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Research on the Mitigating Effect of ESG Performance on Financing Constraints in Commercial Circulation Enterprises: The Moderating Role of Digital Transformation

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Abstract: *Using A-share commercial circulation enterprises from 2012 to 2022 as the research sample, this paper conducts an empirical examination of the impact of ESG (Environmental, Social, and Governance) performance on financing constraints and the moderating effect of digital transformation. The findings indicate that favorable ESG performance can significantly alleviate corporate financing constraints. Specifically, for every one standard deviation increase in the comprehensive ESG score, the improvement in financing constraints amounts to 7.66% of the total fluctuation range of the SA index, demonstrating clear economic significance. Digital transformation, through technological empowerment and efficiency enhancement, markedly strengthens the mitigating effect of ESG on financing constraints, with its positive moderating effect being statistically significant at the 1% level. Among the sub-dimensions of ESG, the Governance (G) and social (S) dimensions emerge as the primary drivers for easing financing constraints, while the environmental (E) dimension exerts an insignificant impact. After controlling for endogeneity using the instrumental variable approach and placebo tests, the conclusions remain robust. This study provides empirical evidence for commercial circulation enterprises in formulating a "digital-ESG" synergistic strategy, financial institutions in innovating ESG financial products, and governments in improving information disclosure systems.*

Keywords: *ESG performance; financing constraints; digital transformation; commercial circulation enterprises; endogeneity test*

1. Introduction

The commercial circulation industry serves as a critical hub linking production and consumption. However, its "asset-light, high-turnover" characteristics expose enterprises in the sector to generally severe financing constraints, which restrict the high-quality development of the industry. The adoption ESG principles and digital transformation has emerged as important approaches to alleviate asymmetry and optimize the financing environment. Nevertheless, existing studies largely overlook the industry-specific attributes of the commercial circulation sector, and lack systematic investigations into the moderating effect of digitalization and the heterogeneous impacts of individual ESG dimensions. Using Chinese A-share listed commercial circulation enterprises from 2012 to 2022 as the research sample, this study empirically examines the mitigating effect of ESG performance on financing constraints, the moderating role of digital transformation, and the differential effects across ESG dimensions. The research conclusions enrich industry-level theoretical findings and provide empirical references for decision-making by enterprises, financial institutions, and government authorities.

2. Theoretical analysis and research hypothesis

2.1 ESG performance and financing constraints

Information asymmetry is a key driver of financing constraints for enterprises. Because external investors find it difficult to fully grasp a company’s true financial condition, they often mitigate the risk of adverse selection through risk premiums or credit rationing [1]. The “asset-light, high-turnover” characteristics of commercial and distribution enterprises result in a scarcity of collateral and cash flow volatility, further exacerbating financing constraints. Signal transmission theory suggests that ESG performance can convey highly credible positive signals, intuitively reflecting a firm’s risk

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management capabilities and long-term value creation potential [2]. Gao Lu (2023) confirms that the fulfillment of corporate social responsibility can supplement the shortcomings of traditional financial reporting and reduce creditors' cognitive ambiguity regarding non-financial risks [3], while a strong ESG track record can also accumulate reputational capital, forming an implicit debt repayment safeguard mechanism recognized by financial institutions. Based on this, Hypothesis H1 is proposed: ESG performance significantly alleviates financing constraints for commercial and distribution enterprises.

2.2 The Moderating Effect of Digital Transformation

2.2.1 Theoretical mechanism

Digital transformation, through dual mechanisms of technological empowerment and efficiency enhancement, synergizes with ESG practices in the commerce and distribution sector to alleviate financing constraints.

(1) At the technological empowerment level, addressing pain points such as high verification costs and questionable credibility of ESG information caused by dispersed industry outlets and fragmented data, blockchain enables full-lifecycle evidence preservation for data related to supply chain transactions, outlet compliance, and customer rights. Meanwhile, big data and artificial intelligence provide real-time monitoring and dynamic disclosure of core indicators such as energy consumption, labor-management relations, and internal controls, replacing traditional static reporting and significantly reducing financing friction caused by information asymmetry [4].(2) In terms of efficiency enhancement, a digital omnichannel management platform bridges the transformation path from ESG value to operational performance: the S dimension uses supply chain digitization to dynamically identify supplier compliance risks, thereby optimizing inventory turnover; the G dimension uses digital internal controls to monitor store operations in real time to reduce losses from non-compliance; the E dimension adopts refined energy consumption management to identify opportunities for cost optimization. Ultimately, this creates a virtuous cycle of "ESG investment—digital implementation—improved operational Performance-enhanced debt-repayment capacity," alleviating external capital's concerns regarding the value of ESG investments and amplifying the effect of ESG in easing financing constraints [5].

