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Digital Transformation and ESG Rating Disagreement: A Dynamic Relationship Test Based on Panel VAR Model

Jingwei Li [1,*]

1   Capital University of Economics and Business, Beijing, 100070, China
*   Correspondence: Jingwei Li, Capital University of Economics and Business, Beijing, 100070, China

Abstract: Previous research focuses on the unidirectional relationship between digital transformation and ESG rating disagreement, even though some evidence suggests that ESG rating disagreement can influence digital transformation, which in turn reduces ESG rating disagreement. Based on the panel VAR, we study the simultaneous relationship between digital transformation and ESG rating disagreement employing data of A-share listed companies from 2011 to 2023 and ESG ratings from eight agencies. Using the panel VAR model, impulse response functions, and variance decomposition, this study provides new empirical evidence on the dynamic relationship between ESG and digital transformation. The findings reveal that ESG rating disagreement and digital transformation exhibit a symmetrically bidirectional dynamic relationship. It is further suggested that ESG rating disagreement and digital transformation exhibit lagged effects on each other.

1. Introduction

Under the global sustainable development agenda and the increasing emphasis on carbon neutrality targets, corporate Environmental, Social, and Governance (ESG) performance has become a key indicator of long-term enterprise value. The growing demand for non-financial disclosure has made ESG factors central to valuation and investment decisions. However, the lack of unified ESG rating standards has led to significant discrepancies among rating agencies, resulting in rating fragmentation. This inconsistency intensifies information asymmetry and financing constraints, raising capital costs and restricting firms' access to external capital.

To mitigate these issues, companies increasingly adopt digital transformation to enhance information transparency and operational efficiency. Technologies such as artificial intelligence, blockchain, and the Internet of Things improve the timeliness and quality of ESG data, thereby contributing to the reduction of rating disagreements. As a result, the interaction between digital transformation and ESG rating divergence has drawn increasing attention in academic and policy discussions.

Most existing studies focus on one-way causal effects. Some emphasize how digital transformation improves ESG information disclosure and reduces disagreement. Others highlight how ESG rating divergence increases financing costs and inhibits digital transformation. However, these approaches often overlook the possibility of bidirectional causality. Relying on unidirectional models may lead to biased estimates, even when the instrumental variables are applied.

This study investigates the dynamic bidirectional relationship between ESG rating disagreement and digital transformation. Using updated data and refined measures, we first confirm through baseline regression and mediation analysis that financing constraints and information transparency are key channels of interaction. We then employ a panel vector autoregression model to address endogeneity and lagged effects. Results show that ESG rating disagreement significantly inhibits digital transformation, while digital transformation slightly reduces rating disagreement.

Impulse response analysis reveals a delayed and persistent negative impact from ESG disagreement on digital transformation, and a quicker but less lasting mitigation effect in the reverse direction. Variance decomposition shows that both variables are mostly influenced by their own inertia, though digital transformation contributes more to reducing ESG disagreement over time.

This study contributes by modeling mutual dynamics, capturing asymmetric lag effects, and quantifying long-term interactions. The structure of the paper is as follows: Section 2 presents the theoretical foundation, Section 3 describes data and variables, Section 4 revisits prior findings, Section 5 introduces the dynamic model, and Section 6 offers conclusions and policy implications.

2. Theorical Analysis and Research Hypothesis

2.1. The Impact of Esg Rating Disagreement on Digital Transformation and Transmission Mechanism

Amid the rise of the digital economy, corporate digital transformation has shifted from a strategic option to a critical necessity for sustainable development and organizational survival. However, its implementation requires substantial capital investment. High costs arise from continuous upgrades of digital systems, including expenditures on R&D, digital tools, infrastructure, and full-cycle implementation [1-4]. Limited investment in advanced digital systems reduces firms' capabilities in data governance and information processing, slowing transformation progress [5]. Moreover, capital shortages restrict infrastructure flexibility and technological integration, further weakening transformation effectiveness [6]. Therefore, sufficient financing capacity is essential to sustain digital transformation.

Meanwhile, ESG rating disagreement has become increasingly common and has exerted growing influence on financing conditions in capital markets. Such disagreement intensifies information asymmetry and increases risk premiums, raising uncertainty for investors [7]. In response, investors demand higher returns to compensate for perceived risks, leading to elevated financing costs for firms [8-10]. This further restricts access to funding, especially for firms facing low consensus among ESG ratings [11-13].

The result is a higher weighted average cost of capital, which weakens firms' ability to invest in digital transformation. Financing barriers driven by ESG rating disagreement may distort capital allocation, limit investment in critical digital infrastructure, and ultimately suppress digital transformation. Based on this reasoning, we propose the following hypothesis:

H1: The higher the ESG rating disagreement, the lower the level of digital transformation.

2.2. The Impact of Digital Transformation on Esg Rating Disagreement and Transmission Mechanism

Current ESG rating differences arise primarily from two factors. First, the quality of ESG information disclosed by companies is uneven and often subjective. Variations in disclosure policies across regions and the absence of a standardized framework encourage selective disclosure, increasing ESG information uncertainty [14]. Second, without unified regulatory standards, ESG rating agencies differ in evaluation criteria, data collection methods, and their ability to detect greenwashing, resulting in significant inconsistency

in ratings [7,15,16]. In response, scholars generally agree that enhancing information transparency is key to mitigating ESG rating disagreement.

