4. AI-BASED DIGITALIZATION AND ESG OF MULTINATIONAL CORPORATIONS[1]

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Abstract

To achieve the "3060" dual-carbon goal, China has been constantly advancing its corporate ESG system, aiming to elevate ESG rating. AI technology has become a major driver for improving corporate ESG performance by optimizing decision-making and enhancing resource efficiency through digitalization. This study explores the impact of AI-based digital transformation on corporate ESG performance based on the data of A-share listed multinational companies spanning the years 2009 to 2022. The findings indicate that digital transformation significantly improves enterprises' ESG scores, showing an empowerment effect. The Mediation effect test shows that digital transformation promotes ESG performance by alleviating financial constraints and enhancing green innovation. Government subsidies positively moderate the relationship between digital transformation and financial constraints. In addition, the enhancement of digital transformation on ESG performance is more significant in state-controlled, large-scale enterprises and enterprises with two-job separation. The study provides new perspectives on the construction of ESG system for multinational enterprises in the context of AI technology and suggests that enterprises accelerate their digital transformation and enhance ESG disclosure, while governments and regulators should improve digital infrastructure and provide incentive policies. This study investigates the influence of digital transformation on ESG performance, with a specific emphasis on non-economic benefits. It offers practical insights for multinational enterprises in developing countries to establish and enhance their ESG systems within the context of the digital

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era. Furthermore, the findings serve as a critical reference for promoting the integration of AI technologies into ESG practices, thereby advancing sustainable development.

Keywords: *AI; digital transformation; ESG performance; mediating effect*

JEL Classification: *L25, L86, Q55*

1. Introduction

In September 2020, China formally announced its targets of reaching "peak carbon" by 2030 and attaining "carbon neutrality" by 2060, signaling a strong commitment to implementing substantial measures. Against this backdrop, China is dedicated to continuously improving its Environmental, Social and Governance (ESG) system, which is used to comprehensively assess the performance of enterprises in terms of sustainable development.

With traditional industries facing stagnating growth and limited scalability, Artificial Intelligence (AI) is increasingly permeating all sectors of the economy and society at an unparalleled rate. Emerging digital industries driven by AI are expanding rapidly, positioning the AI-enabled digital economy as a primary facet of the global economic landscape. As the world's second-largest digital economy, China is actively promoting the construction of Digital China. The ongoing information technology revolution, notably developments in computing, internet, and communications, is propelling the digital economy, which is significant for China's development. In the era of digital economy, the digital transformation of enterprises based on AI-based digital transformation has become essential for corporate survival and growth. Enterprises can leverage AI by integrating it into their operations, products, and services to foster innovation, enhance operational efficiency, and drive sustainable growth. Specifically, in the face of rapidly increasing data volumes and the complexity of information processing, AI utilizes deep learning and advanced data analytics to construct robust data models for extracting actionable insights. This capability not only revolutionizes business operations but also enables intelligent decision-making and management. Through digital transformation, enterprises can achieve synergies between innovation and efficiency, laying a solid foundation for sustainable development.

Research on the impact of AI technology on the economic performance of enterprises has been extensively explored (Mi Alnaser et al., 2023; Pattnaik et al., 2024) , but there is a lack of research regarding its non-economic performance, especially about ESG performance. Consequently, exploring how AI technology influences the ESG performance of multinational enterprises (MNEs) and understanding the underlying mechanisms are critical and important areas of inquiry. This research not only contributes to a more comprehensive understanding of the multidimensional effects of AI technology but also offers effective strategies for MNEs to improve and enhance their ESG performance.

Based on the rapid advancements in AI technology and the "dual-carbon" goals, this study aims to explore the mechanisms and effects of digital transformation on the ESG performance of multinational enterprises. Empirical modeling is conducted by utilizing data from A-share listed enterprises in Shanghai and Shenzhen spanning the years 2009 to 2022 to analyze the influence of AI-based digital transformation on the ESG performance of multinational enterprises. Additionally, the mediating effects of financial constraints and green innovation on the impact of AI-based digital transformation on ESG performance are aimed to be evaluated. Furthermore, this study investigates the moderating effect of government subsidies on the impact of AI-based digital transformation on ESG performance. Through these analyses, the research seeks to provide innovative and actionable policy recommendations to guide policymakers in fostering the digital transformation strategies of multinational enterprises. Importantly, this study highlights the critical role of ESG development in driving sustainable economic growth in developing countries.

Specific research questions include:

1. What is the impact of AI-based digital transformation on the ESG performance of multinational corporations, and through what channels is this impact transmitted?
2. What are the impacts and mechanisms of AI-based digital transformation on the ESG performance of multinational enterprises, considering financial constraints and green innovation as mediating variables?
3. Is there any moderating role of government subsidies in the impact of digital transformation on the ESG performance of multinational enterprises? If such a moderating effect exists, how does it manifest?
4. Are the findings robust? Is there heterogeneity in the impact of digital transformation on the ESG performance of multinational enterprises in terms of enterprise ownership, enterprise size and duality of Chairman of the Board (COB) and Chief Executive Officer (CEO)?

This study makes significant theoretical and practical contributions. It is the latest empirical research result that explores the impact of digital transformation on ESG performance from the perspective of non-economic benefits. It highlights the significance and necessity of developing ESG in developing countries' MNEs and offers new insights into how enterprises' digital transformation influences ESG. This study assists policymakers in developing countries by enhancing their focus on AI and digital technologies to advance ESG initiatives. Additionally, this study also incorporates financial constraints and green innovation into the theoretical framework. For the first time, it establishes a theoretical transmission mechanism of AI-based digital transformation that affects the ESG performance of MNEs. This development enhances the logical connection between AI technology and enterprises' ESG performance, thereby expanding the research boundaries of ESG theory. Not only does this provide empirical evidence to support enterprises in developing countries in achieving high-quality development, but it also serves as an important reference for deepening the integration of AI technology and ESG practice, which holds significant practical implications.

2. Literature review

2.1. Relevant studies on ESG

2.1.1. Factors influencing corporate ESG performance

Corporate ESG performance is influenced by various factors, including national policies, ownership structures, and the size of the enterprise.