2.2.2 Research Hypothesis

To verify the above moderating effect, and combining the logical framework of marginal effect theory, the mitigation effect of ESG on financing constraints (SA index) is expressed as:

$$\frac{\partial \mathrm{SA}_{it}}{\partial \mathrm{ESG}_{it}} = \beta_1 + \beta_3 \times \mathrm{Digital\_Text}_{it} \tag{1}$$

Among them, the sign and significance of β_3 directly reflect the directional direction and strength of the moderating effect of digital transformation. The definitions of other variables in the formula are shown in Table 1. If β_3 is significantly positive, it means that the improvement of digitalization level will systematically increase the marginal mitigation effect of ESG on financing constraints. Essentially, digital transformation reduces the transmission cost and verification cost of ESG signals, making the value of ESG performance more easily perceived and recognized by the capital market[6]. Based on this, Hypothesis H2 is proposed: Digital transformation plays a positive moderating role in the relationship between ESG alleviating financing constraints.

2.3 The influence of ESG sub-dimension heterogeneity

(1) Governance Dimension (G): Foundational factor. Zhao Zhiding et al. note that the "prudent speech, decisive action" strategy builds capital market trust and reduces financing communication costs by strengthening institutional processes, optimizing disclosure quality, and enhancing business ethics compliance. This effect is more pronounced in non-state-owned enterprises and regions with high digital economies [7]. (2) Social Dimension (S): Core factor. Qian Ming et al. find that social responsibility disclosure significantly alleviates corporate financing constraints, with this effect being more pronounced in private enterprises. The underlying mechanism involves companies strengthening stakeholder relationship management to reduce information asymmetry, build market reputation, and secure government resource support [8]. This aligns well with commercial distribution

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enterprises—predominantly private and reliant on supply chain and customer trust. (3) Environmental Dimension (E): Limited Effect. Li Boxun's research indicates that only indicators that can be verified at low cost by financial institutions and incorporated into standardized risk control templates can alleviate financing constraints [9]. Environmental practices in the commerce and distribution sector are concentrated in indirect areas such as logistics energy consumption and packaging reduction, lacking the quantifiable production-end environmental indicators and unified accounting standards found in manufacturing [10]; outsourcing of core environmental operations leads to data fragmentation and extremely high verification costs ; compounded by the "light-asset" nature of the sector and the long-term return characteristics of environmental investments , external investors find it difficult to assess the impact on improved debt-repayment capacity within the credit cycle; consequently, the E dimension struggles to translate into credible financing signals. Based on the above analysis, this paper proposes Hypothesis H3: The mitigating effects of each ESG sub-dimension on financing constraints for commerce and distribution enterprises exhibit heterogeneity, with the governance (G) and social (S) dimensions demonstrating stronger mitigating effects than the environmental (E) dimension.

3. Research design

3.1 Description of variables

Based on the relevant data of China A-share listed companies in 2012-2022, and according to the document *Guidelines for the Classification of Listed Companies (Revised in 2012)*[11]issued by China Securities Regulatory Commission, the sample covers wholesale industry (F51), retail industry (F52), road transport industry (G54), water transport industry (G55), air transport industry (G56) and warehousing industry. Sample data preprocessing follows the following principles: firstly, enterprises and financial enterprises marked as ST/*ST during the sample period are excluded; Secondly, the samples with missing data in the explained variables, explanatory variables, regulating variables, control variables and endogenous related variables are excluded, and the complete observation values of each enterprise for 11 years are ensured to balance the panel characteristics, so as to finally obtain 330 annual observation values of 30 A-share listed companies. Finally, the upper and lower 1% quantiles of continuous variables are truncated to reduce extreme interference. Description and treatment of each variable are shown in Table 1.

Table 1 Description and Processing of Relevant Variables

Variable Category	Variable Name (Code) / Data Source	Variable Definition
Dependent Variable	Financing Constraints (SA)	See formulas (2) and (3) for details
Core Explanatory Variables	ESG Composite Score (ESG), Environmental Dimension Score (E_Score), Social Dimension Score (S_Score), Governance Dimension Score (G_Score) / Huazheng ESG Rating Database	Measure the enterprise's overall ESG performance and the performance of environmental, social, and governance sub-dimensions respectively; a higher score indicates better performance in the corresponding dimension
Moderating Variable	Frequency of Digitalization-related Terms (Digital_Text) / CNRDS	Based on text analysis methods, count the occurrence frequency of digitalization-related vocabulary in enterprise annual reports and other documents
Control Variables	Firm Size (Size) / Natural logarithm of total assets	Measure the overall scale of the enterprise
	Asset-Liability Ratio (Lev) / Total liabilities divided by total assets	Measure the enterprise's financial leverage level
	Return on Assets (ROA) / Net profit divided by total assets	Measure the profitability efficiency of enterprise assets
	Firm Age (Firm_Age) / CSMAR	The duration from the establishment of the enterprise to the observed year
	Equity Concentration (Top1_Holding) / CSMAR	The proportion of shares held by the enterprise's largest shareholder to total shares, reflecting the degree of equity concentration
	Internal Control Quality (IC_index) / Dibo Internal Control Index and Rating	Evaluate the effectiveness of the enterprise's internal control system; a higher index indicates a more sound and effective internal control system
Variables Related to Endogeneity and Robustness	Lagged Term of ESG (ESG_Lag1) / Derived from the 1-period lag of Huazheng Index ESG Rating values	Take the 1-period lagged ESG score respectively, used to alleviate the potential reverse causality endogeneity problem between ESG performance and financing constraints