Li et al. propose that high-quality disclosure not only reduces rating uncertainty but also alleviates information asymmetry by broadening direct information channels for investors [17]. This argument is supported by Kimbrough et al., who stress the importance of reliable and standardized disclosure [18]. From the perspective of rating agencies, Dimson et al. show that greater transparency narrows the space for subjective interpretation and reduces information processing costs [6]. Zhang et al. find that stronger information sharing between companies and agencies decreases search costs and limits selective reporting, lowering rating divergence [19].

In the digital economy era, digital transformation plays a pivotal role in improving corporate information transparency by reshaping operational models and governance systems. Transparency involves aspects such as the availability, reliability, and consistency of information. Digital technologies such as artificial intelligence and big data improve data processing, making unstructured information more accessible and easier to interpret [20]. Blockchain ensures unified standards and immutable records, aiding in reducing asymmetry [21]. Enhanced integration capacity also supports innovation and efficient communication [22]. Huang et al. highlight how digital transformation converts private internal data into accessible shared information, reshaping corporate transparency at its core [23].

These mechanisms suggest that digital transformation improves ESG information environments, reducing rating divergence. Therefore, we propose the following hypothesis:

H2: The higher the level of digital transformation, the lower the ESG rating disagreement.

3. Research Design

3.1. Data and Sample

Our data include all A-share listed companies in China from 2011 to 2023. ESG rating data are sourced from eight agencies widely cited in Chinese academic research, including Huangzheng, SynTao Green Finance, FTSE Russell, Wind, Bloomberg, CNRDS, MSCI, and Sustainalytics. Digital transformation ratings, financial ratios and company-specific information are obtained from the CSMAR. We exclude ST or *ST with abnormal financial data, as well as all firms in the finance industry. Firm-year observations with missing control variables are further omitted, resulting in a final sample of 39341 observations. To mitigate outlier effects, all continuous variables are winsorized by replacing values below the 1st percentile and above the 99th percentile with the values at the 1st and 99th percentiles, respectively.

3.2. Variable Selection

3.2.1. ESG Rating Disagreement

ESG rating disagreement results from significant heterogeneity in evaluation criteria, data sources, and weighting schemes across ESG rating agencies. To measure the ESG rating disagreement, we follow the methodology proposed by Avramov et al [7]. Specifically, we employ ESG ratings from eight widely cited institutions in Chinese academic research to measure ESG rating disagreement. We first standardize ESG scores from all agencies into percentile rankings within a unified scale ranging from 0 to 1. Subsequently, for each firm-year observation, we compute pairwise standard deviations between every pair of ESG percentile rankings and derive the mean of these standard deviations as the proxy variable for ESG rating disagreement. A higher value of this metric indicates greater heterogeneity in ESG assessments across rating providers.

3.2.2. Digital Transformation Rating

Digital transformation represents a comprehensive organizational overhaul through which enterprises leverage digital technologies to restructure business models, optimize operational processes, enhance efficiency, drive innovation, and strengthen competitive advantages. Based on the research paradigm of Zhang & Jing , this study adopts the digital transformation index provided by the CSMAR database and innovatively constructs a structured evaluation system that includes six dimensions: strategic leadership, technology-driven, organizational empowerment, environmental support, digital outcomes, and digital application [24]. This index system not only covers the technological dimension, but also incorporates key elements such as pre-transformation capital investment, existing infrastructure level, innovation output efficiency, and future development potential, thereby achieving a systematic assessment of the level of digital transformation. It is particularly noteworthy that the index employs a scientific weighting method to construct a comprehensive scoring model, thus realizing a multidimensional and systematic measurement of the digital transformation process.

3.2.3. Control Variables

To mitigate the confounding effects of extraneous factors on ESG rating disagreement, this study draws on methodologies from Zhu et al. to incorporate control variables across three dimensions: firm basic characteristics, financial metrics, and governance structures [25]. Specifically, the selected variables include return on assets (ROA), leverage ratio, cash ratio, Tobin's Q, operating income growth rate, ownership concentration, institutional ownership, market value, firm age, board size and total asset turnover. These variables are introduced to account for potential heterogeneity in resource allocation, financial health, and governance efficacy that may independently influence ESG performance and rating discrepancies.

3.2.4. Mediating Variables

Financing constraints serve as a key mediating variable in examining the impact of ESG rating disagreement on corporate digital transformation. This study adopts the WW index proposed by Whited and Wu, which offers advantages over the commonly used KZ index [26]. Unlike the KZ index, the WW index reduces endogeneity by avoiding direct reliance on financial indicators influenced by ESG performance. It also captures dynamic effects through a panel model with firm fixed effects and time trends. In both indices, higher values indicate stronger financing constraints, and the WW index enhances the accuracy and robustness of empirical results.

Information transparency：Building on the work of Lin et al., we employ the KV index to measure information transparency, which incorporates both mandatory disclosure and voluntary disclosure, serving as a comprehensive metric for evaluating the quality of information disclosure in listed companies [27]. The higher the KV value, the lower the quality of enterprise information disclosure.

The KV measurement model is as follows:

$$Ln\left|\frac{\Delta P_t}{P_{t-1}}\right| = \alpha + \beta(Vol_t - Vol_0) + \mu_i, \text{ KV} = \beta \times 1000000$$

Where $Ln\left|\frac{\Delta P_t}{P_{t-1}}\right|$ measures the log-transformed magnitude of price fluctuations. The coefficient β quantifies the marginal impact of trading volume variations on price volatility. Vol_t represents the contemporaneous trading volume, while Vol_0 denotes the benchmark trading volume, operationally defined as the annual mean trading volume. The error term μ_i captures residual volatility factors not explained by the model. In the secondary equation, the β coefficient is normalized by a scaling factor of 1,000,000 to yield the KV metric. This standardization enables more intuitive interpretation of the parameter estimates in empirical applications. The definitions of the variables are shown in Table 1.