The intensity of environmental regulation at the national level significantly influences enterprises' environmental protection behaviors (Dowell and Yeung, 2000; Qin et al., 2024a; Qin et al., 2024b; Zhu et al., 2023) . As a direct form of financial support, government subsidies have a substantial positive impact on enterprises' performance in the ESG domain, especially among non-state-owned enterprises (Lee et al., 2017). These subsidies not only reduce the economic costs associated with implementing ESG strategies but also enhance the efficiency of enterprises' actions in this area. King and Levine (2012) stated that the level of development of the financial market also affected enterprises' ESG performance; the more mature the financial market, the more likely enterprises are to adopt high standards of ESG practices.

Larger enterprises face greater public scrutiny due to their extensive stakeholder groups, creating intrinsic motivation to improve their ESG performance (Thorne et al., 2014). On the one hand, an enterprise's increasing scale is often accompanied by an accumulation of resources, increased visibility, and enhanced disclosure richness, all of which contribute to its ESG performance (Drempetic et al., 2019). On the other hand, the diversification of products, high reputation, and extensive stakeholder groups of large-scale enterprises make them more susceptible to scrutiny

from various sectors of society, making them more inclined to disclose information related to sustainability (Jacob et al., 2014).

State-owned enterprises (SOEs) aim to execute environmental governance in improving the ecological environment, actively fulfill social responsibility, and improve social welfare to maintain social stability. Consequently, they generally outperform non-SOEs regarding ESG performance (Crifo et al., 2015). As a result, these enterprises tend to view ESG performance as a crucial means of gaining the trust of foreign shareholders and thus strive to enhance their ESG performance.

2.1.2. Measurement of corporate ESG performance

Enterprises' ESG ratings directly affect investors' risks and returns (Chibane and Joubrel, 2024). Generally, the higher an enterprise's ESG rating, the lower the investors required returns (Avramov et al., 2022). However, due to inconsistencies in scoring criteria, industry adjustment methods, and data sources employed by rating agencies, different agencies may produce significantly divergent ESG ratings for the same enterprise. This variability in ESG rating methodologies somewhat undermines the effectiveness of these ratings in guiding investment decisions (Papathanasiou and Koutsokostas, 2024).

Earlier, there was a tendency to incorporate financial performance (Gompers and Metrick, 2001) when evaluating ESG performance. Since then, there has been a gradual increase in the number of methods for assessing corporate ESG performance. To estimate ESG more scientifically, Ghoul et al. (2011) employed an integrated approach to measure corporate social performance across six dimensions: community diversity, employee relations, environment, human rights, and product characteristics, as well as research on controversial business issues. Lins et al. (2017) investigated the relationship between ESG ratings and corporate reputation. Based on stakeholder theory, Diez-Caamero et al. (2020) conducted a descriptive comparative analysis of ESG on five thematic blocks: general information, economic-financial and stock market criteria, methodological criteria, enterprise sample descriptions, and public information provision criteria. They classified Corporate Social Responsibility (CSR) into three main categories: indicators, rankings, and ratings.

2.2. Relevant research on digital transformation and AI-based digital transformation

2.2.1. Related studies on digital transformation

Digital transformation is widely regarded as how organizations utilize digital technologies to fundamentally transform their business processes, corporate culture, and customer experience (Vial, 2019). Existing research on digital transformation primarily focuses on its drivers, metrics, and impacts.

Regarding the drivers of digital transformation, Bhandari and Javakhadze (2017) emphasized that with the rapid development of technologies such as cloud computing, big data, and the Internet of Things enabled enterprises to collect and analyze data more effectively, resulting in more accurate and efficient decision-making. Digital transformation is primarily driven by three key factors: customer demand (Sanchis et al., 2020; Verhoef et al., 2021) , internal organizational dynamics (Halpern et al., 2021) and technological advancements (Sanchis et al., 2019). Yuan et al. (2021) sought to assess the extent of digital transformation within enterprises through textual analysis. Wu et al. (2021) suggested that the frequency of the term "enterprise digital transformation" in the annual reports of publicly listed enterprises indicates to a certain extent the importance these enterprises place on this transformation. Consequently, this frequency can serve as a metric for assessing the degree of their digital transformation. In terms of its impact, digital transformation not only enhances the information processing capabilities but also facilitates the free flow and sharing of data and knowledge both internally and externally (Shen and Yuan,

2020). Moreover, it significantly improves production efficiency (Zhao, 2021). Xie and Lyu (2022) demonstrated that the digital transformation of enterprises could improve non-economic performance, a trend strongly linked to the evolution of corporate philosophy driven by social responsibility and sustainable development.

2.2.2. AI-based digital transformation

Recent research on digital transformation has primarily focused on its drivers, measurement, and impacts, with limited attention given to specific approaches, such as AI-based digital transformation. Existing studies predominantly adopt a macro-level perspective, seldom analyzing multinational enterprises at the micro level.

Holmström (2022) suggested that AI technology presented new opportunities for organizations undergoing digital transformation. The study examines the capacity of organizations to implement AI technologies for digital transformation across four key dimensions: technology, activities, boundaries, and goals. Similarly, Feroz and Kwak (2024) argued that integrating AI into business processes has become a pivotal driver of competitive advantage and innovation. Using a grounded theory approach, their research examines the process of digital transformation and AI integration, and introduces the novel concept of "Digital AIzation".

2.3. Literature review

Existing research on digital transformation, ESG performance, and the influence of digitalization on the ESG performance of MNEs has achieved remarkable results, but several gaps remain to be addressed. First, much of the existing research focuses on preliminary analyses of the concepts and drivers of digital transformation. However, it often lacks a comprehensive exploration of its deeper impacts and a theoretical examination of the practices underpinning digital transformation. Second, research on the impact of digital transformation on the non-economic aspects of ESG performance remains insufficient. This gap is particularly evident for MNEs, whose ESG performance encompasses not only corporate reputation and sustainable development but also adaptability to multicultural and complex environments. Current studies examining the influence of digital transformation on MNEs' ESG performance are fragmented and lack a comprehensive theoretical framework. Further research is therefore necessary to investigate how digital transformation shapes ESG practices and the mechanisms driving this relationship. Finally, AI-based digital transformation remains an underexplored area. As digital technology becomes essential for corporate transformation, the rapid evolution of AI amplifies this necessity. Therefore, investigating the impact of AI-based digital transformation on the ESG performance of MNEs is a critical priority for future research.