3.2 Model construction

In order to test the research hypothesis, this paper constructs the following econometric model

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system. Unless otherwise specified, all models use two-way fixed effect panel estimation, control individual effect and time effect synchronously, and make a unified multicollinearity diagnosis (VIF < 10) to ensure the reliability of the estimation[12], which will not be described in detail later.

(1) Main Effect Model (Test of H1)

First, to construct the proxy variable for financing constraints, we adopt the standard SA index formula from Hadlock & Pierce(2010) to calculate the degree of financing constraints for each enterprise in each year[13]:

$$\mathrm{SA}_{i,t} = -0.737 \times \mathrm{Size}_{i,t} + 0.043 \times \mathrm{Size}_{i,t}^2 - 0.040 \times \mathrm{Age}_{i,t} \quad (2)$$

Specifically, $\mathrm{Size}_{i,t}$ denotes the natural logarithm of total assets, and $\mathrm{Age}_{i,t}$ corresponds to the firm age (Firm_Age) defined in Table1. Subsequently, we treat $\mathrm{SA}_{i,t}$ as the dependent variable and employ a fixed-effects panel model to estimate the mitigation effect of ESG performance on financing constraints, as presented in Equation (3):

$$\mathrm{SA}_{i,t} = \alpha_0 + \alpha_1 \mathrm{ESG}_{i,t} + \sum \mathrm{Controls}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (3)$$

Where i and t denote the firm and year, respectively; μ_i represents the firm fixed effect, and λ_t represents the time fixed effect; $\sum \mathrm{Controls}_{i,t}$ stands for the set of all control variables; $\varepsilon_{i,t}$ is the random error term. If α_1 is significantly positive, it indicates that better ESG performance corresponds to a larger SA value (i.e, lighter financing constraints), thus verifying hypothesis H1.

(2)Moderating Effect Model (Test of H2)

Based on the main effect model, we introduce the interaction term between ESG and Digital_Text, with the core test focusing on the coefficient of the interaction term α_3:

$$\mathrm{SA}_{i,t} = \alpha_0 + \alpha_1 \mathrm{ESG}_{i,t} + \alpha_2 \mathrm{Digital\_Text}_{i,t} + \alpha_3 (\mathrm{ESG}_{i,t} \times \mathrm{Digital\_Text}_{i,t}) + \sum \mathrm{Controls}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (4)$$

If α_3 is significantly positive, it indicates that digital transformation enhances the marginal mitigation effect of ESG on financing constraints, thus verifying hypothesis H2.

(3)Heterogeneity Model (Test of H3)

The composite ESG score is replaced by the sub-dimension scores of the Environmental (E), Social (S), and Governance (G) dimensions. The significance and magnitude of the coefficients across these dimensions are then compared:

$$\mathrm{SA}_{i,t} = \alpha_0 + \alpha_1 \mathrm{E}_{i,t} / \mathrm{S}_{i,t} / \mathrm{G}_{i,t} + \sum \mathrm{Controls}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (5)$$

If the coefficients of the G and S dimensions are significantly positive, and their absolute values are larger than that of the E dimension (with the E dimension coefficient being insignificant), hypothesis H3 is verified.

(4)Tool variable method

To address the reverse causality between ESG performance and financing constraints, this study adopts the Two-Stage Least Squares (2SLS) approach: In the first stage, the one-period lagged ESG term (ESG_Lag1) is employed as an instrumental variable to predict the current ESG level. If the first-stage F-statistic is significantly above the critical value and the p-value of the overidentification test is greater than 0.05, the instrumental variable is deemed to satisfy the validity and exogeneity requirements. In the second stage, the fitted values of ESG are used to explain the SA index. If the coefficient of the fitted ESG values in the second stage is significantly negative and consistent in direction with the OLS results, it indicates that after correcting for endogenous biases, sound ESG performance can still significantly alleviate financing constraints for commercial and distribution enterprises, thereby confirming the robustness of the core conclusions.