Table 1. Definition of variables.

Variables		Symbol	Definition
Independent variables	Digital transformation	Digitaltransindex	Digital transformation degree
Dependent variables	ESG rating disagreement	ESGdisagreement	Standard deviation of different ESG ratings
Controls	ROA	roa	Net profit/average total assets
	Leverage ratio	lev	Total liabilities/total assets
	Cash Ratio	cash	Closing cash and cash equivalents balance/total assets
	Tobin's Q	Tobinq	Market value/ replacement cost of its assets
	Growth rate of operating income	grow	(Revenue for the current year - Revenue for the same period last year) x (Revenue for the same period last year)
	Ownership concentration	con	shareholding ratio of the largest shareholder
	Institutional investors proportion	INST	The proportion of shares owned by institutional investors
	Enterprise size	size	A-shares * current closing price A-shares current value+domestically listed foreign shares B-shares * current closing price B-shares current value (Shanghai Stock Exchange * CNY USD, Shenzhen Stock Exchange/HKD CNY, converted to RMB)+(total number of shares - RMB common shares - domestically listed foreign shares B-shares) * (total owner's equity end of period value/paid in capital end of period value)+total liabilities end of period value
	Years in business	age	number of years the business has been established
	board size	Board	the natural logarithm of the total number of board members (including independent directors)
	Total asset turnover	turn	Operating revenue/average total assets
Mediator	Financing constraints	WW	WWindex
	Information transparency	kv	KVindex

Table 2 presents the descriptive statistics of the variables. The mean value of digital transformation is 35.383, with a median of 33.256, a minimum value of 21.866, and a maximum value of 63.303. The mean value of ESG rating disagreement is 0.207, with a median of 0.199, minimum value of 0.012, and maximum value of 0.540. The standard deviation of digital transformation is 9.946, indicating substantial variation in digital transformation levels across firms, while the smaller standard deviation of ESG rating disagreement (0.110) suggests relatively less variation. The descriptive statistics of other control variables are consistent with those reported in existing studies, indicating that the sample falls within reasonable and expected ranges.

Table 2. Descriptive Statistics.

VarName	Obs	Mean	Median	SD	Min	Max
Digitaltransindex	39341	35.383	33.256	9.946	21.866	63.303
ESGdisagreement	39341	0.207	0.199	0.110	0.012	0.540
roa	39341	0.040	0.039	0.066	-0.238	0.226
lev	39341	0.418	0.406	0.210	0.052	0.920
cash	39341	0.168	0.131	0.130	0.010	0.631
Tobinq	39341	2.162	1.706	1.420	0.874	9.335
grow	39341	0.151	0.094	0.386	-0.574	2.335
con	39341	33.944	31.590	14.902	8.380	74.570
INST	39341	43.733	45.102	25.034	0.355	91.679
size	39341	2.11e+10	6.34e+09	5.20e+10	1.00e+09	3.91e+11
age	39341	19.116	19.000	6.048	6.000	35.000
Board	39341	2.117	2.197	0.198	1.609	2.639
turn	39341	0.630	0.540	0.433	0.041	2.576

4. Reexamining the Empirical Results with New Data

In this study, we commence by re-examining prior empirical findings using our novel dataset. Specifically, our analysis proceeds in two key stages: First, we investigate the impact of ESG rating disagreement on digital transformation. Second, we assess the effect of digital transformation on ESG rating disagreement. These baseline regressions not only confirm the consistency of our results with existing literature but also facilitate a deeper exploration of the bidirectional relationship between ESG rating disagreement and digital transformation.

We test the impact of ESG rating disagreement on Digital transformation through following model:

$$Digitaltransindex_{i,t} = \alpha_0 + \alpha_1 ESGdisagreement_{i,t} + \sum controls + Indstry + Year + \epsilon_{i,t}$$

And the impact of Digital transformation on ESG rating disagreement through following model:

$$ESGdisagreement_{i,t} = \beta_0 + \beta_1 Digitaltransindex_{i,t} + \sum controls + Indstry + Year + \epsilon_{i,t}$$

Where $ESGdisagreement_{i,t}$ denotes ESG rating disagreement, $Digitaltransindex_{i,t}$ represents the degree of digital transformation. i denotes company and t denotes year. α_1 and β_1 respectively reflect the impact of ESG rating disagreement on Digital Transformation and the impact of Digital Transformation on ESG rating disagreement. Controls contains a series of control variables. Industry is the industry fixed effect and Year is the year fixed effect, and $\epsilon_{i,t}$ is the random error term.

4.1. Baseline Results

Table 3 reports the slope coefficients of ESG rating disagreement on digital transformation with and without control variables. It demonstrates that ESG rating disagreement exerts a statistically significant negative impact on digital transformation, regardless of whether control variables are included. The estimated coefficients are -0.462 and -0.425, both statistically significant at the 5% level. These results align with the findings of Ren, who reported coefficients of -0.687 and -0.691, confirming a robust negative relationship between ESG rating disagreement and digital transformation [28]. Specifically, the coefficients indicate that a one standard deviation increase in ESG rating disagreement leads to an approximate 0.425-unit decline in corporate digital transformation, underscoring the substantial inhibitory effect of ESG rating disagreement on digital transformation. These findings provide robust support for Hypothesis H1.

