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Research article

Digital government construction and corporate ESG performance: evidence from the "Internet + Government Services" pilot as a quasi-natural experiment

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Abstract: Based on the "Internet + Government Services" pilot as a quasi-natural experiment, this paper examined the impact of digital government construction on corporate ESG performance. The study found that digital government construction contributes to the improvement of corporate ESG outcomes. Mechanism analyses suggest that digital government enhances corporate ESG performance primarily through four channels: promoting green technological innovation, upgrading human capital structures, reducing information asymmetry, and lowering agency costs. Further heterogeneity analyses reveal that the positive effect of digital government on corporate ESG performance is more pronounced among state-owned enterprises, firms with lower financing constraints, large-scale enterprises, and firms located in regions with higher levels of governmental environmental attention. The findings provide important implications for understanding how improvements in governmental digital governance capacity can foster corporate ESG practices in the digital era.

Keywords: digital government construction; ESG; green development

JEL Codes: Q01, G32

1. Introduction

Environmental, social, and governance (ESG) is a comprehensive evaluation system for assessing corporate sustainable development. Enhancing ESG performance is of great significance not only for promoting corporate growth and practicing sustainability principles but also for achieving national strategic goals such as "carbon peaking" and "carbon neutrality". As a core determinant of long-term corporate value creation, ESG performance is receiving increasing attention from capital markets and investors. In essence, ESG performance evaluates a firm's environmental impact, social contributions, and internal governance while pursuing economic benefits.

In recent years, under the combined influence of government ESG regulations, heightened investor scrutiny, and enterprises' own transformation and upgrading needs, an increasing number of Chinese firms have intensified their ESG investments, thereby significantly improving overall ESG performance. Meanwhile, the rapid development of digital technologies—such as the Internet, big data, cloud computing, and artificial intelligence—has reshaped how governments operate and interact with citizens. By integrating such technologies, digital government construction substantially advances the modernization of state governance, enhancing transparency, streamlining administrative processes, and raising the quality and efficiency of public services. In this sense, digital government is not only an integral part of modernization strategies but also a crucial means of releasing additional economic and social benefits (Martins and Veiga, 2022). Against the backdrop of the digital transformation era, the advancement of digital government has triggered profound and irreversible changes in public administration systems worldwide. It has increasingly been regarded as a key strategy for enhancing national competitiveness and improving the quality of public services (Castro and Lopes, 2022). At the same time, the rapid economic expansion in China has served as a powerful catalyst for accelerating digital government transformation. Various institutions are increasingly adopting advanced digital technologies to improve service efficiency, expand service coverage, promote public participation, and enhance citizen-centered governance. Therefore, the construction of digital government is not only an inherent necessity for improving governance capacity but also an essential pathway to meeting public expectations and strengthening public trust. Digital government contributes to greater government transparency, enabling citizens to better understand and monitor governmental decision-making and behavior, while also playing a crucial role in advancing the digitalization and intelligence of modern society. These developments demonstrate that the influence of digital government extends far beyond internal organizational structures and administrative processes. By systematically strengthening governance capacity, digital government is expected to generate improvements across multiple dimensions, including economic regulation, market oversight, social governance, public service delivery, environmental management, administrative efficiency, and overall transparency. Against this background, a natural question arises: Does digital government construction affect firms' ESG performance? If so, in which direction and through what mechanisms? This paper seeks to answer these questions.

Through enhanced regulatory and service mechanisms and a diversified policy toolkit, digital government helps firms maintain a model of sustainable development. By driving cross-departmental and cross-regional data integration, digital government platforms enable enterprises to track real-time market demand, policy changes, and regulatory trends (Awan et al., 2021). Governments can release

laws and regulations, implementation guidelines, and policy updates via digital platforms and open policy databases in standardized and timely ways (Skare et al., 2023). This practice not only improves the accessibility of policy information but also increases transparency, thereby laying a solid foundation for reducing information asymmetry and stabilizing market expectations. By improving the availability and verifiability of administrative data, strengthening interdepartmental coordinated enforcement, and reducing information search and compliance costs, digital government systematically shifts the cognitive and behavioral margins of environmental governance among government, consumers, and the public. In addition, by disclosing more transparent information on emissions, labor practices, and governance—and by revealing market-level green preferences and social norms—digital government facilitates oversight and accountability by social organizations, the media, and consumers, converting these into meaningful constraints and incentives for firms. At the same time, digitalized government supervision precisely links environmental performance with instruments such as credit, taxation, and public procurement. To maintain legitimacy and gain resource, reputation, and financing advantages, firms are thus more inclined to adopt sustainable practices and to create synergies between environmental and operating performance, achieving a "win–win" production model that aligns social responsibility, environmental protection, and green outcomes. All these benefits positively encourage firms to improve their ESG performance.

Leveraging "Internet + Government Services" reform in China as an exogenous shock to digital government construction, this paper examines its impact on corporate ESG performance. The main contributions are as follows: First, the study offers a new perspective on how digital government promotes corporate sustainable development and enriches the literature on determinants of ESG performance. Previous studies have primarily examined the determinants of corporate ESG performance from perspectives such as green credit (Gao and Liu, 2023), carbon control policy risks (Shu and Tan, 2023), and executive incentive mechanisms (Jang et al., 2022). Against the backdrop of rapid digital economic development, this study provides empirical evidence on how digital government construction contributes to the improvement of firms' ESG performance. Meanwhile, this result extends research on the economic effects of digital government. Second, existing studies primarily investigate the determinants of corporate ESG performance from perspectives such as firms' operating cash flow (Zheng et al., 2023), total factor productivity, and the accumulation of goodwill capital (Sui et al., 2024). Building on the key features of digital government, this paper expands the theoretical channels through which ESG performance can be improved. The findings demonstrate that digital government construction promotes ESG outcomes by stimulating green technological innovation, upgrading the human-capital structure, reducing information asymmetry, and lowering agency costs. These results provide empirical evidence on how enhanced digital government effectiveness contributes to better ESG performance and offer practical insights for corporate sustainability in the digital era.