3. Theoretical analysis and research hypothesis

3.1. AI-based digital transformation and ESG performance of multinationals

AI-based digital transformation, characterized by its accessibility, scalability, and measurable impacts, is reshaping corporate productivity and production structures, while exerting substantial influence on ESG strategies and practices. At the environmental level, digital transformation promotes green and sustainable production by strengthening environmental regulations and improving corporate environmental governance (Pang et al., 2021). In terms of social responsibility, digitalization enhances corporate CSR performance and alleviates financial constraints by improving information transparency and optimizing internal governance (Xiao et al., 2021). At the corporate governance level, digital transformation enhances internal information transparency, enabling shareholders and stakeholders to access accurate and timely information,

thereby reducing information asymmetry. Simultaneously, the utilization of big data and AI technology assists managers in making more informed decisions, promotes the improvement of corporate governance, and enhances corporate stability and competitiveness (Qi et al., 2020). Therefore, this study proposes Hypothesis 1.

H1: Digital transformation driven by AI technology significantly and positively improves the ESG performance of multinational enterprises.

3.2. AI-based digital transformation, financial constraints and ESG performance of multinationals

3.2.1. AI-based digital transformation and financial constraints

AI-based digital transformation offers a novel approach to addressing the financing challenges faced by enterprises. Organizations that adopt AI strategies and actively pursue digital transformation align closely with national policy directives, increasing their likelihood of benefiting from preferential policies and support from financial institutions. This alignment effectively alleviates financing pressures.

Financial institutions are increasingly inclined to offer loans to digitally transformed enterprises, alleviating these businesses' financial pressures. Simultaneously, digital transformation allows enterprises to access financing information more efficiently, improves financing efficiency, and assists them in overcoming financial challenges. Furthermore, AI-driven digital transformation significantly mitigates the financial constraints of enterprises by enhancing their access to equity financing, commercial credit, and government subsidies (Yuan et al., 2022).

3.2.2. Financial constraints and ESG performance of MNEs

The alleviation of financial constraints positively influences corporate ESG performance across environmental, social, and governance dimensions. At the environmental level, corporate production activities often lead to negative externalities, such as excessive resource consumption and pollution. The green production can mitigate these adverse effects. Zhai and Liu (2021) emphasized the role of digital finance in fostering corporate green innovation. By offering flexible financing services to alleviate financial constraints, digital finance supports corporate green innovation and incentivizes enterprises to continuously enhance their green innovation capabilities. Regarding social responsibility, the resource dependence theory suggests that enterprises may prioritize economically advantageous projects over environmental and social initiatives when faced with limited resources, leading to capital crowding out (Bhandari and Javakhadze, 2017). Conversely, alleviating corporate financial constraints can offer financial support to distressed enterprises, allowing them to improve or sustain strong ESG performance. In terms of governance, alleviating financial constraints allows enterprises to allocate more resources toward enhancing internal control and governance mechanisms. This, in turn, improves the efficiency and transparency of corporate governance, further strengthening its overall effectiveness. In summary, this study proposes Hypothesis 2.

H2: Digital transformation based on AI technology boosts ESG performance of multinational corporations by alleviating financial constraints.

3.3. AI-based digital transformation, green innovation and ESG performance of multinationals corporations

3.3.1. AI-based digital transformation and green innovation

Green innovation is essential for enterprises aiming to reduce environmental damage and improve resource efficiency, reflecting their commitment to environmental protection and sustainable development. Enterprises adopting green technologies can mitigate pollution, generate market opportunities, and achieve mutually beneficial outcomes for both the economy

and the environment (Ma et al., 2020). However, green innovation is a long-term, complex and highly uncertain process. AI-based digital transformation addresses these challenges and fosters green innovation by strengthening enterprise innovation capabilities (Zhao, 2021). Specifically, AI-based digital transformation alleviates financial constraints, reduces internal control and innovation transaction costs, and promotes green innovation activities, ultimately improving environmental performance. The technology spillover effect enables enterprises to calculate resource demand accurately, assess green benefits, and implement green development concepts, ultimately enhancing environmental performance (Han and Zhang, 2023). Moreover, AI-based digital transformation significantly improves innovation within enterprises and fosters a sustainable production model. This transformation enables enterprises to make informed decisions, implement green technological innovations, and establish a sustainable approach to production and development (Xu et al., 2019).

3.3.2. Green Innovation and ESG Performance of MNCs

Green innovation serves as a catalyst for technological progress and energy efficiency, motivating enterprises to protect the environment while substantially enhancing their ESG performance. According to the "resource-capacity-growth" framework, green innovation allows enterprises to minimize material inputs by adopting new processes, thereby achieving production intensification and cost reduction. Simultaneously, green innovation enhances production capacity and optimizes the input-output ratio (Seman et al., 2019). Green innovation also plays a critical role in mitigating environmental risks. On one hand, enterprises demonstrate their commitment to sustainability by utilizing eco-friendly energy sources and implementing recycling practices to improve resource efficiency. On the other hand, they minimize environmental impact by safely managing industrial waste (Wang et al., 2023). Moreover, enterprises also integrate environmental protection concepts into product innovation, launching products that meet green standards. Green technology innovation not only enhances the technological capabilities and market competitiveness of enterprises but also cultivates the awareness of ecological protection, providing momentum for achieving superior ESG performance. Therefore, this study proposes Hypothesis 3.

H3: AI-based digital transformation significantly enhances the ESG performance of multinational enterprises by fostering green innovation.

3.4 AI-based digital transformation, government subsidies and ESG performance of multinationals

Government subsidies play an important role in improving ESG performance of enterprises. By alleviating financial pressures, these subsidies effectively incentivize enterprises to adopt better ESG practices and promote sustainable development through strategic decision-making and resource allocation (Lee et al., 2017). Enterprises undergoing AI-based digital transformation are more likely to receive increased policy support and subsidies, which enhance their external debt financing capacity and alleviate financial constraints (Gao et al., 2021). At the governance level, these subsidies improve the external governance environment of enterprises, prompting management to prioritize shareholder interests and sustainable development (Liu et al., 2019). Additionally, media monitoring exposes corporate governance problems, curtails opportunistic behavior among managers and reduces agency costs (Dyck et al., 2008). As a result, government subsidies strengthen the mitigating effect of corporate digital transformation on financial constraints, thereby fostering the positive advancement of MNEs in ESG performance. Based on this, this study proposes Hypothesis 4.

