

The Impact of Digital Transformation on Ambidextrous Innovation: The Moderating Role of ESG

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Abstract. Based on the sample of Chinas Shanghai and Shenzhen A-share listed companies from 2010 to 2023, this study employs multiple regression analysis to explore the impact and mechanism of corporate digital transformation on dual innovation, with a focus on analyzing the moderating effect of corporate ESG performance. The research findings indicate that digital transformation has a significant positive promoting effect on dual innovation (including exploratory innovation and exploitative innovation), and corporate ESG performance positively moderates this relationship. Specifically, companies with superior ESG performance demonstrate stronger empowerment effects of digital transformation on dual innovation. Heterogeneity analysis reveals that this positive effect is more pronounced in state-owned enterprises, companies listed on the main boards (Shanghai and Shenzhen Stock Exchanges), and larger firms.

Keywords: digital transformation, dual innovation, exploitative innovation, exploratory innovation, ESG performance

1. Introduction

Amid rapid digital economy growth, digital transformation has become essential for corporate survival. IDC's 2024 report projects global enterprise digital investment to exceed \$3.4 trillion by 2025, with Chinese firms' digital transformation rate rising 47% since 2020. China's digital economy expanded to 50.2 trillion yuan in 2024 (41.5% of GDP) and is expected to surpass 50% by 2025. However, China faces macro challenges: slow efficiency gains in traditional industries, manufacturing productivity gaps, low digital penetration in services, shrinking demographic dividends, and resource constraints—all urging accelerated transformation.

In the digital era, innovation drives sustainable growth, competitiveness, and industrial reshaping. Innovation capability determines whether firms can seize opportunities and achieve long-term value. Dual innovation—balancing utilization (optimizing existing knowledge) and exploration (breaking new ground)—is crucial for adapting to change. McKinsey's 2024 survey found 83% of Chinese firms face an “innovation paradox”: digital investments raise total innovation but exploratory innovation stays below 30%. This raises a key question: Does digital transformation affect dual innovation differently? This paper enriches the economic consequences of digital transformation, expands dual innovation drivers, and explores ESG's moderating role in this relationship.

Existing research focuses on the digital economy's impact on innovation output and efficiency [1]. However, a gap remains on how digital transformation influences innovation via ESG ratings, especially the mechanisms linking DT, ESG, and dual innovation. This study uses 2010–2023 A-share data with Huazheng ESG ratings and dual innovation metrics. Multiple regression analysis examines DT's impact on dual innovation, focusing on ESG's moderating effect.

The paper structure includes literature review, hypotheses, research design, empirical analysis, and policy recommendations.

2. Literature review

This review examines digital transformation (DT), dual innovation, and ESG performance, highlighting ESG's moderating role between DT and dual innovation as a research gap.

As a strategic driver, DT reshapes production and innovation via big data, AI, and cloud computing. Existing research generally confirms that digital transformation significantly enhances corporate innovation efficiency [2], resource allocation capabilities [3], and market competitiveness [4]. This transformation primarily influences corporate behavior through three key pathways: First, data-driven decision-making [5], digital technologies provide enterprises with massive datasets and analytical tools to optimize decision-making processes. Second, process automation [6], intelligent manufacturing reduces operational costs while boosting productivity. Finally, open innovation pathways [7], digital platforms break down information barriers and facilitate collaboration between enterprises and external innovators.

Dual innovation balances adaptive (optimizing existing technologies) and exploratory (developing new technologies) approaches [8]. Existing research has analyzed the driving factors of dual innovation from multiple perspectives. Key drivers include resource foundations [9], sufficient R&D investment, and financial support [10] that directly facilitate dual innovation. Additionally, organizational learning enables enterprises to enhance innovation capabilities by absorbing external knowledge [11]. Finally, the policy environment plays a significant role, where government subsidies and regional innovation policies significantly incentivize exploratory innovation.

Extensive evidence shows DT empowers both innovation types [12] through multiple pathways [13]. On one hand, technologies like big data analytics and artificial intelligence substantially improve market foresight and technological anticipation [14], effectively reducing the high uncertainty risks associated with exploratory innovation while empowering enterprises to identify and seize breakthrough opportunities. On the other hand, IoT, cloud computing, and automation tools optimize internal processes and enhance operational efficiency, laying a solid foundation for exploitative innovation [15]. However, ESG's moderating role remains underexplored. ESG performance has increasingly become a critical metric for assessing corporate sustainability, closely tied to resource acquisition, risk management, and long-term reputation [16]. While existing research focuses on DT's direct economic benefits, systematic studies on how innovation affects ESG performance and subsequently shapes corporate innovation strategies—particularly in dual innovation contexts balancing short and long-term goals—remain limited. Although ESG factors grow in investment importance, their impact mechanisms on dual innovation are still debated. Strong ESG performance may support dual innovation by enhancing reputation, lowering financing costs, and attracting talent [17]. On the other hand, investments to meet ESG requirements could impose resource constraints [18], or steer innovation toward exploitative approaches that prioritize short-term compliance, potentially dampening exploratory drive. Clarifying ESGs mediating role and defining its boundaries in this process is essential.