Table 3. Regression analysis of ESG Rating Disagreement on Digital Transformation of Enterprises.

VARIABLES	(1) Digitaltransindex	(2) Digitaltransindex
ESGdisagreement	-0.462**	-0.423**
	(0.208)	(0.207)
roa		0.0708
		(0.478)
lev		1.115***
		(0.221)
cash		-0.928***
		(0.259)
Tobinq		0.0230
		(0.0229)
grow		0.0808
		(0.0595)
con		-0.0291***
		(0.00386)
INST		-9.94e-05
		(0.00252)
size		0***
		(0)
age		-0.274***
		(0.0695)
Board		1.043***
		(0.205)
turn		-0.339***
		(0.109)
Constant	27.24***	29.26***
	(1.300)	(1.603)
Observations	39,341	39,341
R-squared	0.352	0.359
Number of stkcd	4,931	4,931
Year FE	Yes	Yes
Industry FE	Yes	Yes

Note: Robust standard errors in parentheses, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 4 reports slope coefficients of digital transformation on ESG rating disagreement. It reveals a weaker economic effect in the reverse causal relationship. In both the baseline and controlled models, the coefficients measuring the suppressive effect of digital transformation on ESG rating disagreement are -0.000311 and -0.000287, respectively, which are both significant at 5% level. Overall, Although the marginal effect of digital transformation on reducing ESG rating disagreement is relatively small—indicating that a one-unit increase in digital transformation can only reduce ESG rating disagreement by 0.03%—this impact is statistically significant. This finding confirms that corporate digital transformation can indeed effectively mitigate ESG rating disagreement, thereby providing empirical support for Hypothesis H2.

Table 4. Regression Analysis of ESG Rating Disagreement in Enterprises' Digital Transformation.

VARIABLES	(1) ESG disagreement	(2) ESG disagreement
Digitaltransindex	-0.000311**	-0.000287**
	(0.000140)	(0.000141)
roa		0.0310**
		(0.0125)
lev		0.0285***
		(0.00576)
cash		0.0124*
		(0.00674)
Tobinq		0.000284
		(0.000596)
grow		-0.00343**
		(0.00155)
con		-0.000142
		(0.000101)
INST		-5.69e-05
		(6.56e-05)
size		-0***
		(0)
age		-0.00274
		(0.00181)
Board		0.00235
		(0.00533)
turn		0.00154
		(0.00285)
Constant	0.210***	0.233***
	(0.0339)	(0.0419)
Observations	39,341	39,341
R-squared	0.016	0.018
Number of stkcd	4,931	4,931
Year FE	Yes	Yes
Industry FE	Yes	Yes

Note: Robust standard errors in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

4.2. Mediation Effect Test

To examine the underlying mechanisms through which ESG rating disagreement may affect corporate digital transformation, we employ a two-stage mediation framework incorporating two mediating pathways. The formal model specification is presented as follows:

Transmission mechanism of ESG disagreement:

$$WW_{i,t} = \gamma_0 + \gamma_1 ESGdisagreement_{i,t} + \sum controls + Industry + Year + \epsilon_{i,t}$$

$$Digitaltransindex_{i,t} = \delta_0 + \delta_1 ESGdisagreement_{i,t} + \delta_2 WW_{i,t} + \sum controls + Industry + Year + \epsilon_{i,t}$$

Transmission mechanism of digital transformation:

$$kv_{i,t} = \mu_0 + \mu_1 Digitaltransindex_{i,t} + \sum controls + Industry + Year + \epsilon_{i,t}$$

$$ESGdisagreement_{i,t} = \rho_0 + \rho_1 Digitaltransindex_{i,t} + \rho_2 kv_{i,t} + \sum controls + Industry + Year + \epsilon_{i,t}$$

Where WW represents the mediating variables representing financial constraints, kv represents the kv index measuring Information transparency. γ_1 and μ_1 respectively reflect the impact of ESG rating disagreement on financial constraints and the impact of Digital Transformation on Information transparency. δ_1 and δ_2 respectively denotes the impact of ESG rating disagreement and financial constraints on Digital Transformation. ρ_1 and ρ_2 respectively denotes the impact of Digital Transformation and Information transparency on ESG rating disagreement.

The mediation analysis shows that ESG rating disagreement inhibits the process of corporate digital transformation by increasing financing constraints, while corporate digital transformation can mitigate ESG rating disagreement by enhancing information transparency. Looking at Table 5, ESG rating disagreement significantly increases financing constraints at the 1% level. Column (2) examines the simultaneous impact of ESG rating disagreement and financing constraints on digital transformation. Results show that financing constraints have a significant and economically substantial negative impact on digital transformation. Notably, after controlling financing constraints, the coefficient of ESG rating disagreement becomes statistically insignificant, indicating that financing constraints largely mediate the relationship between ESG rating disagreement and digital transformation. This finding is consistent with the conclusion of Ren, while our results show greater statistical significance and theoretical consistency.

Column (3) indicates that digital transformation significantly reduces the KV index (a higher KV index indicates lower transparency), confirming that digital transformation enhances information transparency, which is consistent with the results of Han et al. In Column (4), when digital transformation and the information transparency index simultaneously affect ESG rating disagreement, the coefficient of ESG rating disagreement remains significant. By combining Columns (3) and (4), we conclude that digital transformation can mitigate ESG rating disagreement by enhancing information transparency.

Table 5. Mediating effects of ESG rating disagreement on corporate digital transformation.