H4: Government subsidies positively moderate the mediating effect of enterprises' AI-based digital transformation on financial constraints. Specifically, as government subsidies increase, enterprises' digital transformation capabilities enhance their ability to alleviate

financial constraints, thereby strengthening their contribution to the ESG performance of MNEs.

4. Modeling setting and data detail

4.1. Data detail and modeling setting

In this study, multinational enterprises were selected from the Wind database based on the criteria of having overseas business revenue within the macro context of the digital economy and the "double carbon" target. To ensure the selected enterprises were in normal operational status, Special Treatment (ST) and Particular Transfer (PT) enterprises were excluded. Additionally, financial and insurance enterprises were removed due to their unique characteristics, along with samples containing incomplete financial data. To address the influence of outliers, continuous variables were Winsorized at the 0.5% and 99.5% levels. Enterprises with terminated, suspended, or interrupted operations were also removed. After the screening process, the final dataset consisted of 17,223 observations of A-share listed enterprises from 2009 to 2022.

4.1.1. Explained variable: ESG performance of multinational enterprises (ESG)

The China Securities Index (CSI) ESG rating score evaluates the ESG performance of multinational enterprises, with a higher score indicating better ESG performance. The CSI rating system assesses ESG performance by comprehensively analyzing the impact of various indicators on ESG outcomes, incorporating 17 environmental, 13 social, and 14 governance indicators as evaluation criteria for each dimension. Specifically, the CSI ESG rating score is calculated by aggregating key indicators and thematic indicators to derive the scores for each dimension, culminating in a total ESG score with a maximum of 100. This evaluation process considers the influence of each indicator on the enterprise, the duration of that influence, and assigns weights based on the degree and duration of the influence.

4.1.2. Core explanatory variable: AI-based enterprise digital transformation (DIG)

Measuring enterprise digital transformation at the micro level remains a key challenge in current academic research. In this study, the annual reports of A-share listed multinational enterprises were analyzed, using keyword searches, matching techniques, and word frequency statistics as indicators to assess their digital transformation. Specifically, this study builds upon the feature word mapping developed by Wu et al. (2021), as shown in Table 1, which encompasses AI presentation technologies and underlying technologies. The AI presentation technologies include artificial intelligence technology and digital technology utilization, while the underlying technologies consist of blockchain technology, cloud computing technology, and big data technology. The frequency of occurrences of these five types of feature words in the annual reports of listed enterprises is logarithmically transformed, resulting in an indicator to measure the digital transformation of multinational enterprises, denoted as DIG.

Table 1 Structured feature word mapping for enterprise digital transformation

Types	keyword
Artificial intelligence technology (AI)	Artificial intelligence, business intelligence, image recognition, investment decision support systems, intelligent data point analysis, intelligent robotics, machine learning, deep learning, semantic search, biometric identification technology, facial recognition, speech recognition, identity authentication, autonomous driving, and natural language processing
Digital technique (DTA)	Mobile Internet, industrial Internet, mobile Internet, internet medical care, e-commerce, mobile payment, third-party payment, NFC payment, smart energy, B2B, B2C, C2B, C2C, O2O, networking, smart wearables, smart agriculture, smart transportation, smart medical care, Intelligent customer service, smart home technology, intelligent investment consulting, intelligent cultural tourism, intelligent

Types	keyword
	environmental protection, smart power grid, intelligent marketing, digital marketing, unmanned retail, internet finance, digital finance, fintech, quantitative finance, and open banking
Blockchain technology (BC)	Blockchain, digital currencies, distributed computing, differential privacy technologies, and smart financial contracts
Cloud computing technology (CC)	Cloud computing, flow computing, graph computing, memory computing, multi-party secure computing, brain-inspired computing, green computing, cognitive computing, converged architecture, billion-level concurrency, exabyte-level storage, Internet of Things, and cyber-physical systems
Big data technology (BD)	Big data, data mining, text mining, data visualization, heterogeneous data, credit investigation, augmented reality, mixed reality, and virtual reality

Source: Authors' calculations

4.1.3. Mediating variables: financial constraints (SA) and green innovation (GP)

Following Hadlock and Pierce (2010), we utilize the Size-Age (SA) index as a measure of financial constraints. The SA index is a comprehensive and accurate measure of the degree of corporate financial constraints. Financial constraints fall sharply as young and small firms start to mature and grow.

Given that green innovation patent applications are time-consuming and are more likely to significantly impacting the ESG performance of enterprises during the application process, these applications align more closely with the requirements of timeliness and reliability compared to green innovation patent grants. To measure the level of green innovation within enterprises, the Green Patent (GP) metric is employed in this study, where a higher number of green patents indicates a greater level of green innovation. However, due to the numerous zero values in the number of green innovation patent applications submitted by enterprises, there is a notable right-skewed distribution. Consequently, the natural logarithm of the number of green innovation patent applications in a given year, plus one, is used as the mediating variable.

4.1.4. Moderating variable: government subsidies (Sub)

Drawing on the related study by Yang et al. (2015), this study utilizes both direct and indirect government subsidies as a measure of government support, which is logarithmically transformed and denoted as Sub.

4.1.5. Control variables

(1) Enterprise size is quantified as the natural logarithm of the enterprise's total assets, referred to as Size. (2) Enterprise age is calculated as the natural logarithm of the difference between the current year and the year of the enterprise's Initial Public Offering (IPO) plus one, denoted as Age. (3) The asset-liability ratio is determined by the ratio of total liabilities to total assets, denoted as Lev. (4) The net profit margin on total assets is assessed using the ratio of net profit to average total assets, denoted as ROA. (5) The shareholding ratio of the Top 10 shareholders is calculated as the ratio of the number of shares held by the Top 10 shareholders to the total number of shares outstanding, denoted as Top10. (6) Tobin's Q is defined as the market value of the enterprise's stock divided by the replacement cost of the enterprise's assets, denoted as Tobin Q. (7) Competitiveness in the marketplace is evaluated using the Herfindahl-Hirschman Index based on the enterprise in which the enterprise operates, denoted as HHI. (8) The duality of COB and CEO is measured by a dummy variable that equals 1 if the same person serve as both the COB and CEO ,and 0 otherwise, denoted as Dual.