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4. Empirical analysis

4.1 Descriptive statistics

Table 2 shows that the mean value of the explained variable financing constraint (SA index) is -2.9641, and the standard deviation is 0.3239, which is within the normal distribution range of financing constraints of A-share listed companies, reflecting that the sample enterprises as a whole are facing moderate constraints; Among the core explanatory variables, the average score of ESG is 73.3494, and the sub-dimensions are characterized by G_score (79.1066) > S_Score (77.5215) > E_score (58.8314), and the standard deviation of S_score (15.2559) is significantly higher than other dimensions, which shows that the corporate social dimension is heterogeneous. The Digital_Text of the adjustment variable has an average value of 15.7363 and a standard deviation of 19.7737, reflecting the obvious differences in the digital transformation process of different enterprises. Among the control variables, the average values of enterprise scale, asset-liability ratio and return on assets are within the reasonable range of the industry, and there are no extreme abnormal values after 1% quantile truncation, which lays a reliable data foundation for subsequent empirical tests.

Table 2 Descriptive Statistics of Variables (N=330)

Variable	Mean	Std. Dev.	Min	Max
SA	-2.9641	0.3239	-3.7412	-2.1789
ESG	73.3494	4.4292	61.01	84.952
E_Score	58.8314	7.4157	45.69	82.85
S_Score	77.5215	15.2559	42.4955	100
G_Score	79.1066	4.2553	62.54	86.717
Digital_Text	15.7363	19.7737	0	141
Size	13.4507	0.9001	11.5186	15.5717
Lev	0.4814	0.2171	0.0347	0.8807
ROA	0.0377	0.0319	-0.1395	0.1363
Firm_Age	21.6309	6.4453	4	38.5
Top1_Holding	0.3702	0.1380	0.1023	0.6329
IC_index	653.6879	97.2193	0	834.1674

4.2 Correlation Analysis

Table 3 Correlation Analysis of Variables

	SA	ESG	E_Score	S_Score	G_Score	Digital_Text	Size	Lev	ROA	Firm_Age
SA	1.0000	0.2135***	0.0321	0.1876***	0.2345***	0.2826***	0.7489***	-0.1562**	0.1987***	0.1245**
ESG	0.2135***	1.0000	0.4131***	0.7169***	0.4798***	0.0759	0.0983*	0.0576	0.1173**	0.1428***
E_Score	0.0321	0.4131***	1.0000	-0.0215	0.1493***	0.0336	0.2911***	0.0762	0.0535	0.2349***
S_Score	0.1876***	0.7169***	-0.0215	1.0000	0.1245	0.1675***	0.0280	0.1183	0.0023	0.0481
G_Score	0.2345***	0.4798***	0.1493***	0.1245**	1.0000	-0.0521	-0.1156**	-0.3550***	0.2035***	0.0001
Digital_Text	0.2826***	0.0759	0.0336	0.1675***	-0.0521	1.0000	0.1215*	0.2152***	-0.0774	0.2412***
Size	0.7489***	0.0983*	0.2911***	0.0280	-0.1156**	0.1215*	1.0000	0.5471***	-0.0117	0.5389***
Lev	-0.1562**	0.0576	0.0762	0.1183**	-0.3550***	0.2152***	0.5471***	1.0000	-0.3842***	0.1415**
ROA	0.1987***	0.1173**	0.0535	0.0023	0.2035***	-0.0774	-0.0117	-0.3842***	1.0000	0.1337**
Firm_Age	0.1245**	0.1428***	0.2349***	0.0481	0.0001	0.2412***	0.5389***	0.1415**	0.1337**	1.0000

Notes: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 3 shows that the explained variable SA is significantly and positively correlated with the core explanatory variable ESG (0.2135***). The correlation coefficients between SA and the sub-dimensions of governance (G_Score) and social (S_Score) are 0.2345*** and 0.1876*** respectively, both of which pass the significance test at the 1% level, while the correlation coefficient with the environmental dimension (E_Score) is 0.0321, which fails the significance test.From the perspective of the moderating variable, the correlation coefficient between SA and digital-related word frequency (Digital_Text) is 0.2826***, indicating that enterprises with a higher degree of digital transformation face relatively lighter financing constraints, which provides preliminary data support for the positive moderating effect of digital transformation.At the level of control variables, the asset-liability ratio (Lev) is significantly and negatively correlated with SA (-0.1562**). The correlation coefficients of return on assets (ROA) and firm age (Firm_Age) with SA are 0.1987*** and 0.1245** respectively, both showing significant positive correlations.In addition, the correlation between ESG and the social dimension (S_Score) is the highest (0.7169***). The correlation coefficients between ESG and the environmental dimension (E_Score) and governance dimension (G_Score) are 0.4131*** and 0.4798*** respectively, all of which are significant at the 1% level.There is no extremely high correlation intensity among the core variables, which lays a foundation for the subsequent empirical analysis.