VARIABLES	(1) WW	(2) Digital transformation	(3) kv	(4) ESG disagreement
ESGdisagreement	0.00723***	-0.360		
	(0.00172)	(0.230)		
WW		-12.34***		
		(0.791)		
digitaltransindex			-0.000811***	-0.000312**
			(0.000152)	(0.000152)
kv				-0.0211***
				(0.00592)
Constant	-0.929***	18.39***	0.161***	0.229***
	(0.0126)	(1.832)	(0.0434)	(0.0434)
Controls	Yes	Yes	Yes	Yes
Observations	33,372	33,372	33,372	33,372
R-squared	0.535	0.376	0.167	0.020
Number of stkcd	4,772	4,772	4,772	4,772
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

4.3. Robustness Test

To ensure the robustness of our conclusions, we conducted robustness tests by employing alternative measures for the dependent variable.

Specifically, for ESG rating disagreement, selecting a large number of ESG rating agencies may trigger multicollinearity issues, while choosing a limited number may lead to insufficient coverage of ESG ratings. In line with the number of ESG rating agencies increasingly adopted by scholars [7,16], this study measures ESG rating disagreement (ESGdis) through an integrated assessment framework incorporating six authoritative ESG rating providers.

Table 6 shows that, compared with the original explained variable and its substitute variable, there is a significant negative relationship between the difference in corporate ESG ratings and digital transformation. Moreover, the statistical significance level remains unchanged. After employing the word-frequency-based method used by the majority of previous scholars to measure the level of digital transformation, the results also indicate a significant negative relationship [20,28]. However, differences in sample selection and the choice of ESG rating agencies may explain the slight variations in the coefficients. The coefficients in Column 2 further validate Hypothesis H1.

Table 6. Robustness tests of ESG rating disagreement on corporate digital transformation.

	(1)	**(2)**
VARIABLES	Digital Transformation	ln_DTword
ESGdisagreement	-0.423**	-0.117**
	(0.207)	(0.0482)
Constant	29.26***	0.563
	(1.603)	(0.368)
Controls	Yes	Yes
Observations	39,341	26,970
R-squared	0.359	0.229
Year FE	Yes	Yes
Industry FE	Yes	Yes

Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Similarly, Table 7 indicates that ESG rating disagreement also exhibits a significant negative correlation with digital transformation, with the significance remaining unchanged when replacing the dependent variable. Examining the coefficients in Column 2 after reducing the number of ESG rating agencies included in the calculation of ESG rating disagreement, the results still demonstrate a significant negative relationship. However, slight inconsistencies in the coefficients persist, likely due to differences in the sample selection or calculation methods for the digital transformation index. Nevertheless, all coefficients consistently demonstrate a significant negative relationship between digital transformation and ESG rating disagreement, further validating Hypothesis H2.

Table 7. Robustness tests of corporate digital transformation on ESG rating disagreement.

	(1)	**(2)**
VARIABLES	ESGdisagreement	ESGdis
digitaltransindex	-0.000287**	-0.000316**
	(0.000141)	(0.000145)
Constant	0.233***	0.222***
	(0.0419)	(0.0431)
Controls	Yes	Yes

Observations	39,341	39,331
R-squared	0.018	0.017
Year FE	Yes	Yes
Industry FE	Yes	Yes

Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

5. Panel Vector Autoregression

Previous literature focuses either on the impact of ESG rating disagreement on digital transformation or on the impact of digital transformation on ESG rating disagreement. It is reasonable to assume that ESG rating disagreement and digital transformation are determined simultaneously. Specifically, companies' higher level of digital transformation is able to reduce the information asymmetry and hence a lower ESG rating disagreement. On the other hand, companies with lower ESG rating disagreement have lower financial constraints to raise funds invested to digital transformation. As a result, these companies can achieve a higher level of digital transformation. Both ESG rating disagreement and digital transformation are endogenous variables. However, in standard panel regression, one of them is assumed to be an exogenous variable. To study the relationship between ESG rating disagreement and digital transformation simultaneously we use panel VAR to treat both of them as endogenous. The specific model is as follows:

$$z_{i,t} = \Gamma_0 + \Gamma_1 z_{i,t-1} + e_t$$

Where $z_{i,t}$ is a two-variable vector {digitaltransindex, ESGdisagreement}, which are the key variables of our research. The term e_t represents the error term, capturing random shocks not accounted for by the model.

This study, based on the lag order selection criteria of the PVAR model, and taking into account the recommended results of the AIC, BIC, and HQIC statistics, ultimately determines to adopt a model setting with a lag of 2. Although the AIC criterion suggests a lag of 2 and the BIC and HQIC suggest a lag of 1, this study ultimately selects a lag of 2. This decision prioritizes the model's ability to capture dynamic interactions over parsimony, as the benchmark analysis framework based on the AIC criterion. This is because the model with 2 lags can capture the dynamic interaction between digital transformation and ESG rating disagreement more comprehensively and better balance the model fitness and complexity. (Table 8).