2. Institutional background, literature review, and hypothesis development

2.1. Institutional background

In 2016, the Chinese State Council issued the Guiding Opinions on Accelerating the Promotion of "Internet + Government Services", designating 80 cities as pilots. By advancing cross-regional, cross-tier, and cross-departmental collaboration in administrative services among pilot cities, the policy aimed to resolve longstanding "departmental silos". The initiative facilitated the use of big data to benefit enterprises and citizens (Liu and Feng, 2025), supported innovation in service delivery, promoted data sharing, and broke through information islands. Through the digital transformation of the governance system, the policy has provided strong momentum for modernizing state governance capacity. This is reflected in the following two aspects:

(1) First, a core objective of digital government is to leverage big-data development to enhance administrative efficiency, thereby providing institutional support for corporate ESG performance. By simplifying procedures, promoting transparency in government services, and lowering institutional frictions faced by enterprises and the public, digital government seeks to make administrative services more proactive, precise, and convenient. Technologies such as big data and cloud computing facilitate interdepartmental collaboration, reduce delays and redundancies in service processes, and improve efficiency through information-sharing mechanisms. The reform has also promoted a shift in service orientation and streamlined processes, further reducing firms' production and transaction costs (Yang et al., 2025).

(2) Second, through digital governance, the government has innovated modes of public service, built unified information platforms, strengthened departmental collaboration, and promoted efficient resource allocation. Measures such as tax incentives and subsidy programs have expanded the scope and reach of information relevant to enterprises. With the aim of achieving "the same matter, the same standards, and the same coding", the policy lays a foundation for information sharing and business coordination, enabling uniform and equitable administrative services. Deep integration of governance and digital technologies allows the government to respond to social concerns in a timely manner and to provide multi-channel, user-friendly administrative services, ensuring inclusiveness and process convenience. The policy also improves network infrastructure and standardizes service guidelines to build a diversified, inclusive information service system for people's livelihoods. By enhancing governmental credibility and governance capacity, it seeks to attain universal coverage and one-stop processing of public affairs and social information services, benefiting enterprises and citizens through improved efficiency and transparency.

2.2. Literature review

2.2.1. Economic impacts of digital government

Digital government construction has significant impacts on socioeconomic development. From a macro perspective, governmental digital transformation connects public agencies and improves the efficiency of information flows across departments (Zou et al., 2023). By integrating information

systems and digitizing processes, it enhances administrative efficiency, policy transparency, and resource allocation, thereby optimizing national governance and promoting functional transformation of government (Wandaogo, 2022). From a regional-development perspective, as a key support for sustainable economic and social development, eco-innovation is critical to achieving a win-win between economic gains and environmental protection. Studies find that digital government positively affects regional eco-innovation, primarily through digital society and digital citizenship (Zhao et al., 2023). Meng et al. (2024) showed that digital government reduces urban carbon emissions by upgrading green finance, aggregating green resources, and promoting green technological innovation. Digital-government policies also significantly increase per-capita patent applications and foster regional innovation—effects that are particularly pronounced in regions with advanced marketization, strong intellectual-property protection, robust network infrastructure, and favorable business credit conditions (Gan et al., 2024). Using panel data for Chinese cities from 2016 to 2022, Jiao et al. (2025) found that digital government promotes common prosperity by increasing the tax base.

At the micro firm level, digital government notably advances corporate digital transformation, with stronger effects among firms with higher R&D intensity and in regions with stronger governmental support (Meng et al., 2025). Digital-government initiatives provide replicable experience throughout the "cloud adoption, data utilization, and intelligence enablement" process, stimulating endogenous momentum for firms' digital transformation (Tang et al., 2025). Digital government also helps firms gain more financial resources and institutional support, thereby improving total factor productivity and competitiveness (Zhu and Yu, 2024). In addition, digital government significantly boosts corporate investment. Liu et al. (2025) showed that it promotes investment by reducing uncertainty, administrative burdens, and information-matching costs, while Huang (2025) found that optimizing resource allocation and increasing credit supply willingness further raise investment levels. Digital government also promotes entrepreneurship (Gan et al., 2023) and corporate digital innovation (Wang et al., 2022).

2.2.2. Drivers of improved corporate ESG performance

One stream of research has examined external drivers. At the policy level, Shu and Tan (2023) discussed how carbon-control policy risk affects ESG performance and found that such risk tightens financing constraints and raises bank lending costs, thereby limiting funding available for ESG activities. Wang and Ye (2024) investigated whether and how the environmental protection tax affects environmental governance outcomes, finding a positive effect on ESG investment, primarily because tax burdens and ex-post noncompliance costs stimulate ESG spending. Ni et al. (2023) showed that green credit policies affect ESG performance by easing financing constraints and improving investment efficiency. Regarding external economic shocks, Zhu and Zhang (2024) evaluated the economic effects of supply-chain digitalization and showed that it improves ESG performance through corporate governance, total factor productivity, and financing-constraint channels. Zheng et al. (2023) reported that customer concentration significantly reduces firms' ESG performance by suppressing innovation and increasing pressures to maximize shareholder returns.

Another stream has focused on internal determinants. Using Chinese listed firms between 2010 and 2022, Wang and Yang (2024) found that digital technological innovation improves overall ESG

and each of the E/S/G dimensions, with mechanisms running through green innovation and governance optimization. Based on 2006–2021 A-share data, Zeng et al. (2023) documented that executive equity-incentive plans positively affect ESG performance, with options having stronger effects than restricted stock. Jang et al. (2022) showed that executives' share pledging significantly reduces ESG performance, especially in the environmental and social dimensions. Finally, Chen et al. (2020) showed that, as sustainable and responsible investment becomes mainstream, institutional investors can improve corporate ESG through CSR-related proposals.

2.2.3. Digital economy development and ESG

Related research has explored how the digital economy improves ESG and through which mechanisms. Zhao et al. (2025) found a positive association between the use of data as a production factor and ESG improvement, with stronger effects among firms with greater organizational resilience. The positive impact is more pronounced for firms in growth and decline stages than for mature firms. Corporate digital transformation enhances ESG performance by strengthening internal controls and catalyzing green innovation; moreover, supportive industrial policy positively moderates the effect of digital transformation on ESG (Lu et al., 2024). Mu et al. (2023) showed that digital finance promotes ESG by easing financing constraints. From the perspective of digital-finance literacy, Fan et al. (2025) found that literacy significantly improves overall ESG, particularly in the social dimension, while effects on environmental and governance dimensions are relatively limited.