In summary, while DT-dual innovation relationship is well-established, ESG's moderating role requires further study.

3. Research hypothesis

Corporate digital transformation integrates digital technologies into core operations to enable dual innovation. Technologies like big data and AI improve knowledge acquisition and reduce uncertainty, facilitating exploratory innovation. Meanwhile, IoT and cloud computing optimize supply chains and workflows, accelerating exploitative innovation. This mechanism drives coordinated development through resource restructuring and enhanced agility. DT reshapes innovation ecosystems through three core mechanisms: First, data-driven decision-making enhances market insight and reduces exploratory innovation risks while optimizing R&D pathways. Second, digital platforms break organizational barriers, enabling knowledge sharing internally and open innovation externally. Finally, operational flexibility allows cost-effective resource allocation and rapid experimentation. These three levers—enhanced insight, connectivity, and agility—create an environment where both innovation types thrive.

H1: Digital transformation has a positive effect on dual innovation

Digital transformation optimizes resource allocation. According to dynamic capability theory, digital capabilities improve how firms integrate and use ESG resources, enhancing their innovation impact. While strong ESG performance drives innovation via green financing, reputation, and stakeholder trust, it requires digital support to realize its full value. DT enables this through three pathways: ESG data platforms allow real-time risk monitoring, turning non-financial data into innovation insights; blockchain increases supply chain transparency, making sustainability a source of differentiation; and digital collaboration breaks down internal barriers, aligning ESG goals with R&D. These mechanisms show that digitally advanced firms better leverage ESG resources for dual innovation.

H2: Corporate ESG performance positively moderates the impact of digital transformation on dual innovation.

4. Research design

4.1. Data sources and data processing

This paper selects the Shanghai and Shenzhen A-share data from 2010 to 2023, sourced from WIND and CSMAR. The number of green patents is derived from the China Research Data Service Platform (CNRDS); ESG and financial data come from Guotai An (CSMAR) and Wind (WIND) databases; corporate executives environmental attention and multi-strategy orientation data are obtained from the WinGo financial database. Considering data quality and validity, the following basic processing is applied to the initial data: (1) Exclude ST/*ST firms, financial institutions, and delisted companies to ensure relative stability and specificity in their operations and financial conditions, thereby enhancing the reliability and generalizability of research findings; (2) Excluding enterprises with missing data values prevents biases and misinterpretations caused by incomplete datasets; (3) Applying 1% truncation to all continuous variables reduces interference from outliers in data analysis, improving both predictive accuracy and interpretability of the model. The total sample size is 32,910.

4.2. Research model

4.2.1. Benchmark regression model

The benchmark regression model is used to test the direct impact of digital transformation (DT) on dual innovation (AI), and the following model is constructed:

$$AI_{it} = \alpha_0 + \alpha_1 DT_{it} + \alpha_c Controls_{i,t} + \delta_t + \varepsilon_i + \mu_{i,t}$$

This model examines whether digital transformation significantly enhances corporate dual innovation. AI_{it} denotes firm i 's ambidextrous innovation level in year t , DT_{it} represents the degree of digital transformation of the enterprise, and α_1 is its regression coefficient, reflecting the marginal impact of digital transformation on ambidextrous innovation. $Controls_{i,t}$ represents control variables (e.g., firm size, leverage) to exclude confounders. δ_t and ε_i denote year and firm fixed effects controlling for time trends and individual heterogeneity, while $\mu_{i,t}$ is the random error term. A significantly positive α_1 supports H1, confirming DT's positive effect on ambidextrous innovation.