Table 8. PVAR lag order selection criteria.

lag	AIC	BIC	HQIC
1	4.02471	6.82542*	4.92455*
2	3.96115*	7.23591	5.02228
3	4.07256	7.92541	5.33221
4	4.15776	8.73649	5.66916
5	4.34275	9.87344	6.1879

The second-order panel vector autoregression model reveals an asymmetric dynamic relationship between digital transformation and ESG rating disagreement. Results show that ESG rating disagreement significantly inhibits digital transformation, with first- and second-order lag coefficients of -1.765 and -1.166, both significant at the 1 percent level. This indicates a strong lagged effect, suggesting that financing constraints induced by ESG disagreement may gradually suppress digital transformation. In contrast, digital transformation has a weaker yet significant effect in reducing ESG rating disagreement, with lag coefficients of -0.00207 and -0.00111. The comparison highlights that the inhibitory effect of ESG rating disagreement is substantially stronger than the mitigating effect of digital

transformation. This suggests a substantial short-term barrier imposed by ESG disagreement, while digital efforts only slightly enhance transparency and do not fundamentally resolve rating divergence (Table 9).

Table 9. Second order Lag Panel Vector Autoregressive Model.

	(1)	**(2)**
VARIABLES	Digitaltransindex	ESGdisagreement
L.Digitaltransindex	0.507***	-0.00207***
	(0.0137)	(0.000357)
L.ESGdisagreement	-1.765***	0.174***
	(0.331)	(0.00996)
L2.Digitaltransindex	0.142***	-0.00111***
	(0.00621)	(0.000160)
L2.ESGdisagreement	-1.166***	0.0365***
	(0.255)	(0.00775)
Observations	24,423	24,423
Model	PVAR(2)	PVAR(2)

Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Figure 1 impulse-responses for 2 lag VAR of digitaltransindex ESGdisagreement, Errors are 5% on each side generated by Monte-Carlo with 500 reps.
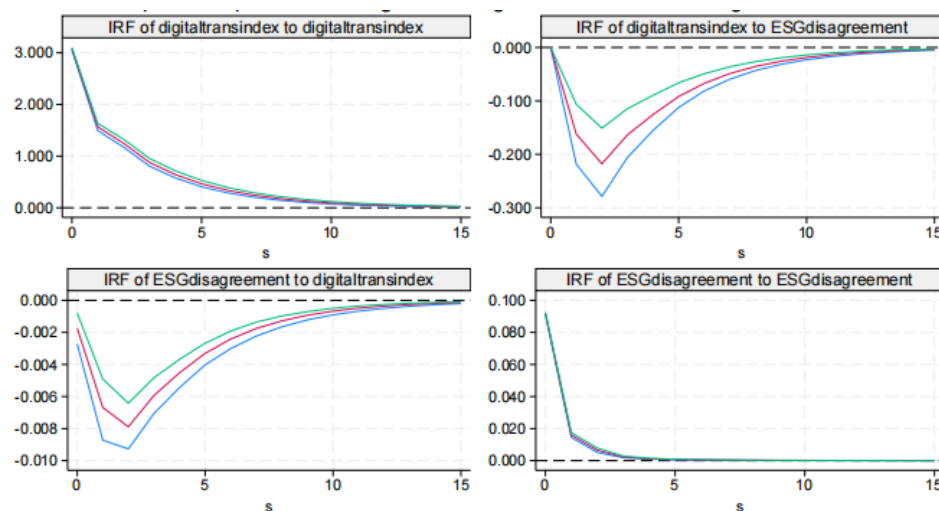
Figure 1. Impulse-responses for 2 lag VAR of digitaltransindex ESGdisagreement.

Figure 1 presents the impulse response functions, which illustrate the dynamic interactions between digital transformation and ESG rating disagreement. The results show that digital transformation exhibits a strong self-reinforcing effect. An initial shock leads to a rapid increase in its level, with the effect peaking and then gradually declining.

Similarly, ESG rating disagreement also shows a self-reinforcing pattern. According to Li & Xin and Geng et al., increased disagreement can trigger greenwashing strategies, such as selective disclosure or symbolic compliance, which degrade information quality and increase market uncertainty [29,30]. These behaviors may worsen over time but tend to lose strength after five periods, suggesting the self-reinforcing effect has limited duration.

Moreover, ESG rating disagreement has a significant negative impact on digital transformation, following an inverted U-shape. The negative influence intensifies quickly, peaking at the second period, and then gradually weakens. This demonstrates a clear time-lag effect, suggesting that increased rating disagreement may gradually lead to

higher financing constraints, which in turn delay digital investment and weaken transformation momentum.

Conversely, digital transformation effectively reduces ESG rating disagreement, especially in the short term. The effect peaks in the second period and remains strong until around the fifth period, gradually declining afterward. This indicates that although digital transformation enhances transparency and reduces rating divergence, its impact is subject to delays caused by the pace of data updates, adjustments in rating methodologies, and investor adaptation.

To further verify the causal relationship between ESG rating disagreement and digital transformation, Table 10 shows that changes in ESG rating disagreement can significantly affect corporate digital transformation decisions, while digital transformation can also significantly reduce ESG rating disagreement. There is a bidirectional causal relationship between the two. In terms of the strength of the effect, the impact of digital transformation on ESG rating disagreement (chi2 = 77.754) is stronger than the reverse effect (chi2 = 33.008), indicating that the role of digital transformation in promoting rating convergence is more direct, while the driving effect of ESG rating disagreement on digital transformation may be through a longer chain reaction.

Table 10. Granger Causality Test.