Several studies take a disaggregated view. Tian et al. (2024) argued that digital economy improves ESG via green innovation and digital transformation, with stronger effects on environmental performance and governance. Li (2022) focused on the digital-transformation–environmental-performance nexus, finding a U-shaped relationship. Niu et al. (2023) showed that digital transformation reduces information asymmetry between managers and shareholders, mitigates managerial myopia, and improves corporate governance. From the digital-finance perspective, Luo et al. (2025) showed that digital finance enhances CSR and governance but has a limited effect on environmental performance; another work found that digital finance can significantly spur green innovation and thereby improve environmental outcomes (Feng et al., 2022). Meng et al. (2025) documented a positive effect of fintech on corporate governance. Kong and Liu (2023) found that digital technological innovation substantially improves corporate social responsibility by enhancing pollution control and internal-control efficiency. Li et al. (2024) further showed that digital technological innovation raises workers' incomes and reduces environmental pollution, thereby improving firms' social responsibility.

2.3. Theoretical analysis and hypotheses

Stakeholder theory emphasizes that corporate decision-making should consider not only shareholder interests but also the needs of other stakeholders. ESG practices represent a strategic tool for aligning these interests and sustaining legitimacy (Lokuwaduge and Heenetigala, 2017). Given rising investor concerns, poor ESG performance often signals inadequate responsibility, thus weakening capital market appeal. Digital government improves transparency in information disclosure,

enabling investors to more easily evaluate corporate ESG outcomes, which in turn compels firms to strengthen environmental and social responsibility practices.

Resource allocation theory posits that digital government reforms based on big data management enhance efficiency in integrating and allocating resources. By reducing policy uncertainty and transaction costs, digital government creates an institutional environment conducive to corporate sustainable investment (Hao et al., 2024). Digital platforms allow policymakers to monitor industry structure, employment, and competitiveness in real time, thereby enabling data-driven, differentiated allocation of resources. This improves regulatory efficiency, incentivizes firms to pursue green transformation, increases environmental investments, and strengthens employee protection, ultimately boosting ESG performance.

New economic geography theory further stresses the spatial role of policies and infrastructure. In regions with stronger government support, digital government provides greater policy backing, fiscal subsidies, and digital infrastructure, thereby fostering ecosystems that enhance firms' ESG practices (Zhu et al., 2023).

Hypothesis 1: Digital government construction significantly improves corporate ESG performance.

Green innovation refers to innovations in processes, technologies, or products that reduce pollution and improve resource efficiency (Schiederig et al., 2012). However, such innovation is costly and often suffers from weak endogenous motivation (Feng et al., 2022). Digital government provides institutional support for green innovation by improving data sharing, strengthening online regulatory platforms, and offering precise and efficient policy resources. These mechanisms reduce information barriers, increase policy transmission efficiency, and help firms access subsidies and technology resources more effectively, thereby enhancing green R&D and environmental performance.

Hypothesis 2: Digital government promotes corporate ESG performance by strengthening firms' green innovation capabilities.

Digital government platforms improve the match between policy supply and talent demand through targeted fiscal incentives and talent introduction programs. By tracking the distribution and flow of digital technology talent, governments foster the agglomeration of high-skilled labor, which provides key support for ESG practices. High-skilled labor is complementary to advanced technologies, enabling firms to better adapt to new production processes and organizational structures. This not only facilitates sustainable business models but also generates spillover effects in green innovation. Moreover, skilled human capital enhances governance capacity, operational efficiency, and innovation willingness, embedding ESG considerations into corporate strategies. Meanwhile, the upgrading of human capital structure enhances firms' managerial capabilities and strengthens their market competitiveness, thereby improving their ESG performance (Sui et al., 2024).

Hypothesis 3: Digital government improves corporate ESG performance by promoting human capital upgrading.

In an environment of information asymmetry, governments, investors, and the public often struggle to obtain timely and comprehensive information about firms' ESG activities, weakening their ability to monitor corporate sustainability. Digital government initiatives improve administrative efficiency by streamlining procedures, enhancing information disclosure and data analytics, and providing high-granularity public data (Meng et al., 2024), thereby reducing information barriers as well as communication and compliance costs. Hence, digital governance also

enhances policy transparency and predictability. During administrative approvals, firms improve transparency through voluntary disclosure and credit commitments, while governments share essential operational and credit data with credit-service platforms. As a result, financial institutions can rely on more complete information to assess firms' creditworthiness and financing needs, thereby mitigating information asymmetry, improving credit access, and lowering financing costs (Ding et al., 2024). These developments collectively reduce information asymmetry between banks and firms (Nagar et al., 2019). As information asymmetry diminishes, firms' sustainability practices face stronger external scrutiny, reinforcing public, financial, and regulatory oversight and ultimately enhancing corporate ESG performance.

Hypothesis 4: Digital government enhances corporate ESG performance by reducing information asymmetry.

According to principal–agent theory, a well-functioning institutional environment helps reduce conflicts of interest and lower transaction costs. Digital government alleviates internal agency conflicts by strengthening market supervision, curbing rent-seeking, and enhancing policy predictability (Wang et al., 2022). This implies that digital governance reinforces internal corporate governance by improving information disclosure and incentive mechanisms, aligning managerial and shareholder interests, reducing managerial opportunism, and increasing the cost of misconduct. Digital regulatory tools further provide firms with policy guidance and information services (Liu and Feng, 2025), encouraging them to optimize governance structures and reduce agency costs. In addition, digital government reforms supported by big data and information technologies enhance firms' resource allocation efficiency and information access by offering open and easily accessible policy and market data (Peng et al., 2024). This enables managers to better anticipate regulatory and market changes, make more rational decisions, and thereby reduce agency costs (Qian et al., 2025), ultimately improving corporate ESG performance (Chen and Zou, 2025).

Hypothesis 5: Digital government enhances corporate ESG performance by lowering agency costs.

3. Research design

3.1. Data

This study primarily employs panel data of A-share listed firms in China's non-financial industries from 2012 to 2023 as the sample data. For ESG ratings, we adopt the Huazheng Index rating methodology. Firm-level ESG rating data are mainly obtained from the WIND database, while other firm-level financial and governance data are sourced from the CSMAR and CNRDS databases. The data are processed as follows: (1) firms with ST or *ST status are removed; (2) observations with missing key variables are excluded; and (3) all key variables are winsorized at the 1% level in both tails.