4.2.2. Moderating effect model (interaction term)

The moderating effect model is used to test whether digital transformation enhances the promoting effect of ESG on dual innovation, that is, whether there is a synergistic effect between ESG and DT. The following model is constructed:

$$AI_{it} = \theta_0 + \theta_1 DT_{it} + \theta_2 ESG_{it} + \theta_3 (DT_{it} \times ESG_{it}) + \theta_4 Controls_{it} + Size + Lev + FIXED$$

The key to this model lies in the interaction term $DT_{it} \times ESG_{it}$, whose coefficient θ_3 reflects the moderating effect of digital transformation on the relationship between ESG and ambidextrous innovation. If θ_3 is significantly positive, it indicates that a higher level of digital transformation strengthens the positive impact of ESG on ambidextrous innovation, thereby supporting research hypothesis H2.

4.3. Variable measurement

4.3.1. Dependent variable: dual innovation (exploration vs. exploitation)

Building upon the "exploration-utilization" dual innovation paradigm, this study maps corporate innovation strategies through patent-level technical knowledge restructuring patterns. Specifically, we construct the following model based on the overlap between the top four subclasses in the International Patent Classification and patent families from year t and the past five years ($t-1$ to $t-5$):

- (1) Utilization innovation (UI_{it})

$$UI_{it} = \frac{1}{1000} \sum_{p \in P_{it}} I \left\{ IPC4_p \cap \bigcup_{T=1}^5 IPC4_{i,t-T} \neq \emptyset \right\}$$

Here, P_{it} represents all invention patents granted to firm i in year t ; $IPC4_p$ indicates the primary first four subclasses IPC of patent P ; and the indicator function $I\{\cdot\}$ is used to mark whether there is repetition in the technological field. Dividing by 1000 aims to mitigate the influence of scale effects.

(2) Exploratory innovation (EI_{it})

$$EI_{it} = \frac{1}{1000} \sum_{p \in P_{it}} I \left\{ IPC4_p \cap \bigcup_{T=1}^5 IPC4_{i,t-T} \neq \emptyset \right\}$$

This indicator captures the expansion of knowledge in new technological areas and can be seen as a proxy for breakthrough innovation. It is worth noting that in order to control for the granularity bias in the IPC classification, this paper further employs "technological co-classification entropy" for robustness testing, and the results remain consistent.

4.3.2. Explaining variables: digital transformation

The digital transformation measurement employs text analysis methods by extracting keyword frequency ratios in corporate annual reports related to digitalization to construct a digital intensity index. This approach objectively reflects a company's emphasis on and actual investment in digital technologies, aligning with existing literature. To improve accuracy, we manually verified the keyword database, removing generic terms and retaining those with high technical specificity.

4.3.3. Moderating variables: ESG

ESG performance is measured using the Huazheng ESG rating score as a proxy variable, covering three dimensions: Environment (E), Society (S), and Governance (G). The environmental dimension includes indicators such as carbon emissions and resource utilization efficiency; the social dimension focuses on employee welfare and community contributions; while the governance dimension evaluates board structure and information disclosure transparency. The Huazheng rating system uses a nine-tiered scale from AAA to C, which this study converts into a continuous variable (1-9 points), where higher scores indicate superior ESG performance.

4.3.4. Control variables

To comprehensively analyze the relationship between digital transformation and dual innovation, this study incorporates a series of control variables to eliminate interference from other potential factors. Firm size is measured by the natural logarithm of total assets, firm age by years since establishment, financial leverage by debt-to-asset ratio, profitability by return on equity (ROE), and ownership concentration by the shareholding ratio of the Top5 shareholders.

Table 1. Research variables

type of variable	Variable name	measurement methods
explained variable	Dual innovation (AI)	Utilization innovation: $\log(\text{utility model} + \text{design patent application quantity} + 1)$
		Exploratory innovation: take the logarithm of invention patent applications +1
		Total innovation: $\log(1 + \text{number of patents})$ (robust test)
explanatory variable	Digital Transformation (DT)	Text analysis method: frequency ratio of "digital" related words in annual reports
regulated variable	ESG expression	Huade ESG rating
	scale	Natural logarithm of total assets
controlled variable	enterprise age	Establishment period
	fixed assets ratio	Net fixed assets/total net assets
	financial leverage	$\text{EBIT}/(\text{EBIT}-\text{I-D}/(1-\text{T}))$
	Equity concentration	Top5 shareholding ratio

5. Results

5.1. Descriptive statistics

Table 2 presents descriptive statistics for key variables, covering 2010–2023 Shanghai and Shenzhen A-shares. The final sample includes 32,910 firm-year observations after cleaning. Exploratory innovation (EI) shows a mean of 5.985 (SD=19.262), ranging 0–1336, reflecting large variations in breakthrough innovation. Utilization innovation (UI) has a higher mean (87.223) and wider dispersion (SD=489.893), indicating a general preference for incremental innovation. Digital transformation (DT) averages 14.462 (SD=34.722), revealing divergent digital maturity across firms, while ESG performance averages 4.024 (SD=1.354), being relatively concentrated despite outliers like 18.25. Control variables include: Size (mean=22.326), Lev (0.448), FIXED (0.208), Top5 (51.685%), and FirmAge (3.013, log). enterprise age (FirmAge) is 3.013 (after logarithm).