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4.3 Baseline Regression: Main Effect Test

Table 4 shows that the regression coefficient of ESG, the core explanatory variable, is 0.0056, which is significantly positive at the level of 5% (t=2.4348, p=0.0156), indicating that the corporate financing constraint (SA index) is significantly improved by 0.0056 for every unit of ESG performance improvement, that is, the improvement of ESG by one standard deviation can make the financing constraint account for 7.66% of the total SA fluctuation, and the hypothesis H1 is verified. At the same time, the VIF values of all variables are less than 3, and there is no collinearity interference problem. As for control variables, the coefficient of enterprise Size is 0.2247, the coefficient of return on assets (ROA) is 0.2156, and the coefficient of Firm_Age is 0.0512, all of which are positive and significant at the levels of 1%, 1% and 10% respectively. The coefficient of asset-liability ratio (Lev) is -0.1234, which is significantly negative at the level of 5%, that is, the larger the scale, the stronger the profit, the longer the operating years, the lighter the financing constraints, and the higher the leverage, the heavier the constraints. The first largest shareholder's shareholding ratio (Top1_Holding) coefficient is 0.1492, and the internal control quality (IC_index) coefficient is 0.0003, both of which are not statistically significant. The model adjustment R^2 is 0.6595, R^2 is 0.6612, and F statistic is 152.4159, which is significant at 1% level. The overall fitting effect is good, and the regression results are statistically robust.

Table 4 Baseline Regression Results and Multicollinearity Test

Variable	Coefficient	Std. Error	t-value	p-value	significance level	VIF
ESG	0.0056	0.0023	2.4348	0.0156	**	1.041
Size	0.2247	0.0178	12.6202	0.0000	***	2.407
Lev	-0.1234	0.0482	-2.5602	0.0112	**	2.500
ROA	0.2156	0.0815	2.6454	0.0085	***	1.366
Firm_Age	0.0512	0.0243	2.1070	0.0362	*	1.518
Top1_Holding	0.1492	0.5621	0.2654	0.7908	-	1.419
IC_index	0.0003	0.0002	1.5000	0.1340	-	1.089
Sample Size	330	-	-	-	-	-
Number of Firms	30	-	-	-	-	-
Number of Years	11	-	-	-	-	-
R^2	0.6612	-	-	-	-	-
Adjusted R^2	0.6595	-	-	-	-	-
F-statistic	152.4159	-	-	0.0000	***	-
Firm Fixed Effects	Controlled	-	-	-	-	-
Year Fixed Effects	Controlled	-	-	-	-	-

Notes: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

4.4 Moderating Effect Analysis

Table 5 Regulative effect regression results and multicollinearity test table

Variable	Coefficient	Std. Error	t-value	p-value	significance level	VIF
ESG	0.0032	0.0015	2.1333	0.0338	**	1.213
Digital_Text	0.0015	0.0006	2.5000	0.0129	**	1.345
ESG_Digital_Text_ Interaction	0.0008	0.0002	4.0000	0.0001	***	1.567
Size	0.2312	0.0185	12.4973	0.0000	***	2.411
Lev	-0.1201	0.0491	-2.4460	0.0150	**	2.502
ROA	0.2089	0.0823	2.5383	0.0116	***	1.368
Firm_Age	0.0498	0.0245	2.0327	0.0428	**	1.520
Top1_Holding	0.1567	0.5632	0.2782	0.4458		1.421
IC_index	0.0002	0.0002	1.0000	0.3173		1.091
Sample Size	330					
Number of Firms	30					
Number of Years	11					
R^2	0.6825					
Adjusted R^2	0.6798					
F-statistic	196.72			0.0000	***	
Firm Fixed Effects	Controlled					
Year Fixed Effects	Controlled					

Table 5 shows that the coefficient of the core interaction term ESG_Digital_Text_Interaction is 0.0008, which is significantly positive at the 1% level (t=4.0000, p=0.0001), indicating that digital transformation significantly strengthens the mitigating effect of ESG on financing constraints of commercial circulation enterprises. Meanwhile, according to the marginal effect expression (1) above, the marginal benefits under different digitalization levels can be compared intuitively: two

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representative scenarios are selected, namely digital-related word frequency (Digital_Text) of 10 (approximately 25th percentile, low digitalization level) and 50 (1.7 standard deviations higher than the mean, high digitalization level). By substituting into expression (1), the marginal effect of ESG increases from 0.0112 to 0.0432, with an increase of 3.85 times. It can be seen that the higher the digitalization level, the lower the cost of verification and transformation of ESG information, and the easier its financing value can be amplified by the capital market, thus hypothesis H2 is verified. In addition, the VIF values of all variables are less than 3, and the adjusted R^2 of the model reaches 0.6798, indicating that the results remain robust.