The dependent variable is firms' ESG performance, *ESG*. The Huazheng ESG rating system evaluates firms' ESG performance on a nine-level scale: C, CC, CCC, B, BB, BBB, A, AA, and AAA, ranked from low to high. Following prior practice, we assign scores of 1 to 9 to these ratings, with higher values indicating stronger ESG performance.

The core explanatory variable is digital government construction, *DID*. According to the Implementation Plan for Promoting "Internet + Government Services" and Launching the Information-

Benefiting-People Pilot Program, 80 cities were selected as pilot sites. We treat firms located in these pilot cities as belonging to the treatment group, while firms in non-pilot cities form the control group. For firms located in pilot areas from 2016 onward, the variable *DID* equals 1; otherwise, it equals 0.

Control variables at the firm level include firm size (*size*), measured by using the logarithm of total assets; leverage ratio (*debtratio*) is determined by the ratio of total liabilities to total assets; firm age (*age*) is the logarithm of the difference between the observation year and the year of establishment plus one; cash flow level (*cash*) is the ratio of net cash flow from operating activities to total assets; ownership concentration (*share*) is the shareholding ratio of the top 10 shareholders; proportion of independent directors (*indratio*) is determined by the number of independent directors to total directors; and return on assets (*ROA*) is the ratio of net profit to total assets. Regional-level control variables include economic development level (*gdp*), measured by the logarithm of per capita GDP; fiscal expenditure ratio (*fiscal*), measured by the ratio of local fiscal expenditure to regional GDP; industrial structure (*indstr*), measured by the proportion of the added value of the tertiary industry in regional GDP; digital inclusive finance index (*dfi*)[1], measured by the Digital Financial Inclusion Index; and internet penetration rate (*internet*), measured by the number of internet users per 100 persons.

3.2. Model specification

Using the Internet + Government Services reform as a quasi-natural experiment for digital government construction, we apply a difference-in-differences (DID) model to examine the effect of digital government on firms' ESG performance:

$$ESG_{it}=\alpha_0+\beta_1 DID_{it}+\beta_2 Controls_{it}+\lambda_t+\eta_i+\varepsilon_{it} \quad (1)$$

where i and t denote firm and year, respectively. ESG_{it} represents firm i's ESG performance in year t; DID_{it} is the treatment indicator of digital government construction; $Controls_{it}$ is the set of control variables; λ_t denotes year fixed effects; η_i denotes firm fixed effects; and ε_{it} is the random error term.

Table 1 lists the variable definitions and measurement methods. Table 2 reports the descriptive statistics of the variables. The mean value of ESG performance is 4.174, with a standard deviation of 0.888, suggesting substantial heterogeneity in ESG outcomes across firms. The descriptive statistics of other variables are generally consistent with prior literature.

[1] Following Liao et al. (2022), we use the Digital Financial Inclusion Index as a proxy for the level of regional digital finance development.

Table 1. Variable definitions and measures.

Variable type	Variable name	Variable symbol	Description
Variable being explained	ESG performance	*ESG*	Huang Zheng ESG rating, which assigns values from 1 to 9, corresponding to ratings from "C" to "AAA".
Explanatory variables	Digital government construction	*DID*	Value of 1 if the enterprise is located in a pilot city for digital government in year t or after, and 0 otherwise
Firm-level control variables	Financial leverage	*debtratio*	Liability/total assets
	Enterprise size	*size*	Ln(enterprise assets)
	Age of establishment	*age*	Ln(observation year-year of establishment+1)
	Cash weighting	*cash*	Operating net cash flow/total assets
	Shareholding ratio of the top ten shareholders	*share*	Expressed using the total shareholding of the top 10 shareholders as a percentage of the company's total share capital
	Proportion of independent directors	*indratio*	Number of independent directors as a percentage of the total number of board members
	Capital return	*ROA*	Net profit/total assets
Regional-level control variables	Economic development level	*gdp*	Ln(per capita GDP)
	Fiscal expenditure ratio	*fiscal*	Local fiscal expenditure/regional GDP
	Industrial structure	*indstr*	Added value of the tertiary industry/regional GDP
	Digital inclusive finance index	*dfi*	Digital Financial Inclusion Index
	Internet penetration rate	*internet*	Number of internet users per 100 persons

Table 2. Descriptive statistics.

Variables	Observations	Mean	Standard deviation	Minimum	Maximum
ESG	29,289	4.174	0.888	1	8
DID	29,289	0.568	0.495	0	1
debtratio	29,289	0.404	0.201	0.051	0.887
size	29,289	22.224	1.275	19.863	26.243
age	29,289	2.958	0.325	1.792	3.555
cash	29,289	0.049	0.066	−0.152	0.250
share	29,289	0.587	0.152	0.232	0.949
indratio	29,289	0.378	0.0539	0.333	0.571
ROA	29,289	0.035	0.081	−2.834	0.786
gdp	29,289	11.537	0.478	10.209	12.207
fiscal	29,289	0.157	0.052	0.078	0.355
indstr	29,289	0.587	0.128	0.335	0.849
dfi	29,289	2.715	0.671	1.016	3.632
internet	29,289	9.906	12.345	1.529	388.917

4. Empirical results

4.1. Baseline regression

Table 3. Benchmark regression.

	(1)	(2)
	ESG	*ESG*
DID	0.135***	0.104**
	(2.649)	(2.015)
debtratio		−0.955***
		(−13.211)
size		0.218***
		(9.747)
age		0.109
		(0.510)
cash		−0.178*
		(−1.827)
share		−0.002
		(−0.026)
indratio		0.934***
		(4.028)
ROA		0.013
		(0.127)
gdp		−0.113
		(−0.666)
fiscal		−1.043***
		(−2.655)
indstr		0.491
		(1.258)
dfi		0.082
		(0.363)
internet		−0.005**
		(−2.227)
Controls	No	YES
Firm FE	YES	YES
Year FE	YES	YES
Observations	29289	29289
Adj.R^2	0.401	0.417

Note: ***, **, * show significance at the 1%, 5%, and 10% levels. Estimates use clustered standard errors at the city level. This note applies to the tables below.