Table 2. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Exploratory innovation	32910	5.985	19.262	0	1336
Utilization-based innovation	32910	87.223	489.893	0	17573
Digital transformation	32910	14.462	34.722	0	547
ESG	32910	4.024	1.354	-7.75	18.25
Size	32910	22.326	1.370	14.942	28.697
Lev	32910	0.448	1.032	-0.195	178.346
FIXED	32910	0.208	0.160	0	0.954
Top5	32910	51.685	15.482	0	99.23
FirmAge	32910	3.013	0.304	1.386	4.290

5.2. Baseline regression results

Table 3 reports regression results of digital transformation (DT) on dual innovation. Columns 1-3 use exploratory innovation (y1) as dependent variable, columns 4-6 use exploitative innovation (y2). DT shows significantly positive effects on both y1 and y2 (coefficients 0.068-0.547, all at 1% level), supporting H1. This confirms DT enhances both innovation types through improved information processing and resource expansion. Among controls, Size positively affects both innovations, indicating larger firms' resource advantages. FIXED shows positive correlation, reflecting physical investment's complementarity with innovation. FirmAge is significantly positive, suggesting mature firms better convert experience into innovation. However, Lev and Top5 show varying effects across specifications, indicating complex impacts of capital structure and governance on innovation strategies.

Table 3. Benchmark regression results

	Exploratory innovation	Exploratory innovation	Exploratory innovation	Utilization innovation	Utilization innovation	Utilization innovation
Digital transformation	0.085*** (0.019)	0.068*** (0.018)	0.313*** (0.035)	0.547*** (0.033)	0.432*** (0.029)	0.313*** (0.035)
Size		37.059*** (0.456)	74.743*** (1.191)		75.978*** (0.758)	74.743*** (1.191)
Lev		-0.391 (0.578)	0.786 (0.662)		-1.938*** (0.960)	0.786 (0.662)
FIXED		37.537*** (3.838)	39.322*** (8.149)		14.841*** (6.373)	39.322*** (8.149)
Top5		-1.008*** (0.041)	-2.279*** (0.086)		-2.341*** (0.067)	-2.279*** (0.086)
FirmAge		14.107*** (2.041)	69.444*** (7.382)		31.274*** (3.390)	69.444*** (7.382)
_cons	110.544***	-714.658***	-1620.951***	202.412***	-1467.638***	-1620.951***
company	NO	NO	YES	NO	YES	YES
year	NO	NO	YES	NO	YES	YES
N	32910	32910	32910	32910	32910	32910

Standard errors in parentheses *p<0.1, **p<0.05, ***p<0.01 (same below)

5.3. Moderating effect

To test ESG's moderating role, we add a DT×ESG interaction term in Table 4. The term shows significantly positive coefficients for both exploratory (0.024, 1% level) and utilization innovation (0.043, 5% level), supporting H2 that stronger ESG enhances DT's impact on dual innovation. These results indicate robust ESG builds sustainable foundations, while DT amplifies ESG's innovation effects through data integration and transparency. For instance, digital platforms enable real-time ESG monitoring, and blockchain improves supply chain transparency, jointly boosting innovation efficiency.

Table 4. Moderating effects

	Exploratory innovation	Utilization innovation
Digital Transformation B	-0.015	-0.019
ESG	1.736*** (0.493)	3.576*** (0.708)
Moderator variable	0.024*** (0.004)	0.043** (0.020)
Size	38.486*** (0.695)	73.970*** (1.193)
Lev	-0.080 (0.511)	0.815 (0.662)
FIXED	32.077*** (5.233)	39.724*** (8.136)
Top5	-1.034*** (0.055)	-2.284*** (0.086)
FirmAge	26.636*** (3.698)	68.580*** (7.334)
N	32910	32910

5.4. Heterogeneity analysis

This study examines group differences in DT's impact through ownership nature (SOEs vs. non-SOEs) and listing location, with results in Tables 5-6. For exploratory innovation (y1), DT's coefficient is 0.048 (10% level) in non-SOEs versus 0.126 (5% level) in SOEs, indicating SOEs' stronger exploratory innovation due to resource and policy advantages. Meanwhile, DT shows insignificant impact (-0.042) in non-listed firms but significant effect (0.077, 5% level) in listed companies, reflecting market supervision and financing access's positive role.