Null hypotheses	Chi2	p	Whether there is Granger causality
ESG rating disagreement is not the Granger reason for digital transformation.	33.008	0.000	Yes
Digital transformation is not the Granger reason for ESG rating disagreement.	77.754	0.000	Yes

Based on the 10-period variance decomposition results, our study reveals the dynamic interaction between digital transformation and ESG rating disagreement. By examining the sources of fluctuations in digital transformation and ESG rating disagreement in Table11, it is found that both are primarily driven by their own inertia. Although the contribution of this self-influence slightly decreases over time, it remains as high as 99.1% and 97.9% by period 10, respectively. Among them, the contribution rate of ESG rating disagreement to corporate digital transformation starts at 0 and gradually increases to a stable level of 0.9% by period 7. In contrast, the contribution rate of corporate digital transformation to ESG rating disagreement eventually stabilizes at 2.1% by period 8. There is a symmetrical but inconsistent mutual influence pattern between the two. This indicates that digital transformation exhibits strong path dependency. In contrast, ESG rating disagreement is relatively more influenced by external factors—particularly digital transformation—although internal inertia still plays the dominant role, suggesting that both systems are highly stable. In addition, the dynamic interaction between digital transformation and ESG rating disagreement exhibits symmetry in their delayed response patterns, although the magnitude and direction of influence differ. This is because, in the early stages of development, the influence between digital transformation and ESG rating disagreement is 0. As time goes by, the mutual inhibitory effect gradually increases, further demonstrating that the influence of both is characterized by time lags.

Table 11. variance decomposition.

Response variable	Pulse variable	Number of lag periods									
		1	2	3	4	5	6	7	8	9	10
Digitaltransindex	Digitaltransindex	1.000	0.998	0.995	0.993	0.992	0.992	0.991	0.991	0.991	0.991
	ESGdisagreement	0.000	0.005	0.012	0.016	0.019	0.020	0.020	0.021	0.021	0.021

ESGdisagreem ent	Digitaltransin dex	0.000	0.002	0.005	0.007	0.008	0.008	0.009	0.009	0.009	0.009
	ESGdisagreem ent	1.000	0.995	0.988	0.984	0.981	0.980	0.980	0.979	0.979	0.979

6. Conclusion

Information asymmetry has created a two-way interaction between ESG rating disagreement and corporate digital transformation, shaping the evolving pattern of ESG investment. This study uses the average standard deviation of ESG ratings from eight agencies and examines data from Chinese A-share listed firms from 2011 to 2023. The results show that ESG rating disagreement increases financing constraints, thereby suppressing digital transformation, while digital transformation reduces ESG rating disagreement by improving information transparency. Granger causality tests establish a bidirectional relationship, and panel autoregression reveals significant time-lag effects. Over time, both variables exert mutual influence but are largely driven by their own inertia.

These findings offer important policy implications. First, firms should integrate digital strategies into ESG governance, building intelligent disclosure systems and applying technologies such as blockchain to improve data transparency. Second, regulatory agencies should promote standardized ESG disclosure rules, enhance transparency in rating methodologies, and encourage the use of advanced technologies to improve rating consistency. Third, investors should adopt a long-term perspective in evaluating ESG performance, recognizing that the effects of digital transformation on ESG ratings unfold gradually. A dynamic assessment approach can help avoid biases stemming from short-term fluctuations and better identify firms with sustainable improvement potential.

References

1. A. Raj, A. Jain, P. Pathak, V. M. Singh, S. K. Singh, S. P. Singh et al., "Barriers to the adoption of Industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective," *Int. J. Prod. Econ.*, vol. 224, 2020, Art. no. 107546, doi: 10.1016/j.ijpe.2019.107546.
2. J. T. Mentzer, W. DeWitt, J. S. Keebler, S. Min, N. W. Nix, C. D. Smith et al., "Defining supply chain management," *J. Bus. Logist.*, vol. 22, no. 2, pp. 1–25, 2001, doi: 10.1002/j.2158-1592.2001.tb00001.x.
3. A. Hjalmarsson, D. Rudmark, J. S. Lindgren, J. Hedestig, K. Bergek, M. A. Bergvall-Kåreborn et al., "Beyond innovation contests: A framework of barriers to open innovation of digital services," in *Proc. Eur. Conf. Inf. Syst. (ECIS)*, Tel Aviv, Israel, Jun. 2014, pp. 1–13.
4. A. A. Pflaum and P. Gölzer, "The IoT and digital transformation: Toward the data-driven enterprise," *IEEE Pervasive Comput.*, vol. 17, no. 1, pp. 87–91, 2018, doi: 10.1109/MPRV.2018.011591066.
5. . F. Wamba, S. Akter, A. Edwards, G. Chopin, D. Gnanzou, M. R. Asare et al., "Big data analytics and firm performance: Effects of dynamic capabilities," *J. Bus. Res.*, vol. 70, pp. 356–365, 2017, doi: 10.1016/j.jbusres.2016.08.009.
6. E. Dimson, P. Marsh, and M. Staunton, "Practical applications of divergent ESG ratings," *Pract. Appl.*, vol. 9, no. 3, pp. 1–7, 2021, doi: 10.3905/pa.9.3.466.
7. D. Avramov, S. T. Jostova, A. Philipov, M. Y. Yao, H. Hung, J. Kwon et al., "Sustainable investing with ESG rating uncertainty," *J. Financ. Econ.*, vol. 145, no. 2, pp. 642–664, 2022, doi: 10.1016/j.jfineco.2021.09.009.
8. B. R. Gibson, P. Krueger, and P. S. Schmidt, "ESG rating disagreement and stock returns," *Financ. Anal. J.*, vol. 77, no. 4, pp. 104–127, 2021, doi: 10.1080/0015198X.2021.1963186.
9. Q. Zeng, Y. Liu, L. Guo, F. Wang, S. Xu, H. Xie et al., "ESG rating disagreement, volatility, and stock returns," *Financ. Res. Lett.*, vol. 72, 2025, Art. no. 106602, doi: 10.1016/j.frl.2024.106602.
10. J. Wang, Q. Yu, S. Zhang, Y. Li, M. Ren, X. Chen et al., "ESG rating disagreement and stock returns: Evidence from China," *Int. Rev. Financ. Anal.*, vol. 91, 2024, Art. no. 103043, doi: 10.1016/j.irfa.2023.103043.
11. J. Zhou and X. Lei, "ESG rating uncertainty and corporate financial misconduct," *J. Bus. Res.*, vol. 189, 2025, Art. no. 115092, doi: 10.1016/j.jbusres.2024.115092.
12. M. Ren, C. Cao, and Z. Shen, "ESG rating disagreement, financing costs, and enterprise value," in *Proc. Int. Conf. Manag. Sci. Eng. Manag.*, Singapore: Springer Nature, 2024, pp. 681–692, doi: 10.1007/978-981-97-5098-6_69.
13. J. Wu, "Economic policy uncertainty, investor sentiment, and stock price synchronisation: Evidence from China," *Math. Probl. Eng.*, vol. 2022, Art. no. 7830668, 2022, doi: 10.1155/2022/7830668.