Table 3 reports the results of the baseline regressions. Column (1) presents the estimates without control variables, controlling only for firm and year fixed effects, while Column (2) further includes

firm-level and city-level control variables. In both specifications, the coefficient of the core explanatory variable is positive and statistically significant. Specifically, the coefficient of DID is 0.135 in Column (1) and significant at the 1% level. After adding control variables, the coefficient remains positive and significant at the 5% level, with an estimated value of 0.104 in Column (2). This indicates that digital government construction significantly improves corporate ESG performance. In terms of economic magnitude, the coefficient of 0.104 accounts for approximately 2.49% of the sample mean of ESG performance (4.174) and 11.71% of one standard deviation (0.888). Although the effect size is moderate, it is still economically meaningful. ESG ratings are relatively persistent and ordinal, so even a moderate improvement may be important for firms close to a rating threshold. Moreover, since the "Internet + Government Services" pilot is implemented at the city level, the estimated effect reflects an average improvement across a broad group of listed firms rather than an isolated firm-level change. Such improvements may have practical implications for investor screening, corporate financing conditions, reputational value, and policy evaluation. Overall, these findings support Hypothesis 1, namely that digital government construction promotes firms' ESG performance.

4.2. Robustness checks

4.2.1. Parallel trend test

A prerequisite for applying the difference-in-differences (DID) model is that the treatment and control groups exhibit parallel trends prior to policy implementation. As shown in the dynamic effect results in Figure 1, before the implementation of the digital government policy, there was no significant difference in ESG performance between listed companies in pilot cities and those in non-pilot cities, thereby satisfying the parallel trend assumption of the DID model. Moreover, starting from the third year after policy implementation, the coefficient of the DID variable becomes significantly positive, indicating that digital government construction improves firms' ESG performance. This further validates the robustness of the empirical results.

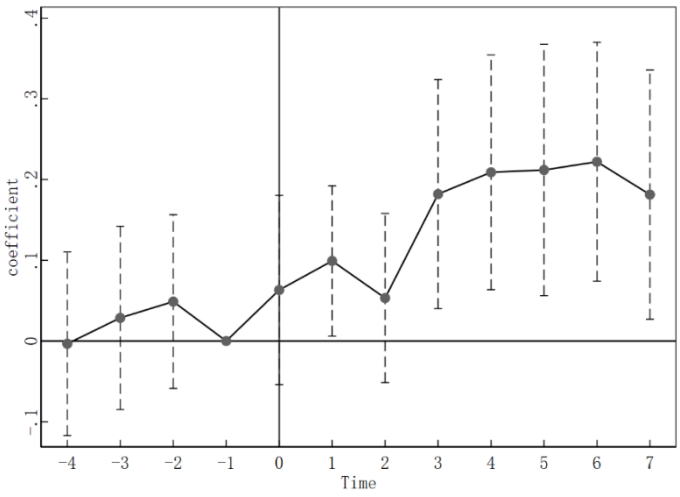

Figure 1. Parallel trend test.

4.2.2. Placebo test

To further verify that the improvement in firms' ESG performance is indeed attributable to digital government construction rather than confounding policy factors, we conduct a placebo test. Specifically, we randomly assign firms into treatment and control groups, generate a pseudo-policy grouping variable, and interact it with the policy shock variable for re-estimation. By repeating this random grouping experiment 500 times, we obtain the coefficient distribution of the interaction term as well as the significance test results. As shown in Figure 2, the coefficients of the interaction term are mostly centered around zero. This suggests that the observed policy effect is not driven by random factors, thereby further supporting the robustness of the baseline regression results.

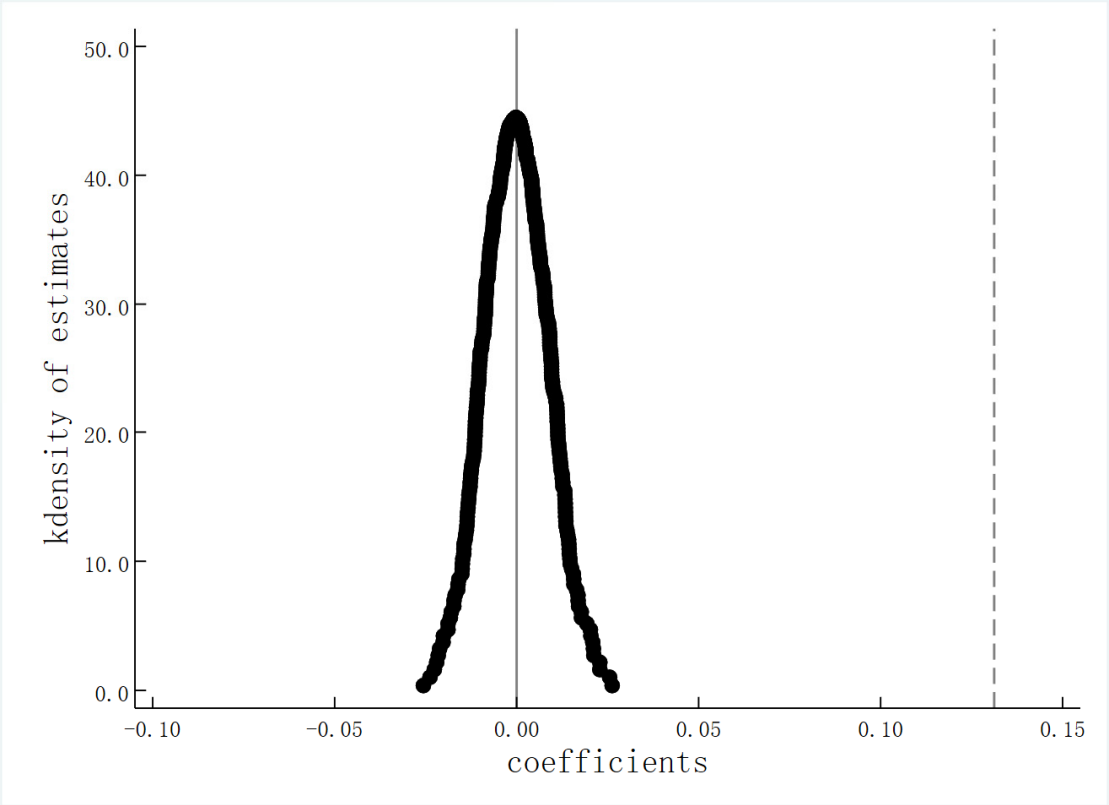

Figure 2. Placebo test results.