Table 5. Heterogeneity analysis of exploratory innovation

	Exploratory innovation	Exploratory innovation	Exploratory innovation	Exploratory innovation
Digital transformation	0.048*	0.126**	-0.042	0.077**
	(0.025)	(0.056)	(0.027)	(0.033)
Size	36.647***	37.307***	42.850***	38.124***
	(0.892)	(1.382)	(1.687)	(0.802)
Lev	-0.064	-19.290***	-11.718	-0.151
	(0.510)	(6.141)	(7.451)	(0.517)
FIXED	41.744***	5.452	51.118***	24.105***
	(6.977)	(8.489)	(11.958)	(5.857)
Top5	-1.364***	-0.386***	-1.106***	--0.885***
	(0.066)	(0.112)	(0.113)	(0.064)
FirmAge	22.386***	19.816**	29.041***	26.882***
	(4.115)	(7.843)	(6.164)	(4.498)
N	20713	11413	6539	26371

For utilization innovation (y2), both SOEs and non-SOEs show significant DT effects (coefficients 0.161/0.297, 1% level), with SOEs demonstrating stronger impacts. Among listed companies, SSE/SZSE-listed firms exhibit more pronounced effects (0.315, 1% level) versus non-main-board listings (0.108, 5% level). This confirms DT's widespread yet variably moderated impact on utilization innovation across corporate attributes and external factors.

Table 6. Heterogeneity analysis of utilization innovation

	Utilization innovation	Utilization innovation	Utilization innovation	Utilization innovation
Digital Transformation B	0.161***	0.297***		
	(0.020)	(0.037)		
Size	72.069***	69.739***	91.700***	71.464***
	(1.533)	(2.225)	(2.772)	(1.350)
Lev	0.811	- 23.141***	-50.808***	0.755
	(0.684)	(8.201)	(11.806)	(0.653)
FIXED	80.518***	-7.475	91.208***	30.242***
	(10.958)	(12.359)	(19.343)	(8.882)
Top5	-2.544***	-1.183***	-1.798***	-1.880***
	(0.109)	(0.159)	(0.189)	(0.097)
FirmAge	45.218***	102.539***	53.322***	83.176***
	(8.089)	(14.568)	(11.361)	(8.864)
Digital Transformation A			0.108**	0.315***
			(0.045)	(0.046)
N	20713	11413	6539	26371

5.5. Robust tests

Robustness tests in Table 7 confirm the reliability of baseline results. First, substituting the core variable with an alternative DT measure yields significantly positive coefficients (0.050-0.227, 1% level) for both innovations. Second, results remain stable when adjusting sample periods and controlling for industry fixed effects. Lastly, while financial leverage shows minor variations, all other controls maintain consistent significance, supporting conclusion robustness.

Table 7. Robustness tests

	Exploratory innovation	Exploratory innovation	Exploratory innovation	Utilization innovation	Utilization innovation	Utilization innovation
Digital Transformation A		0.058*** (0.013)	0.071*** (0.013)	0.206*** (0.017)	0.227*** (0.020)	0.209*** (0.018)
Digital Transformation B	0.050*** (0.011)					
Controls	YES (0.692)	YES (0.812)	YES (0.686)	YES (1.192)	YES (1.437)	YES (1.145)
Lev	-0.114	-0.359	0.118	0.782	0.608	1.011
N	32910	25576	29674	32910	25576	29674

This study empirically confirms that digital transformation significantly enhances dual innovation, with corporate ESG performance positively moderating this relationship. Heterogeneity analysis shows the effect varies by firm traits and market conditions. All findings withstand robustness checks, providing reliable evidence on the DT-ESG-innovation mechanism.

6. Conclusions

This study of Shanghai and Shenzhen A-shares (2009-2023) demonstrates that digital transformation significantly boosts dual innovation, with ESG performance positively moderating this effect. Heterogeneity analysis reveals stronger impacts in state-owned enterprises, main-board listed firms, and larger companies, highlighting the role of resource endowment and policy support. These robust findings provide both theoretical insights and practical guidance for sustainable innovation strategies.

Policymakers should promote digital infrastructure and SME transformation while enhancing ESG incentives to align sustainability with innovation. Tools like tax incentives and green finance can stimulate R&D in exploratory and green technologies. Future research should examine industry heterogeneity and conduct international comparisons of institutional impacts on the DT-ESG-innovation relationship.

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