4.5 Heterogeneity Analysis

In accordance with the Guidelines for the Industry Classification of Listed Companies (Revised 2012) issued by the China Securities Regulatory Commission [10], 330 firm-year observations are classified into two subsamples based on business attributes: "Wholesale and Retail" (Wholesale F51, Retail F52) and "Transportation and Storage" (Road Transportation G54, Water Transportation G55, Air Transportation G56, Storage G59). As shown in Table 6: the regression coefficients of the governance (G) and social (S) pillars are significantly positive at the 1% or 5% level in both industries. For the wholesale and retail sector, the coefficient of the G pillar is 0.0061 ($p = 0.0041$) and that of the S pillar is 0.0052 ($p = 0.0190$); for the transportation and storage sector, the coefficient of the G pillar is 0.0058 ($p = 0.0125$) and that of the S pillar is 0.0049 ($p = 0.0205$). In contrast, the coefficients of the environmental (E) pillar are insignificant at the 10% level ($p = 0.2229$ and $p = 0.2623$, respectively) and their absolute values are notably smaller than those of the G and S pillars, providing support for Hypothesis H3. This indicates that as non-manufacturing entities, the indirect influence and long-term return characteristics of the environmental pillar for commercial and distribution enterprises have not yet been fully recognized by the capital market. The adjusted R^2 values of the two subsamples range from 0.6721 to 0.6897 and from 0.6715 to 0.6922, respectively, indicating adequate model fit, which ensures the reliability and generalizability of the heterogeneous findings.

Table 6 Heterogeneity Analysis Results of ESG Sub-dimensions

Group	Dimension	Coefficient	Std. Error	t-statistic	p-value	95% CI Lower Bound	95% CI Upper Bound	Sample Size	R^2	Adjusted R^2	significance level
Retail and Wholesale Group	G	0.0061	0.0021	2.9048	0.0041	0.0019	0.0103	187	0.6925	0.6897	***
	S	0.0052	0.0022	2.3636	0.0190	0.0008	0.0096	187	0.6887	0.6858	**
	E	0.0011	0.0009	1.2222	0.2229	-0.0007	0.0029	187	0.6753	0.6721	
Transport and Warehousing Group	G	0.0058	0.0023	2.5217	0.0125	0.0012	0.0104	143	0.6951	0.6922	**
	S	0.0049	0.0021	2.3333	0.0205	0.0007	0.0091	143	0.6869	0.6837	**
	E	0.0009	0.0008	1.1250	0.2623	-0.0007	0.0025	143	0.6748	0.6715	

4.6 Robustness Tests

To verify the robustness of the core conclusions, a placebo test is performed to rule out random disturbances. The ESG composite score, the interaction term between ESG and digital transformation, the governance (G) pillar, and the social (S) pillar are randomly sampled and reassigned 1,000 times, and the baseline regression is repeated to obtain the distribution of placebo coefficients (see Figures 1–4). Given that the environmental (E) pillar exhibits neither statistically nor economically significant effects on mitigating financing constraints, it is excluded from the test to maintain focus on the core findings. The results show that the placebo coefficients of the four variables follow an approximately normal distribution with means close to zero (−0.0002 for the ESG composite, 0.0001 for the interaction term, −0.0003 for the G pillar, and −0.0002 for the S pillar) and corresponding p-values all greater than 0.987. In contrast, the baseline regression coefficients (0.0056 for the ESG composite, 0.0008 for the interaction term, 0.0061 for the G pillar, and 0.0052 for the S pillar) deviate significantly from the center of the distribution, cluster in the right tail, and show no overlap with the placebo coefficients. These findings confirm that the core effects are not driven by random factors, thereby corroborating the robustness of the empirical results.

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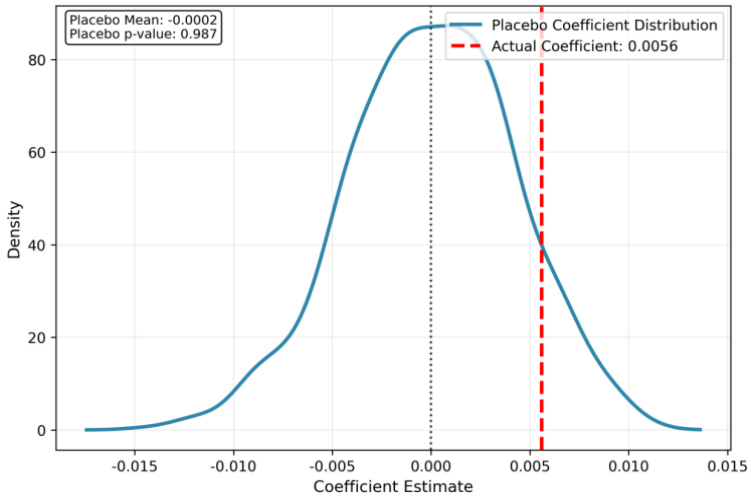