4.2.3. Propensity score matching (PSM) test

Considering that digital government construction may be influenced by external factors, which could lead to sample selection bias and undermine the reliability of the empirical conclusions, we further employ the propensity score matching (PSM) method to ensure robustness. Specifically, firm control variables from the baseline regression model are used as covariates, and a logit model with nearest-neighbor 1:2 matching is applied to match firms in pilot cities with those in non-pilot cities. Subsequently, regressions are conducted based on the matched sample. As reported in Column (1) of Table 4, the coefficient of the explanatory variable remains significantly positive at the 1% level. This indicates that the research results continue to hold after addressing potential sample selection bias.

4.2.4. Alternative measures of ESG performance

We also validate the robustness of our findings by employing alternative measures of firms' ESG performance. To further eliminate concerns that differences across rating agencies may affect the results, we adopt Bloomberg's ESG ratings as an alternative measure, denoted as *ESG*_1. As shown in Column (2) of Table 4, the results remain robust.

Table 4. Robustness tests: PSM and alternative measures of ESG performance

	(1)	(2)
	ESG	*ESG*_1
DID	0.123**	0.865**
	(2.307)	(2.161)
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
Observations	22610	8640
Adj.R^2	0.406	0.804

4.2.5. High-dimensional fixed effects and alternative sample period

To further account for unobservable factors at the regional and industry levels, we additionally include province fixed effects and industry fixed effects on top of firm fixed effects and year fixed effects. As shown in Column (1) of Table 5, the results remain consistent. In addition, to eliminate potential confounding effects of the COVID-19 pandemic, we restrict the sample period to 2012–2019. The results reported in Column (2) of Table 5 indicate that our main conclusions remain highly robust.

Table 5. High-dimensional fixed effects and changing the sample period.

	(1)	(2)
	ESG	*ESG*
DID	0.103**	0.089*
	(1.974)	(1.890)
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
Province FE	YES	NO
Industry FE	YES	NO
Observations	29289	18028
Adj.R^2	0.422	0.432

4.2.6. Ruling out alternative hypotheses

(1) New energy demonstration city pilot policy

To ensure the smooth implementation of the "dual carbon" development goals and promote the green and low-carbon transformation of traditional Chinese enterprises, China issued the Notice on the Publication of the List of Innovative New Energy Demonstration Cities (Industrial Parks) (First Batch) in 2014 (hereinafter referred to as the "New Energy Demonstration City Pilot Policy"). This policy designated 81 cities and 8 industrial parks as new energy demonstration zones. Its implementation encouraged cities to pursue green transformation strategies tailored to their own development conditions and resource endowments, thereby supporting enterprises in exploring sustainable business models centered on environmental protection. By improving urban energy efficiency, the policy also enhanced firms' green technology innovation and industrial upgrading, which may in turn affect corporate ESG performance. To control for this potential confounding effect, we construct a dummy variable, *DID_infor*, indicating whether a firm is located in a city subject to the new energy demonstration policy.

(2) VAT retained credit rebate policy

To promote high-quality enterprise development, China introduced the VAT retained credit rebate policy in 2018. This policy significantly reduced firms' tax burdens and production costs, thereby increasing available funds for green R&D and green transformation. Moreover, it encouraged enterprises to engage in environmental investments and eased financing constraints, all of which may improve ESG performance. To control for such influences, we construct a dummy variable, *DID_tax*, to capture whether a firm was affected by the VAT rebate policy.

(3) Broadband China pilot policy

In the era of digital economy, to promote the development of digital infrastructure, China launched the "Broadband China" Strategy and Implementation Plan in August 2013 and subsequently designated 120 pilot cities during 2014, 2015, and 2016. The Broadband China Pilot Policy substantially reduced barriers to information flow and technological diffusion, while also lowering enterprise costs and facilitating corporate transformation. Furthermore, the policy increased demand for high-skilled human capital, whose values and competencies play a critical role in driving ESG improvements. In addition, Broadband China alleviated corporate information asymmetry, enabling firms to access policy signals and investor trust more effectively, thereby creating favorable conditions for ESG enhancement. To account for this, we construct a dummy variable, *DID_band*, to identify firms located in Broadband China pilot cities.

(4) Smart city policy

In 2012, China launched the Notice on the Implementation of the National Smart City Pilot Program, under which 290 cities have since been designated as pilot smart cities. The Smart City Policy incentivized firms to increase technological investments, supported by tax incentives and fiscal subsidies that eased financial constraints and improved corporate governance. Meanwhile, smart city development enhanced government oversight of firms, compelling them to better fulfill their social responsibilities. By fostering efficient resource integration and low-carbon development, the policy created favorable conditions for corporate sustainability. To control for this influence, we construct a dummy variable, *DID_fan*, indicating whether a firm is subject to the smart city pilot program.

Finally, we incorporate these policy dummy variables into the baseline regression model as additional controls to rule out the confounding effects of other concurrent policies. The regression results reported in Table 6 confirm that, even after excluding the potential influence of these alternative policies, our main conclusions remain valid.

Table 6. Rule out alternative explanations.

	(1)	(2)	(3)	(4)	(5)
	ESG	*ESG*	*ESG*	*ESG*	*ESG*
DID	0.094*	0.104**	0.108**	0.106**	0.093*
	(1.690)	(2.009)	(2.089)	(2.045)	(1.667)
DID_infor	0.020				0.036
	(0.534)				(0.871)
DID_tax		0.066			0.065
		(1.500)			(1.485)
DID_band			−0.028		−0.030
			(−0.729)		(−0.736)
DID_fan				0.055	0.050
				(1.074)	(0.965)
Controls	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Observations	29289	29289	29289	29289	29289
Adj.R^2	0.417	0.417	0.417	0.417	0.417

5. Mechanism analysis

The impact of digital government construction on corporate ESG performance is mainly realized through four interrelated mechanisms: green technological innovation, human capital structure, information asymmetry, and agency costs. Among them, green technological innovation and human capital structure reflect the role of digital government in enhancing firms' capacity to implement ESG practices, while information asymmetry and agency costs capture the strengthening effect of digital government on external monitoring and internal governance discipline. Accordingly, this paper proceeds from these four mechanisms to systematically examine the internal pathways through which digital government construction affects corporate ESG performance.

5.1. Green technological innovation

Green technological innovation reflects the environmental capability component of the capability-enhancement channel. The more precise and efficient social governance driven by digital government has substantially transformed traditional models of environmental regulation (Janowski et al., 2018). To gain the trust of investors, consumers, and the government, firms can no longer rely on superficial environmental strategies; instead, they must improve their environmental performance through genuine green innovation.

