

The Green Revolution in Digital Transformation: How Can Companies Realize a Sustainable Future?

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Abstract—Based on the data of China's A-share listed companies from 2011–2022, this paper assessed the impact of the level of corporate digital transformation on sustainability performance and its mechanism of action from a technological innovation-driven perspective. It is found that digital transformation significantly improves firms' sustainability performance, especially in terms of environmental, governance, and innovation performance, while the impacts in terms of economic performance and social responsibility performance may be complex. In addition, green innovation partially mediates the relationship between digital transformation and firms' sustainability performance, suggesting that digital transformation further contributes to the improvement of firms' sustainability performance by promoting green innovation. Our study not only provides strategic guidance for Chinese firms on digital transformation and sustainability but also provides directions for policymakers to help corporate sustainability.

Keywords—digital transformation, sustainability, green innovation

I. INTRODUCTION

In the wave of globalization and technological innovation, digital transformation has become a strategic choice for enterprises to adapt to the challenges of the new era, which not only represents a technological advancement but also an important way for enterprises to pursue innovation, efficiency, and competitiveness. At the same time, sustainable development, as a global long-term goal, requires enterprises to pay attention to environmental protection and social well-being while pursuing economic growth so as to realize the harmonious coexistence of economic, environmental, and social values. While digital transformation and sustainable development may appear to focus on different areas on the surface, they share the pursuit of a balanced and long-term vision of development. This vision emphasizes the realization of current development needs through innovation and optimal resource allocation without sacrificing future generational benefits. Therefore, exploring the relationship between enterprise digital transformation and sustainable development is the key to understanding and promoting the development of modern enterprises. How enterprises can effectively integrate digitalization and sustainable development strategies, balance the efficiency improvement brought by digitization with the realization of sustainable development performance, and even use digital transformation as a catalyst to promote sustainable development and achieve a harmonious symbiosis of economic, environmental, and social values has become the core topic of current enterprise strategic planning.

Current research on the impact of digital transformation on

corporate sustainability is still in the rapid development stage, and the measurement of digital transformation and sustainable development needs to be further deepened. In addition, the mechanism of the impact of digital transformation on enterprise sustainable development is still to be widely explored. Currently, digitalization and greening have become two core topics of enterprise development, and both have different degrees of importance for enterprise sustainable development. Based on this, this paper would like to explore this mechanism from the perspective of green innovation, which is not only a key way for firms to respond to environmental challenges and develop sustainable products and services but also an important mechanism for realizing the convergence of digital transformation and sustainable development goals. At the same time, we will explore the process of digitalization for sustainability based on Chinese listed companies. As the world's largest emerging market country, China is playing an increasingly important role in the global economy, and its corporate behavior and strategies not only have far-reaching impacts on the domestic economy but also have significant effects on the global market and environment. The practices of Chinese companies in digital transformation and sustainable development provide unique cases and data for the study and are more than expected to provide valuable insights and recommendations for business executives and policymakers in China and around the world.

Our study primarily contributes in two ways: firstly, by focusing on the Chinese scenario, it enhances the existing research on the non-economic effects of digital transformation. Second, green innovation is a key driver for economic transformation and the realization of the SDGs, and exploring the technology-driven effects through the green innovation lens enriches current research on related mechanisms.

The remainder of this paper proceeds as follows: Section II provides the theoretical framework and research hypotheses. Section III shows our study design. Section IV presents the empirical results and discusses the impact mechanisms. Section V summarizes the research findings, management implications, and existing limitations.

II. LITERATURE REVIEW

A. Impact of Digital Transformation on Corporate Sustainable Development

Digital transformation is a key strategy for enterprises to cope with rapidly changing global markets and adapt to emerging business models, and it is also an important driver

for enterprises to achieve sustainable development (Berman, 2012; Warner & Wäger, 2019). Current research on the impact of digital transformation on corporate sustainability focuses on the economic, social, and environmental dimensions. At the economic level, digital transformation can improve the operational efficiency and market responsiveness of enterprises through automation and data analytics, etc., thereby reducing costs and enhancing the competitiveness and profitability of enterprises (Kraus *et al.*, 2021; Leão & da., 2021), which provides financial support and investment attractiveness for the sustainable development of enterprises. At the societal level, digital technologies help firms improve pollution management capabilities and internal control efficiency, thereby enhancing CSR performance (Kong & Liu, 2023). At the environmental level, digital transformation can improve resource utilization efficiency by promoting green technology innovation (Xue *et al.*, 2022).