Figure 1 Distribution of ESG Composite Score Coefficients

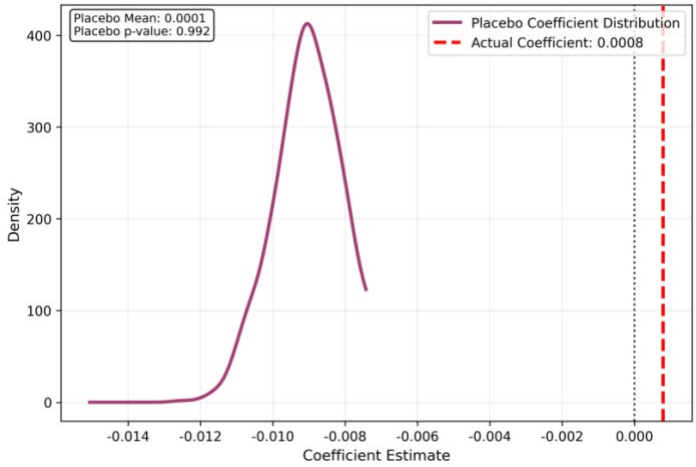

Figure 2 Distribution of ESG × Digitalization Interaction Term Coefficients

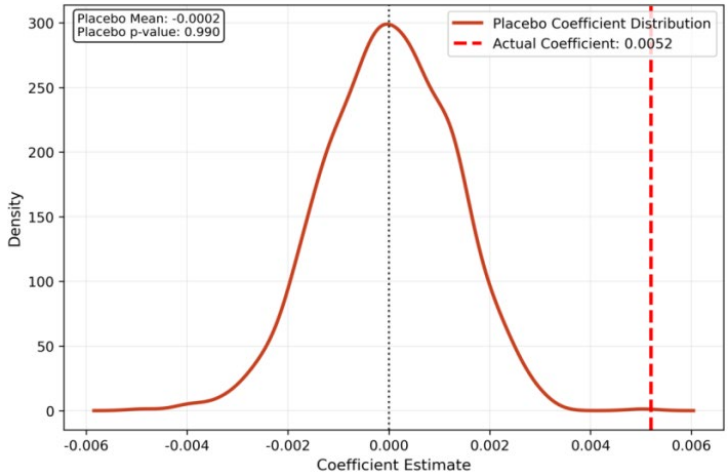

Figure 3 Distribution of Social (S) Dimension Coefficients

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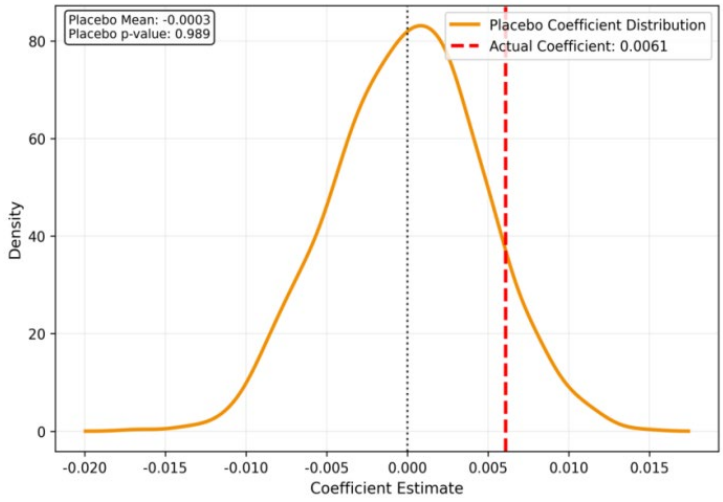

Figure 4 Distribution of Governance (G) Dimension Coefficients

4.7 Endogenous test

To address the endogeneity issue of reverse causality between ESG performance and financing constraints of commercial and distribution enterprises, the first-order lagged term of ESG (ESG_Lag1) is adopted as the instrumental variable, and the two-stage least squares (2SLS) method is used for regression correction. As shown in Table 7, the first-stage F-statistic is 28.76, which is well above the critical value of 10, ruling out weak instrument concerns. The p-value of the overidentification test is 0.345 (> 0.05), supporting the exogeneity assumption of the instrumental variable. In the second-stage regression, the mitigation coefficient of the ESG composite score on financing constraints is 0.0072 ($p < 0.01$), exhibiting higher significance than that of the baseline OLS regression (0.0056, $p < 0.05$) with a consistent sign, suggesting that the baseline regression underestimates the true mitigating effect of ESG performance. After correcting for endogeneity bias, the core conclusion that superior ESG performance significantly alleviates financing constraints of commercial and distribution enterprises remains robust, providing unbiased and reliable empirical support for Hypothesis H1.