On the one hand, digital government platforms and information-sharing mechanisms enhance the transparency of environmental data, emission indicators, and policy orientations. This enables firms to promptly access regulatory requirements and supportive policies related to the green transition, thereby reducing the information search costs and policy uncertainty associated with green innovation (Cao et al., 2025). On the other hand, through institutional arrangements such as digitalized green finance, carbon emission trading, and government procurement, digital government directly incorporates environmental compliance and green innovation performance into firms' financing and market access conditions, thus providing strong incentives for green innovation activities. Moreover, digital technologies enrich the channels for multi-stakeholder collaborative governance, strengthening the participation and oversight of the public and social organizations in monitoring firms' environmental performance.

Overall, digital government promotes firms' green technological innovation, which in turn enhances their ESG performance. To empirically examine this mechanism, we use two indicators to measure corporate green innovation: (1) the natural logarithm of the number of green invention patents obtained by the firm in that year plus one, *patent*1; (2) the natural logarithm of the sum of the firm's green invention patents and utility model patents in that year plus one, *patent*2. As reported in Table 7, digital government construction significantly promotes firms' green technological innovation. These findings provide evidence consistent with the green technological innovation channel proposed in Hypothesis 2.

Table 7. Mechanism of green technological innovation.

	(1)	(2)
	*patent*1	*patent*2
DID	0.057***	0.061***
	(2.993)	(2.787)
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
Observations	29289	29289
Adj.R^2	0.647	0.648

5.2. Human capital structure

Human capital structure captures another dimension of the capability-enhancement channel, focusing on the organizational and knowledge-based capacity required for ESG implementation. Digital government governance provides firms with policy guidance and resource support for green transition and social responsibility projects, thereby encouraging enterprises to increase investment in R&D personnel, digital technology experts, and green management professionals. This facilitates the upgrading of human capital toward higher skills, green innovation, and compliance-oriented governance. Meanwhile, digital government construction can also reduce costs and promote human capital upgrading through administrative information-sharing platforms. Specifically, digital government significantly lowers firms' costs in recruiting skilled personnel and workers' costs in accessing education and training, thereby optimizing the allocation structure of human resources. Such

upgraded human capital is more compatible with the R&D and application of green technological innovation. In addition, high-skilled employees substantially enhance firms' governance capacity and promote the fulfillment of corporate social responsibility. Hence, digital government construction improves corporate ESG performance by driving the upgrading of human capital structures.

To empirically measure this mechanism, we use two indicators: (1) the ratio of technical personnel to total employees, *tech*, to capture the function-based upgrading of human capital, and (2) the ratio of employees with graduate degrees or above to total employees, *study*, to capture the education-based upgrading of human capital. As shown in Table 8, the regression results demonstrate that digital government construction significantly promotes the upgrading of corporate human capital structure. These results further support the capability-enhancement channel by showing that digital government construction promotes the upgrading of firms' human capital structure. Thus, Hypothesis 3 is confirmed.

Table 8. Mechanism of upgrading the human capital structure.

	(1)	(2)
	tech	*study*
DID	0.009**	0.005***
	(2.234)	(2.853)
Controls	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
Observations	29141	26366
Adj.R^2	0.855	0.895

5.3. Information asymmetry

After examining firms' internal capability enhancement, we further investigate the governance-discipline channel from the perspective of information transparency. Information asymmetry between governments and firms under traditional governance frameworks often results in lengthy approval processes for green projects and high institutional transaction costs, with market participants bearing substantial negotiation and bargaining expenses to secure resources (Feng et al., 2022). Digital government construction alleviates information asymmetry between firms and governments, investors, and the public, thereby creating an institutional environment conducive to improving corporate ESG performance.

To measure information asymmetry, we employ the KV index, where a lower value indicates lower levels of information asymmetry. The KV index is calculated as follows:

$$\ln|(P_t-P_{t-1})/P_{t-1}|=\lambda_0+\lambda(Vol_t/Vol_0-1)+\epsilon_{i,t} \quad (2)$$

where P_t is the closing price on day t, Vol_t is the trading volume on day t, and Vol_0 is the annual average daily trading volume. The firm-specific λ estimates are used to construct the KV index. The regression result, as shown in Column (1) of Table 9, indicates that digital government construction significantly reduces corporate information asymmetry. This result supports the governance-discipline channel by indicating that digital government construction improves the information environment faced by firms. Therefore, Hypothesis 4 is supported.

5.4. Agency costs

Agency costs represent the internal governance consequence of the governance-discipline channel. Digital government reduces the costs for governments and financial institutions to detect corporate greenwashing, labor violations, or governance deficiencies, thereby highlighting the governance effect of digital government in enhancing ESG outcomes. At the same time, open data and intelligent supervision increase both the likelihood of detecting corporate misconduct and the severity of penalties. This raises reputational risks and non-compliance costs for firms, while also enabling the public and media to conduct low-cost monitoring through digital platforms. Collectively, these mechanisms incentivize firms to improve ESG performance.

With the development of digital governance platforms, corporate credit disclosure systems, and big data supervision, firms' operational, financial, and compliance information can be disclosed and shared more comprehensively and in real time. This allows shareholders and external investors to more effectively monitor managerial decisions, reducing opportunism and moral hazard, and thereby lowering agency costs. As corporate governance efficiency improves, managers become more attentive to environmental compliance, social responsibility, and transparent governance in order to gain support from capital markets and government incentives. Ultimately, this leads to an overall improvement in ESG performance. To capture agency costs, we use two measures: (1) the ratio of administrative expenses to operating revenue, *operate*, and (2) the ratio of administrative plus sales expenses to operating revenue, *fee*. When agency conflicts are alleviated under digital government construction, these ratios decline, reflecting improved governance efficiency and contributing to enhanced ESG performance. As shown in Columns (2) and (3) of Table 9, regression results show that digital government construction significantly reduces agency costs. These findings further support the governance-discipline channel, suggesting that digital government construction improves corporate ESG performance by strengthening monitoring and reducing agency costs. Thus, Hypothesis 5 is confirmed.

Table 9. Mechanisms of information asymmetry and agency costs.