Accordingly, we propose the following assumptions:

H1: Digital transformation significantly improves the corporate sustainability performance.

B. The Mediating Role of Green Innovation

In the process of enterprise digital transformation, through green innovation, enterprises can develop new environmentally friendly products and services (He *et al.*, 2024), open up blue oceans in the market, reduce costs, and increase revenue sources. Second, digital transformation can strengthen the interaction between enterprises and consumers. Through social media and online platforms, enterprises can better understand consumer needs and preferences, thus promoting user-centered green innovation (Mao & Chang, 2023). On the environmental front, digital transformation reduces reliance on natural resources and environmental impacts through smart technologies, such as the Internet of Things (IoT) and automated systems, which enable companies to monitor and manage energy consumption and emissions in real time (Guan *et al.*, 2023).

Accordingly, we propose the following assumptions:

H1: Digital transformation significantly improves firms' sustainability performance by promoting green innovation.

III. MATERIALS AND METHODS

A. Data Sources and Sample Selection

We use the data of China's A-share listed companies from 2011–2022 as our research sample, ESG performance data from China CSI Index Information Rating Company^①, green innovation data from China Research Data Service Platform (CNRDS)^②, corporate digital transformation and the rest of the China Stock Market and Accounting Research (CSMAR) Database^③.

To ensure the accuracy of the data, the following criteria are used to clean the data: (1) all financial and real estate samples are deleted; (2) st-type firms are excluded; and (3) missing samples are eliminated. To mitigate the adverse effects of outliers, all major continuous variables are winsorized at the upper and lower 1% levels. Ultimately,

11,339 firm-year observations from 1,379 firms are obtained.

B. Definition of Variables

In this paper, sustainable development performance is measured in five dimensions: economic performance, environmental performance, social performance, governance performance, and innovation performance, and the combination of financial and non-financial performance can better represent the sustainable development status of enterprises. Specifically, the return on total assets is selected as the economic performance metric, the scores of CSI ESG dimensions represent the environmental performance, social performance, and governance performance, respectively, and the natural logarithm of the number of invention patent applications of the enterprise in year plus one represents the innovation performance. On this basis, principal component analysis is used to calculate the composite score of each dimension to measure sustainable development.

This paper adopts the Enterprise Digital Transformation Index launched in the CSMAR to measure the degree of enterprise digital transformation, which takes into account six aspects: strategic leadership at the enterprise level, technology-driven, organizational empowerment, digital application, digital outcomes, and digital environment support at the macro level, and fully reflects the new thinking of corporate governance research in the era of digital economy.

Referring to Xu & Cui (2020) and Wang & Wang (2021), the total amount of green innovation obtained by summing up the number of green invention patent applications and the number of green utility model patent applications of listed companies is added up to a natural logarithm, which is used to measure the level of green innovation of the enterprises.

With reference to the practice in the relevant literature (Mao *et al.*, 2024; Zhou *et al.*, 2023), we also selected a series of control variables.

Table 1. Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max.
Sustainable development	11,339	0.010	0.491	-2.757	1.703
Digital transformation	11,339	36.857	10.754	21.539	80.040
Green innovation	11,339	0.441	0.931	0	6.616
Size	11,339	23.213	1.286	19.585	26.452
SOE	11,339	0.519	0.500	0	1
ListAge	11,339	2.486	0.681	0	3.401
Lev	11,339	0.478	0.198	0.032	0.908
Cashflow	11,339	0.059	0.069	-0.199	0.267
Fixed	11,339	0.226	0.175	0.002	0.719
Intangible	11,339	0.049	0.056	0	0.343
Growth	11,339	0.173	0.403	-0.658	4.024
TobinQ	11,339	1.971	1.431	0.802	15.607
Board	11,339	2.174	0.200	1.609	2.708
Indep	11,339	37.566	5.531	28.570	60
Dual	11,339	0.206	0.405	0	1

C. Model Construction

To test the impact of digital transformation on corporate sustainability performance, this paper constructs the following model:

$$SD_{it} = \alpha_0 + \alpha_1 DT_{it} + \alpha_2 Controls_{it} + \lambda_t + \mu_i + \varepsilon_{it} \quad (1)$$

where i denotes the firm, t denotes time, and SD_{it} denotes the

^① Data source: <https://www.chindices.com/index.html>.