4.2. Modeling setting

This study sets up the following benchmark regression model to explore the impact of corporate digital transformation on the ESG performance of multinational corporations:

$$ESG_{it} = \partial_0 + \partial_1 DIG_{it} + \sum \partial_m Controls_{it} + \sum Year + \sum Enterprise + \varepsilon_{it} \quad (1)$$

where i denotes enterprise, t denotes year. The dependent variable ESG_{it} represents the ESG performance of enterprise i in year t, and the independent variable DIG_{it} represents the degree of digital transformation of multinational enterprise i in year t. $\sum Controls_{it}$ is denoted as the control variable, and $\sum Year$ is the year control variable, the $\sum Enterprise$ is the enterprise control variable, and ε_{it} is the random error term.

Referring to the testing process summarized by Wen and Ye (2014), this study verifies the mediating effects of financial constraints and green innovation, based on which models (2) and (3) are constructed.

$$SA_{it} = \beta_0 + \beta_1 DIG_{it} + \sum \beta_m Controls_{it} + Year_t + Enterprise_i + \varepsilon_{it} \quad (2)$$

$$GP_{it} = \beta_0 + \beta_1 DIG_{it} + \sum \beta_m Controls_{it} + Year_t + Enterprise_i + \varepsilon_{it} \quad (3)$$

Then, this study constructs an ordered response model (Ologit) to analyze the relationships among digital transformation, financial constraints, and the ESG performance of MNEs. Additionally, it examines the Ologit model concerning digital transformation, green innovation, and the ESG performance of MNEs.

As shown below:

$$ESG_{it} = \gamma_0 + \gamma_1 DIG_{it} + \gamma_2 SA_{it} + \sum \gamma_m Controls_{it} + Year_t + Enterprise_i + \varepsilon_{it} \quad (4)$$

$$ESG_{it} = \gamma_0 + \gamma_1 DIG_{it} + \gamma_2 GP_{it} + \sum \gamma_m Controls_{it} + Year_t + Enterprise_i + \varepsilon_{it} \quad (5)$$

Next, this study tests the moderation effect of government subsidy, according to which models (6) and (7) are constructed:

$$SA = b_0 + b_1 DIG + b_2 Sub + b_3 DIG \times Sub + \sum Controls + Year + Enterprise + \varepsilon \quad (6)$$

$$ESG = c_0 + c_1 DIG + c_2 Sub + c_3 DIG \times Sub + c_4 SA + \sum Controls + Year + Enterprise + \varepsilon \quad (7)$$

In the model presented above, $DIG \times Sub$ represents the cross-multiplier term of digital transformation and government subsidies. First, it is necessary to test whether the parameter b_3 in model (6) is significant. If it is both significant and positive, the next step is to test whether the coefficient c_4 in model (7) is also significant. If both parameters are significant and positive, then the H4 is validated.

5. Empirical Analysis

5.1. Benchmark regression result of AI-based enterprise digital transformation on ESG performance

The results of the benchmark regression are shown in Table 2. Column (1) includes only the core explanatory variable, enterprise digital transformation, while Columns (2) to (4) incorporate the relevant control variables, time-fixed effects, and individual fixed effects in that order. Column (1) shows that the digital transformation variable (DIG) is significantly positive at the 1% level, indicating that AI-based enterprise digital transformation can effectively enhance the ESG performance of MNEs. Similarly in Column (4), the coefficient of digital transformation remains significant at the 1% level. This finding implies that the more advanced the AI-based digital transformation of multinational enterprises, the higher their ESG performance levels. Overall, the results confirm that AI-based enterprise digital transformation significantly enhances ESG performance, supporting Hypothesis 1.

Table 2 Benchmark model regression results

	(1) ESG	(2) ESG	(3) ESG	(4) ESG
DIG	0.0753***	0.0692***	0.0710***	0.0666***
	(0.0057)	(0.0057)	(0.0061)	(0.0092)
Size		0.1981***	0.2025***	0.2877***
		(0.0076)	(0.0077)	(0.0197)
Age		-0.0715***	-0.0599***	-0.5775***
		(0.0192)	(0.0214)	(0.0914)
ROA		2.6849***	2.6695***	0.3383**
		(0.1468)	(0.1481)	(0.1391)
Tobin Q		-0.0584***	-0.0523***	-0.0029
		(0.0064)	(0.0068)	(0.0071)
Lev		-0.8650***	-0.8802***	-1.1227***
		(0.0508)	(0.0518)	(0.0751)
Top10		0.1239***	0.1136***	0.1291*
		(0.0409)	(0.0412)	(0.0727)
HHI		-0.2408***	-0.2388***	-0.1463**
		(0.0467)	(0.0469)	(0.0730)
Dual		-0.0121	-0.0118	-0.0378*
		(0.0164)	(0.0165)	(0.0220)
Constant term	4.1270***	0.3064*	0.1718	-0.2046
	(0.0106)	(0.1598)	(0.1698)	(0.4717)
Year fixed effects	No	No	Yes	Yes
Enterprises fixed effect	No	No	No	Yes
Observed value	16335	15898	15898	15623
Adj. R2	0.0107	0.1158	0.1184	0.5656

*Note: * p<0.01, ** p<0.05, * p<0.1, Same as in the table below.*

Source: Authors' calculations

5.2. Analysis of the mediating effects of financial constraints and green innovation

The results of the mediation test are presented in Table 3. Column (1) shows that the regression coefficient for digital transformation is 0.0666, which is significant at the 1% level. This finding suggests that AI-based digital transformation significantly improves the ESG performance of multinational enterprises. Column (2) reveals that the regression coefficient for DIG is -0.0277, which is also significant at the 1% level, indicating that AI-based digital transformation reduces financial constraints. Column (3) demonstrates that after incorporating both financial constraints and digital transformation variables, the regression coefficients for DIG and SA are 0.0545 and -0.4331, respectively, both significant at the 1% level. These results demonstrate that AI-based digital transformation can enhance the ESG performance of multinational enterprises by alleviating financial constraints. Thus, H2 is supported.