Table 7 Results of Instrumental Variable Validity Tests

Regression Method	Benchmark OLS	2SLS (First Stage)	2SLS (Second Stage)	IV Diagnostic Statistics
Dependent Variable	SA	ESG	SA	-
Core Explanatory Variable	ESG	ESG_Lag1	ESG Instrumental Variable Estimation	-
ESG_Lag1 Coefficient	-	0.3154(p<0.01)	-	Relevance: First-stage F-statistic = 28.76 (F > 10, weak instrument concern rejected)
ESG Coefficient	0.0056**	-	0.0072***	Exogeneity: The p-value of the overidentification test is 0.345, supporting the null hypothesis that the instrumental variables are exogenous.
Std. Error	0.0023	-	0.0025	-
t-value	2.4348	-	2.8800	-
p-value	0.0156	-	0.0043	-
Adjusted R^2	0.6595	0.5326	0.6781	-
Sample Size	330	330	330	-
Number of Firms	30	30	30	-
Number of Years	11	11	11	-
Control Variables	Table 1 Size, Lev, etc.	Table 1 Size, Lev, etc.	Table 1 Size, Lev, etc.	-
Fixed Effect Type	Firm + Year	Firm + Year	Firm + Year	-

5. Main results

This study takes A-share listed companies in China from 2012 to 2022 as samples, and draws three

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core conclusions: First, ESG performance has a significant alleviation effect on corporate financing constraints. Table 4 shows that its comprehensive score coefficient is 0.0056($p<0.05$), and the coefficient rises to 0.0072($p<0.01$) after being corrected by 2SLS method. The instrumental variables pass the test, and the effect is stable. Second, digital transformation plays a positive regulatory role. In Table 5, the coefficient of interaction between them is 0.0008($p<0.01$), and the mitigation effect of ESG under high-value digital word frequency is 3.85 times that of low value. Digitalization can reduce the cost of ESG signal transmission and verification. Third, the influence of ESG sub-dimension is heterogeneous. Table 6 shows that the G and S dimension coefficients of retail, wholesale, transportation and warehousing enterprises all passed the significance test, but the E dimension failed, because the G and S dimensions meet the demands of capital risk assessment, and the current financing value of E dimension has not been fully released.

6. Policy suggestions

(1) At the enterprise level, enterprises should formulate a "digital-ESG" collaborative development strategy, prioritize targeted efforts on the G and S dimensions, integrate ESG practices into business management, improve the equity check-and-balance mechanism and internal control system, and accumulate reputation capital through supply chain social responsibility audits and customer rights protection. They should also accelerate digital transformation, achieve ESG data storage and dynamic disclosure via blockchain and big data technologies, and appropriately deploy E-dimension practices—including new energy transport vehicle adoption and green warehousing construction—tailored to industry characteristics, thereby maximizing synergistic effects in alleviating financing constraints. (2) Financial institutions should innovate ESG financial products and evaluation systems. Specifically, they need to establish differentiated financing criteria for the commercial circulation industry, incorporate core indicators of the G and S dimensions into credit approval and investment decision-making, and develop financial products adapted to the collaborative development mode. Moreover, they should construct a digital ESG information verification platform, integrate multi-source information to enhance evaluation efficiency, and thereby mitigate financing frictions arising from information asymmetry. (3) At the government level, the government needs to improve institutional guarantees and policy incentives, establish an industry-differentiated ESG information disclosure system, and unify disclosure standards and calibers. It should provide tax relief and financial subsidies to enterprises advancing coordinated "digital-ESG" transformation, encourage financial institutions to boost ESG financial product innovation, and offer risk compensation for eligible ESG-related financing businesses. Additionally, the government should promote the localization and industrialization of the ESG evaluation system, optimize E-dimension evaluation indicators, fully unlock the financing value of ESG practices across all dimensions, and facilitate the high-quality development of the industry.

7. Conclusion

This paper takes China A-share listed companies in 2012-2022 as samples, tests the mitigation effect of ESG on financing constraints and the positive adjustment effect of digital transformation, clarifies the three-dimensional heterogeneity of ESG and verifies the robustness of the conclusion; The research reveals the digital collaborative empowerment mechanism and provides industry experience evidence, which can be introduced into the ESG cognitive expansion research of management in the future. Limited by design and data, this study can further enhance the conclusion value and present the difference of ESG financing effect by expanding the sample size, improving the digital evaluation index and disassembling the conduction path.

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