^② Data source: <https://www.cnrd.com/>.

^③ Data source: <https://data.csmar.com/>.

sustainability performance of firm i in year t , and DT_{it} denotes the degree of digital transformation of firm i in year t , and $Controls_{it}$ is a set of control variables. In addition, to mitigate the endogeneity problem to some extent, we also control for firm fixed effects and year fixed effects.

To verify the mediating role of green innovation in the impact of digital transformation on corporate sustainability performance, a model is constructed with reference to Wen's (2004) three-step mediation effect test. The model is constructed as follows:

$$GI_{it} = \beta_0 + \beta_1 DT_{it} + \beta_2 Controls_{it} + \lambda_t + \mu_i + \varepsilon_{it} \quad (2)$$

$$SD_{it} = \beta_3 + \beta_4 DT_{it} + \beta_5 GI_{it} + \beta_6 Controls_{it} + \lambda_t + \mu_i + \varepsilon_{it} \quad (3)$$

where GI_{it} represents the level of green innovation of enterprises, and the rest of the variables are the same as in Model 1.

IV. RESULT AND DISCUSSION

A. Benchmark Regression

The results in column (1) of Table 2 show that the coefficient of digital transformation is significantly positive and passes the test at the 1% significance level, which suggests that digital transformation indeed enhances corporate sustainability performance. Further exploring the impact of digital transformation on different segmented dimensions of corporate sustainability, the results show that

digital transformation exerts a significant positive enhancement in the environmental, governance, and innovation performance dimensions, while this enhancement is not significant in the economic and social performance dimensions. Digitalization can directly bring technological innovation, especially green technological innovation, and optimize internal and external management processes, which has a direct and obvious effect on the protection of the environment, the internal governance capacity, and the enhancement of innovation capacity. In terms of economic and social performance, the impact is likely to be more complex. In fact, although digital transformation can help enterprises improve efficiency, reduce costs, and transform and upgrade in the long run, in the initial stage of enterprise digital transformation, enterprises need to make large investments in digital technology, and the profitability performance of enterprises will be reduced (Yonghong *et al.*, 2023), so the promotion effect of economic performance may not be obvious. In terms of social responsibility performance, the impact on performance in terms of social responsibility is more complex because digital technology will cause a certain degree of replacement of ordinary assembly line workers, and the new jobs created may not be able to exert a compensatory effect in the short term (Dengler & Matthes, 2019). However, as a whole, the effect of digital transformation on corporate sustainability performance is significant. Therefore, H1 is accepted.

Table 2. Digital transformation and sustainable development

	(1)	(2)	(3)	(4)	(5)	(6)
	M1	M2	M3	M4	M5	M6
Variables	SD	Economic	Environment	Social	Governance	Innovation
DT	0.002*** (0.001)	5.43e-05 (9.88e-05)	0.038*** (0.013)	0.004 (0.019)	0.040*** (0.013)	0.003* (0.002)
Control	YES	YES	YES	YES	YES	YES
Firm	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES
Constant	-4.553*** (0.184)	-0.280*** (0.027)	23.720*** (3.501)	21.350*** (5.222)	47.000*** (3.655)	-8.902*** (0.559)
Obs	11,339	11,339	11,339	11,339	11,339	11,339
R2	0.255	0.345	0.094	0.073	0.093	0.315

Abbreviation: DT, digital transformation. SD, sustainable development.

Note: ***, **, * show level of significance of parameter at 1%, 5%, and 10%, respectively.