14. A. Tsang, T. Frost, and H. Cao, "Environmental, social, and governance (ESG) disclosure: A literature review," *Brit. Account. Rev.*, vol. 55, no. 1, Art. no. 101149, 2023, doi: 10.1016/j.bar.2022.101149.

15. S. Scalet and T. F. Kelly, "The ethics of credit rating agencies: What happened and the way forward," *J. Bus. Ethics*, vol. 111, no. 4, pp. 477–490, 2012, doi: 10.1007/s10551-012-1212-y.

16. F. Berg, J. F. Kölbel, and R. Rigobon, "Aggregate confusion: The divergence of ESG ratings," *Rev. Finance*, vol. 26, no. 6, pp. 1315–1344, 2022, doi: 10.1093/rof/rfac033.

17. L. Wang, Q. Liu, and K. Li, "ESG rating divergence and corporate bond pricing: Information mining or information deterioration," *Stud. Int. Financ.*, vol. 3, pp. 87–96, 2024.

18. M. D. Kimbrough, J. J. McWilliams, C. B. Williams, H. Y. Lee, F. Zhou, S. Park et al., "Does voluntary ESG reporting resolve disagreement among ESG rating agencies?," *Eur. Account. Rev.*, vol. 33, no. 1, pp. 15–47, 2024, doi: 10.1080/09638180.2022.2088588.

19. H. Zhang, Z. Gao, and A. Han, "Enterprise digital transformation empowers industry chain linkage: Theoretical and empirical evidence," *J. Quant. Technol. Econ.*, vol. 40, no. 5, pp. 46–67, 2023.

20. F. Wu, Y. Wang, L. Zhang, G. Yang, and J. Li, "Enterprise digital transformation and capital market performance: Empirical evidence from stock liquidity," *Manag. World*, vol. 37, no. 7, pp. 130–144, 2021.

21. A. Jeppsson and O. Olsson, "Blockchains as a solution for traceability and transparency," 2017 [Online]. Available: https://www.diva-portal.org.

22. G. W. Hou and C. X. Gao, "Study on the impact of corporate network structure on enterprise innovation performance from the perspective of digital transformation capability," *Sci. Technol. Manag. Res.*, vol. 42, pp. 106–111, 2022.

23. Q. Huang, Y. Yu, and S. Zhang, "Internet development and productivity growth in manufacturing industry: Internal mechanism and China experiences," *China Ind. Econ.*, vol. 8, no. 1, Art. no. 1019581, 2019.

24. W. W. Zhang and W. M. Jing, "Digital economy regulation and digital transformation of enterprises: A balancing analysis of benefits and costs," *J. Quant. Technol. Econ.*, vol. 21, pp. 2254–2281, 2023.

25. J. Zhu, Y. Chen, M. Zhou, F. Zhao, L. Liu, X. Zhang et al., "Does ESG rating disagreement impede corporate green innovation?," *Glob. Finance J.*, vol. 64, 2025, Art. no. 101068, doi: 10.1016/j.gfj.2024.101068.

26. T. M. Whited and G. Wu, "Financial constraints risk," *Rev. Financ. Stud.*, vol. 19, no. 2, pp. 531–559, 2006, doi: /10.1093/rfs/hhj012.

27. C. Lin, X. Mao, and K. Liu, "On the gender of secretary of the board of directors and the quality of information disclosure: Evidence from Shanghai and Shenzhen A shares market," *J. Financ. Res.*, no. 9, pp. 193–206, 2016.

28. H. Ren, "ESG rating disagreement and corporate digital transformation," *Financ. Res. Lett.*, vol. 75, 2025, Art. no. 106903, doi: 10.1016/j.frl.2025.106903.

29. E.-H. Kim and T. P. Lyon, "Greenwash vs. brownwash: Exaggeration and undue modesty in corporate sustainability disclosure," *Organ. Sci.*, vol. 26, no. 3, pp. 705–723, 2015, doi: 10.1287/orsc.2014.0949.

30. Y. Geng, J. Chen, and R. Liu, "ESG rating disagreement and corporate green innovation bubbles: Evidence from Chinese A-share listed firms," *Int. Rev. Financ. Anal.*, vol. 95, 2024, Art. no. 103495, doi: 10.1016/j.irfa.2024.103495.