **2015**, *64*, 4557–4578. [\[CrossRef\]](#)
49. Vial, G. Understanding digital transformation: A review and a research agenda. *J. Manag. Inf. Syst.* **2019**, *28*, 118–144. [\[CrossRef\]](#)
50. Verhoef, P.C.; Broekhuizen, T.; Bart, Y. Digital Transformation: A Multidisciplinary Reflection and Research Agenda. *J. Bus. Res.* **2021**, *122*, 889–901. [\[CrossRef\]](#)
51. AlNuaimi, B.K.; Singh, S.K.; Ren, S.; Budhwar, P.; Vorobyev, D. Mastering Digital Transformation: The Nexus Between Leadership, Agility and Digital Strategy. *J. Bus. Res.* **2022**, *145*, 636–648. [\[CrossRef\]](#)
52. Audretsch, D.B.; Heger, D.; Veith, T. Infrastructure and Entrepreneurship. *Small Bus. Econ.* **2015**, *44*, 219–230. [\[CrossRef\]](#)
53. Müller, O.; Fay, M.; Brocke, J. The Effect of Big Data and Analytics on Firm Performance: An Econometric Analysis Considering Industry Characteristics. *J. Manag. Inf. Syst.* **2018**, *35*, 488–509. [\[CrossRef\]](#)
54. Levinsohn, J.; Petrin, A. Estimating Production Functions Using Inputs to Control for Unobservables. *Rev. Econ. Stud.* **2003**, *70*, 317–341. [\[CrossRef\]](#)
55. Hsieh, C.T.; Klenow, P.J. Misallocation and manufacturing TFP in China and India. *Q. J. Econ.* **2009**, *124*, 1403–1448. [\[CrossRef\]](#)
56. Whited, T.M.; Zhao, J. The Misallocation of Finance. *J. Financ.* **2021**, *76*, 2359–2407. [\[CrossRef\]](#)
57. Levi, R.; Singhvi, S.; Zheng, Y. Economically motivated adulteration in farming supply chains. *Manag. Sci.* **2020**, *66*, 209–226. [\[CrossRef\]](#)
58. Eslamipour, R. A Biobjective Model for Integrated Inventory and Transportation at Tactical and Operational Levels with Green Constraints. *IEEE Trans. Eng. Manag.* **2023**, *99*, 1–12. [\[CrossRef\]](#)

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