Table 3 Mediated effects test

	(1) ESG	(2) SA	(3) ESG	(4) GP	(5) ESG
DIG	0.0666***	-0.0277***	0.0545***	0.0529***	0.0645***
	(0.0092)	(0.0011)	(0.0095)	(0.0091)	(0.0087)
SA			-0.4331***		
			(0.0834)		
GP					0.0384***
					(0.0085)
Constant term	-0.2046	-3.4796***	1.3023**	-1.3296***	-0.1574
	(0.4717)	(0.0639)	(0.5469)	(0.4181)	(0.3977)
Control variable	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Enterprises fixed effect	Yes	Yes	Yes	Yes	Yes
Observed value	15623	15623	15623	16140	15623
Adj. R2	0.5656	0.9307	0.5665	0.6700	0.5662

Source: Authors' calculations

As shown in Column (4), the regression coefficient for DIG is 0.0529, which is significant at the 1% level. These findings demonstrate that digital transformation positively impacts green innovation in enterprises. In Column (5), the coefficients for DIG and GP are 0.0645 and 0.4533, respectively, both of which remain significant at the 1% level after accounting for financial constraints and digital transformation. This indicates that AI-based digital transformation can enhance corporate ESG performance through green innovation. Thus, H3 is verified.

5.3. Analysis of the moderating effect of government subsidies

To examine how government subsidies influence the moderating effect of enterprises' digital transformation on financial constraints, this study conducts regression analysis on models (4) and (5), with the results presented in Table 4. Column (1) demonstrates the moderating effect of government subsidies during the digital transformation process aimed at alleviating financial constraints. The regression coefficient for subsidies (Sub) is -0.0099, which is significant at the 1% level, indicating that government subsidies can significantly reduce financial constraints. The regression coefficient for $DIG \times Sub$ is -0.0080, which is also significant at the 1% level. This indicates that government subsidies can positively moderate the effect of digital transformation

on financial constraints. After incorporating government subsidies and the interaction term between government subsidies and digital transformation in Column (2), the regression coefficient for SA is -1.0117, which is also significant at the 1% level. This suggests that the mechanism through which AI-based digital transformation can improve enterprises' ESG by alleviating financial constraints remains valid, even after accounting for the moderating role of government subsidies. Thus, H3 is verified.

Table 4 Moderating effects test

	(1) SA	(2) ESG
DIG	-0.0155***	0.0568***
	(0.0008)	(0.0099)
Sub	-0.0099***	-0.0051
	(0.0003)	(0.0039)
DIG×Sub	-0.0080***	-0.0117***
	(0.0001)	(0.0021)
SA		-1.0117***
		(0.1248)
Constant term	-3.5233***	3.3539***
	(0.0543)	(0.6320)
Control variable	Yes	Yes
Year fixed effects	Yes	Yes
Enterprises fixed effect	Yes	Yes
Observed value	15623	15623
Adj. R2	0.9670	0.5680

Source: Authors' calculations

5.4. Robustness test of the impact of digital transformation on ESG performance

5.4.1. Replacement of the explanatory variable ESG performance

Corporate ESG performance data (ESG_PB) provided by Bloomberg Consulting is used to replace the CSI ESG performance data previously used in the benchmarking model for analysis. In addition, this study employs the annual median value (ESG_median) of the CSI ESG performance data for measurement purposes. The empirical results, presented in Table 5, indicate that after substituting the explanatory variable, the regression coefficients for DIG are significantly positive at the 1% and 5% levels, respectively. Consequently, the main conclusions of this study remain valid.

Table 5 Replacement of explanatory variables

	(1) ESG_PB	(2) ESG_median
DIG	0.0319***	0.0200**
	(0.0101)	(0.0100)
Constant term	1.5698***	-0.5443
	(0.5641)	(0.5052)
Control variable	Yes	Yes
Year fixed effects	Yes	Yes

Enterprises fixed effect	Yes	Yes
Observed value	13905	15623
Adj. R2	0.5554	0.5232

Source: Authors' calculations

5.4.2. Sample processing

Although this study initially Winsorized all continuous variables by 0.5% in both directions during the data processing phase, it subsequently adjusted the variables by 1% and 1.5% in both directions to mitigate the impact of extreme outliers on the results. The corresponding regression outcomes are presented in Columns (1) and (2) of Table 6. Additionally, to account for the effects of listing and delisting on the results, this study retains only those listed enterprises that have been operational for five or ten consecutive years. The corresponding regression results are shown in Columns (3) and (4) of Table 6.

The empirical results indicate that the regression coefficients for DIG are consistently significantly positive at the 1% level. This finding suggests that the main conclusions of this study remain valid even after more rigorous data processing. Furthermore, the results demonstrate that AI-based digital transformation can significantly promote the ESG performance of multinational enterprises.

Table 6 Sample processing

	(1) ESG	(2) ESG	(3) ESG	(4) ESG
DIG	0.0643***	0.0629***	0.0627***	0.0687***
	(0.0086)	(0.0085)	(0.0091)	(0.0108)
Constant term	0.1819	0.5492	0.5426	-0.0023
	(0.4027)	(0.4092)	(0.4829)	(0.5565)
Control variable	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Enterprises fixed effect	Yes	Yes	Yes	Yes
Observed value	15623	15623	14346	9574
Adj. R2	0.5651	0.5659	0.5513	0.5302

Source: Authors' calculations

5.5. An endogeneity test of the impact of digital transformation on the ESG performance

5.5.1. Instrumental variables approach

This study addresses the potential endogeneity problem in the empirical testing process, specifically regarding the causal relationship between corporate digital transformation and the ESG performance. To tackle the issue of reverse causality, we employ an instrumental variable approach. Drawing on the methodologies of Song et al. (2021) and Lewbel (1997), an instrumental variable for corporate digital transformation is constructed by utilizing the mean value of digital transformation within enterprises (DIG_iv) for the same year. This variable is highly correlated with digital transformation but not with ESG performance, satisfying the conditions for instrumental variable construction.