B. Robustness Tests

To ensure the robustness of the model results in this paper, we take the approach of replacing the explanatory variables by referring to Wu *et al.* (2021), which is based on text analysis to count the frequency of digital transformation words in the firms' annual reports, and take the natural logarithm for measuring the degree of digital transformation of the firms after addition of one (Table 3, column (1)). The measurement of digital transformation was lagged by one period (Table 3, column (2)), the sample during the Xinguan epidemic was deleted (Table 3, column (3)), and the mean value of digital transformation of other companies listed in the same province was used as an instrumental variable with reference to Gao & Wang (2023) (Table 3, column (4)), and an instrumental variable test was also conducted (Table 4). The results show that our benchmark regression results are robust.

Table 3. Robustness checks

	(1)	(2)	(3)	(4)
	M7	M8	M9	M10
Variables	SD	SD	SD	SD
DT			0.003*** (0.001)	0.023*** (0.002)
DT2	0.001** (0.000)			
lagged_DT		0.002*** (0.001)		
Control	YES	YES	YES	YES
Firm	YES	YES	YES	YES
Year	YES	YES	YES	YES
Constant	-0.315*** (0.106)	-0.121 (0.115)	-0.212* (0.114)	-3.852*** (0.106)
Observations	9,995	9,732	8,476	11,339
R-squared	0.178	0.206	0.146	0.282

Note: ***, **, * show level of significance of parameter at 1%, 5%, and 10%, respectively.

C. Analysis of Intermediary Mechanisms

Next, we will verify the process of digital transformation's impact on corporate sustainability performance from the perspective of green technology innovation. The results of testing the technology-driven effect of green innovation are shown in Table 5. In column (1), digital transformation is significantly and positively related to green innovation at the 1% level, a result that indicates that firms' digital transformation promotes their level of green innovation. In column (2), green innovation is significantly positive at the 5% level, and the coefficient of digital transformation level is still significantly positive, which indicates that there is a partial mediating effect of green innovation, i.e., digital transformation promotes the firm's sustainability performance through green innovation. As explored in the previous section, the use of green innovation technology in the process of digital transformation can help enterprises achieve more efficient resource utilization, more comprehensive supply chain management capabilities, and faster market responsiveness and contribute to the enhancement of enterprise sustainable development performance from all aspects of production and operation. Therefore, H2 is accepted.

Table 4. Mechanism checking

	(1)	(2)
	M11	M12
Variables	GI	SD
DT	0.009*** (0.001)	0.002** (0.001)
GI		0.044*** (0.005)
Control	YES	YES
Firm	YES	YES
Year	YES	YES
Constant	-0.266 (0.351)	-4.542*** (0.184)
Observations	11,339	11,339
R-squared	0.034	0.260

Note: ***, **, * show level of significance of parameter at 1%, 5%, and 10%, respectively.

V. CONCLUSION

Based on the data of China's A-share listed companies from 2011 to 2022, we comprehensively assessed the degree of digital transformation of enterprises by using the enterprise digital transformation index and comprehensively measured the sustainability performance of enterprises through principal component analysis, verified the positive impact of digital transformation on the sustainability performance of enterprises, and examined the mediating effect of green innovation therein from the technology-driven perspective.

The findings of the study have important implications for business managers and policymakers. Business managers should recognize that by adopting and integrating digital technologies, they can not only improve operational efficiency and market competitiveness but also facilitate the green transformation of their enterprises, develop new environmentally friendly products and services, and meet market and consumer demand for sustainable products. In addition, managers need to pay attention to the initial

economic performance challenges that may arise during the digital transformation process and develop appropriate risk management and cost-benefit analyses to ensure a smooth transition and long-term success in the transformation process. For policymakers, the findings suggest the need to develop and implement policies that support digitalization and green innovation in enterprises. Policymakers should encourage firms to invest in digital and green technologies by providing incentives, R&D subsidies, and tax benefits. At the same time, policymakers should also consider establishing a regulatory environment that is conducive to innovation and sustainable development, including setting environmental standards and promoting the development and application of green technologies, which together will contribute to a greener, more efficient, and sustainable business future.

This study also has some limitations. First, the impacts of the economic and social responsibility dimensions of sustainable development need to be further analyzed and demonstrated. Secondly, the exploration of the mechanism of action mainly focuses on the internal, but the external environmental factors should not be neglected as an important influential force.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Xiaoyi Zhan conducted the research; Guangjin Li analyzed the data; both authors had approved the final version.

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