In addition, the instrumental variable exogeneity test requires two instrumental variables. This study also uses the digital transformation index from the previous period as one of the instrumental variables, which meets the conditions of exogeneity and correlation. The regression results of the two-stage least squares method for the instrumental variables are shown in Columns

(1) and (2) of Table 7. The first-stage results in Column (1) indicate that the coefficients of the instrumental variables, DIG_iv and l.digital, are significantly positive at the 1% level, confirming that the instrumental variables satisfy the correlation condition. The Anderson-LM test, with a p-value less than 0.01, significantly rejects the null hypothesis of underidentification. Furthermore, the Cragg-Donald Wald F statistic exceeds the critical value of 10% bias in the Stock-Yogo weak ID test, allowing us to reject the null hypothesis of weak instruments. Finally, the coefficient of DIG remains significantly positive at the 1% level, demonstrating that the core findings of this study remain robust and credible.

Table 7 Instrumental variables approach

	(1) DIG	(2) ESG
DIG		0.0775***
		(4.01)
DIG_iv	0.193***	
	(7.27)	
l.digital	0.465***	
	(55.70)	
Anderson canon. corr. LM		3060.58
Cragg-Donald Wald F		1693.63
Sargan statistic		5.66
Control variable	Yes	Yes
Year fixed effects	Yes	Yes
Enterprises fixed effect	Yes	Yes
Observed value		13456
Adj. R2		-0.1252

Source: Authors' calculations

5.5.2. Propensity score matching

This study uses propensity score matching to estimate the net effect of digital transformation on ESG performance and financial constraints of multinational enterprises. The sample is divided into control and experimental groups based on whether their digital transformation scores exceed the mean. Control variables and year are selected as covariates for matching. Three types of matching-1:1, 1:3, and 1:5-are applied, and samples that do not belong to the common support domain are excluded. The empirical results are shown in Columns (1) to (3) of Table 8. The results show that the regression coefficients for DIG are consistently significantly positive at the 1% level, indicating that the main conclusions of this study remain valid even after applying the propensity score matching method.

Table 8 Propensity scores matching approach

	(1) ESG	(2) ESG	(3) ESG
DIG	0.0757***	0.0749***	0.0690***
	(0.0108)	(0.0095)	(0.0093)
Constant term	-0.9585	-0.5167	-0.4385
	(0.5923)	(0.5033)	(0.4868)
Control variable	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Enterprises fixed effect	Yes	Yes	Yes
Observed value	12179	14675	15264
Adj. R2	0.5893	0.5737	0.5692

Source: Authors' calculations

5.5.3. Omitted variable bias

To address the interference from the omitted variable bias caused by time-varying confounders, we implement a range of high-dimensional fixed effects to mitigate estimation bias. Specifically, fixed effects that combine year, enterprise, and city are sequentially introduced. These high-dimensional fixed effects significantly reduce the potential bias caused by omitted variables. For instance, the year × city fixed effect can account for the impact of economic development in different cities on the ESG performance of MNEs during that year.

The empirical results are shown in Table 9, which shows that the regression coefficients for digital transformation are consistently significantly positive at the 1% level, even after accounting for various high-dimensional fixed effects. This indicates that digital transformation can significantly improve the ESG performance of enterprises.

Table 9 Missing variables

	(1) ESG	(2) ESG	(3) ESG	(4) ESG
DIG	0.0687***	0.0690***	0.0730***	0.0739***
	(0.0103)	(0.0104)	(0.0104)	(0.0109)
Constant term	-0.2235	-0.0866	-0.6536	-0.3938
	(0.5300)	(0.5335)	(0.5449)	(0.5644)
Control variable	Yes	Yes	Yes	Yes
year×city	Yes	Yes	Yes	Yes
year×ind2	No	Yes	Yes	Yes
city×ind2	No	No	Yes	Yes
year×city×ind2	No	No	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Enterprises fixed effect	Yes	Yes	Yes	Yes
Observed value	14577	14562	14526	13381
Adj. R2	0.5806	0.5894	0.5975	0.5945

Source: Authors' calculations

5.6. Heterogeneity analysis of the impact of digital transformation on the ESG performance

5.6.1. Heterogeneity analysis of enterprise ownership, enterprise size and dual-employment

In this study, we analyze the heterogeneity in terms of enterprise ownership, enterprise size, and duality of COB and CEO, respectively.

First, the heterogeneity of corporate digital transformation on the ESG performance of MNEs is examined by comparing state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs). The results are shown in Columns (1) and (2) of Table 10. Column (1) illustrates the impact of digital transformation on the ESG performance of MNEs within SOEs, with a regression coefficient of 0.1316, which is significantly positive at the 1% level. In contrast, Column (2) displays the effect of digital transformation on ESG performance among non-SOEs, with a regression coefficient of 0.0588, also significantly positive at the 1% level. A comparison of the results in Columns (1) and (2) indicates that the influence of AI-based enterprise digital transformation on ESG performance is more obvious in state-owned enterprises.

Table 10 Heterogeneity test

Variable	(1) nationalized business	(2) non-state enterprise	(3) Large-scale enterprises	(4) Small-scale enterprises	(5) two jobs in one	(6) Non-dual functions
	ESG	ESG	ESG	ESG	ESG	ESG
DIG	0.1316***	0.0588***	0.1096***	0.0589***	0.0500***	0.0725***
	(0.0169)	(0.0110)	(0.0140)	(0.0139)	(0.0168)	(0.0117)
Constant term	-3.5479***	-0.8432	-6.7387***	0.7602	1.7848*	-1.6040***
	(0.9099)	(0.5927)	(0.8986)	(0.8224)	(0.9515)	(0.6098)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Enterprise fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observed value	4489	10939	7745	7634	4904	10432
Adj. R^2	0.6234	0.5632	0.6184	0.5818	0.5994	0.5944

Source: Authors' calculations

Second, the heterogeneous effects of enterprise digital transformation on ESG performance are further examined concerning enterprise size. Enterprises are categorized based on the median size, as shown in Columns (3) and (4) of Table 10. Column (3) presents the impact of enterprise digital transformation on ESG performance among large-scale enterprises, with a regression coefficient of 0.1096, which is statistically significant at the 1% level. Column (4) details the effect of corporate digital transformation on ESG performance in small enterprises, with a regression coefficient of 0.0589, which is also significant at the 1% level. A comparison of the results in Columns (3) and (4) indicates that the influence of AI-based enterprise digital transformation on ESG performance is more pronounced in large enterprises. This disparity may reflect the advantages that larger enterprises possess in terms of resources, technology, and management capabilities, which enable them to implement digital transformation more effectively and, consequently, enhance their ESG performance to a greater extent. Nevertheless, small enterprises, while experiencing a lesser degree of benefit, still show a positive impact of AI-based digital transformation on their ESG performance.

This study ultimately examines the heterogeneity associated with the duality of CEO and COB. When the same individual occupies both the CEO and COB positions, it reflects a concentration of power within the organization. Conversely, when these roles are held by separate individuals, it suggests a reduction in the CEO's power. The findings are presented in Columns (5) and (6) of Table 10. Column (5) illustrates the effect of digital transformation on ESG performance in corporates where the roles of COB and CEO are unified. The regression coefficient for digital transformation is 0.0500, which is statistically significant at the 1% level. In contrast, Column (6) reflects the impact of digital transformation on ESG performance where the roles of COB and CEO are separate, with a regression coefficient of 0.072, which is also significant at the 1% level. A comparative analysis of the results in Columns (5) and (6) reveals that the influence of AI-based corporate digital transformation on ESG performance is more pronounced in corporates where the roles of COB and CEO are separate. Specifically, the effect of digital transformation on ESG performance appears to be relatively weaker in corporates where these roles are unified, despite the positive contribution of duality to ESG outcomes. This phenomenon may be attributed to a higher concentration of decision-making authority in such corporates, potentially resulting in inefficiencies in the decision-making and execution processes related to digital transformation, as

well as a slower response to environmental changes. Conversely, the beneficial impact of AI-based corporate digital transformation on ESG performance is more evident in corporates where the roles of COB and CEO are distinct. This may stem from a clearer delineation of responsibilities at the management level, which facilitates more effective planning and implementation of digital strategies, thereby enhancing ESG performance.

5.6.2. Marginal impact of digital transformation on ESG performance

This study employs quantile regression to investigate the differential impact of digital transformation on enterprises ESG performance. The regression outcomes, derived from the application of quantile regression to assess the relationship between corporate digital transformation and ESG scores are shown in Table 11. The analysis focuses on the effects of digital transformation on ESG scores at the 20th, 40th, 60th, and 80th percentiles. The findings indicate that digital transformation exerts a more pronounced effect on enterprises with higher ESG scores, suggesting an increasing marginal effect of digital transformation on ESG scores.

Table 11 Interquartile regression of enterprises' digital transformation on ESG scores

	(1)	(2)	(3)	(4)
	ESG	ESG	ESG	ESG
DIG	0.0520***	0.0560***	0.0686***	0.0804***
	(0.0102)	(0.0057)	(0.0079)	(0.0057)
Constant term	0.3279	0.9254***	-0.3025	1.5259***
	(0.2881)	(0.1618)	(0.2232)	(0.1622)
Control variable	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Enterprises fixed effect	Yes	Yes	Yes	Yes
Observed value	15898	15898	15898	15898
Pseudo R^2	0.0710	0.0451	0.0705	0.0502

Source: Authors' calculations

6. Conclusion and policy recommendations

6.1. Conclusions

Based on data from A-share listed MNs from 2009 to 2022, this study explores the mechanisms and effects of AI-based digital transformation on corporate ESG performance. The empirical results indicate the following: First, AI-based digital transformation significantly promotes the ESG performance of multinational enterprises; specifically, a higher degree of digital transformation correlates with improved ESG scores. Second, AI-based digital transformation promotes ESG performance by alleviating financial constraints and enhancing green innovation. The research conclusions remain robust. Third, government subsidies positively moderate the effect between digital transformation and financial constraints. Increased government subsidies strengthen the capacity of AI-based digital transformation to alleviate financial constraints, thereby amplifying its positive impact on the ESG performance. Fourth, the heterogeneity tests reveal that the positive

effect of AI-based digital transformation on ESG performance is more significant in state-controlled enterprises, large enterprises, and those with a duality of COB and CEO.

6.2. Policy Recommendations

1. Enhancing AI Infrastructure and Talent Development. Multinational enterprises must invest more in AI infrastructure, proactively adapt to emerging technological changes, and leverage AI to enhance their digital capabilities. Additionally, these enterprises need to cultivate specialized talent to master and apply AI technology effectively. The complexity and high costs associated with AI technology present significant barriers to its widespread adoption. Consequently, it is essential to increase research and development (R&D) investment in AI technology and talent training to reduce the barriers and costs associated with technology implementation. Furthermore, the government should provide financial subsidies, tax incentives, and other policy support to stimulate the intrinsic motivation of enterprises to boost their investment in AI R&D.

2. Integrating Green Development with AI Technology. Multinational enterprises must integrate green development with AI technology. This integration will promote the application and innovation of green technologies, leading to the efficient use of resource and environmentally friendly production practices. For instance, in manufacturing enterprises, AI technology is applied to real-time pollution monitoring and intelligent early warning systems. Such initiatives ensure that AI-based digital transformation positively impacts ESG performance. Furthermore, multinational enterprises must establish digital platforms to facilitate the sharing and implementation of green technologies.

3. Strengthening Policy and Financial Support. Government departments need to enhance top-level design and fully leverage the guiding role of government policies for multinational enterprises. Government departments should strengthen environmental regulation, actively develop and refine laws related to green innovation and environmental protection, and align more closely with international rules and standards. This approach will provide multinational enterprises with more precise policy guidance and support. Furthermore, financial institutions should be encouraged to increase credit support for green innovation and digital transformation, thereby alleviating financial constraints for enterprises. Additionally, a cooperation mechanism between the government and multinational enterprises should be established to create a supportive environment for multinational enterprises to transform digitally by combining AI technology.

However, despite its contributions, this study has several limitations that warrant further research. In the empirical regression analysis, the values of some adjusted R^2 are low. Future studies should incorporate additional variables at both enterprise and country levels to enhance the validity of the findings. Additionally, this study does not account for the unique characteristics of industries in which multinational enterprises operate, potentially limiting the generalizability of the results. Moreover, international cooperation in addressing AI and ESG is important; therefore, multilateral dialogues on the development and deployment of internationally accepted standards and best practices that align AI development with ESG principles should be engaged in by governments. Cross-border collaboration can be promoted in the areas of research, industry, and regulators to share knowledge, best practices, and innovative solutions. By fostering international cooperation, governments can ensure that AI technologies are developed and implemented in a way that respects human rights, promotes sustainability, and contributes to global prosperity.

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