	(1)	(2)	(3)
	KV	*operate*	*fee*
DID	−0.020***	−0.006***	−0.008**
	(−2.968)	(−2.861)	(−2.219)
Controls	YES	YES	YES
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Observations	29289	29289	28934
Adj.R^2	0.283	0.717	0.833

6. Further analysis

6.1. Heterogeneity analysis

6.1.1. Ownership structure

Enterprises with different ownership structures vary in terms of access to government support, resources, and informational advantages, implying that the impact of digital government construction on ESG performance may differ between state-owned and non-state-owned firms. Under digital government reforms, state-owned enterprises (SOEs) often assume greater political and social responsibilities, and governments tend to place stronger emphasis on their ESG performance. Moreover, SOEs face stricter policy constraints and assessment pressures, which incentivize them to leverage digitalized compliance governance to improve ESG outcomes. In addition, SOEs generally enjoy broader financing channels and lower funding costs, enabling them to more rapidly transform regulatory pressures into green investments and social responsibility actions. To test this, we classify all firms into SOEs and non-SOEs, generating a dummy variable, *nation*, which equals 1 if the firm is state-owned, and 0 otherwise. By interacting *DID* with *nation* and incorporating it into the baseline model, we examine whether digital government construction has heterogeneous effects across ownership types. Column (1) of Table 10 shows that the positive effect of digital government construction on ESG performance is more pronounced among SOEs. This suggests that SOEs, benefiting from resource advantages and policy support, achieve better ESG outcomes when digital government reforms improve the business environment.

6.1.2. Financing constraints

Financing constraints determine firms' ability and willingness to translate the informational transparency and policy incentives of digital government into ESG improvements. Enhancing ESG performance often requires sustained, long-term investment, such as in green technology R&D and energy-saving equipment. Firms with stronger financing constraints face greater difficulties in accessing external capital and suffer from insufficient internal cash flow, meaning that even if digital government reduces information asymmetry, they may still lack the resources to actively improve ESG performance. By contrast, firms with weaker financing constraints can more readily convert the advantages of transparency into green investment and governance enhancement. We adopt the Whited–Wu (WW) index to capture financing constraints, where higher values indicate greater constraints. Based on the annual average WW index, we generate a dummy variable *WW*, which equals 1 when the firm's index is above the average, and 0 otherwise. The interaction term $DID \times WW$ is then included in the baseline model. Column (2) of Table 10 indicates that digital government reforms significantly improve ESG performance among firms with lower financing constraints, whereas the effect is weaker for firms facing tighter financial frictions due to their limited investment capacity.

6.1.3. Firm size

Firms of different sizes differ in resource endowments, their capacity to withstand institutional pressures, and governance capabilities. Large enterprises possess greater financial, human, and technological resources, enabling them to respond more swiftly to digital government initiatives by channeling resources into green innovation and human capital upgrading. They are also subject to greater market attention and regulatory scrutiny, with more established internal governance systems. In addition, motivated by reputational concerns, large enterprises have stronger incentives to enhance ESG performance to maintain credibility with investors and society. In contrast, small- and medium-sized enterprises (SMEs), constrained by limited resources and capabilities, face higher cost pressures and are less able to undertake effective transformation, even when digital government reduces information asymmetry. We define a dummy variable, *size*, which equals 1 if the firm's size exceeds the annual average, and 0 otherwise, and interact it with *DID*×*size*. Column (3) of Table 10 shows that the positive impact of digital government on ESG performance is stronger for larger firms.

6.1.4. Governmental environmental attention

Governmental environmental attention reflects local governments' prioritization in allocating policy resources and enforcement efforts. Regions with stronger environmental attention are more likely to integrate digital governance with green finance, green procurement, and tax incentives, thereby creating stronger incentives for firms to enhance ESG performance. Conversely, regions with lower attention lack such institutional linkages, resulting in weaker corporate motivation for ESG improvements. Furthermore, in regions with high environmental attention, local governments typically invest more resources in environmental governance and more effectively deploy digital tools in regulatory enforcement, thereby increasing the costs of non-compliance. In these areas, digital government platforms are also more likely to strengthen the collection, disclosure, and supervision of environmental data, amplifying the constraints and incentives for corporate environmental responsibility. We construct an indicator of local government environmental attention based on keyword frequency analysis of municipal government work reports across six dimensions: environmental protection, pollution control, resource conservation, collaborative governance, ecological civilization, and sustainable development. A dummy variable, *env*, equals 1 if the indicator is above the annual average, and 0 otherwise. We then include the interaction term *DID*×*env* in the regression model. Column (4) of Table 10 shows that the positive effect of digital government construction on ESG performance is more pronounced in cities with higher governmental environmental attention.

Table 10. Heterogeneity results.

	(1)	(2)	(3)	(4)
	ESG	*ESG*	*ESG*	*ESG*
DID	0.063	0.127**	0.066	0.046
	(1.086)	(2.486)	(1.204)	(0.784)
DID×nation	0.102**			
	(2.138)			
DID×WW		−0.043*		
		(−1.964)		
DID×size			0.069**	
			(2.197)	
DID×env				0.058*
				(1.875)
Controls	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	29289	29289	29289	22280
Adj.R^2	0.417	0.417	0.417	0.415

6.2. Dimension-specific test of ESG performance

To further examine which dimension of ESG performance is more responsive to digital government construction, we decompose the overall ESG score into environmental, social, and governance dimensions, denoted as *EScore*, *SScore*, and *GScore*, respectively. The regression results are reported in Table 11. The coefficient of DID in Column (1) is 0.120 and is significant at the 5% level, indicating that digital government construction significantly improves firms' environmental performance. In Columns (2) and (3), the coefficients of DID are also positive but not statistically significant. This suggests that digital government construction has a positive but relatively weaker effect on firms' social and governance performance. Overall, the results indicate that the improvement in corporate ESG performance driven by digital government construction is mainly reflected in the environmental dimension.

One possible explanation is that the "Internet + Government Services" pilot is more directly related to environmental governance. Digital government construction improves the transparency of environmental information, strengthens digital supervision, and reduces firms' costs of obtaining green policy information. These changes enable firms to respond more quickly to environmental regulation and green transition policies, thereby improving their environmental performance. By contrast, the social and governance dimensions are more closely related to firms' internal management practices, labor relations, board governance, and long-term organizational arrangements. These dimensions usually require a longer adjustment period and are less directly affected by digital government construction in the short run.

Table 11. Dimension-specific test.

	(1)	(2)	(3)
	EScore	*SScore*	*GScore*
DID	0.120**	0.049	0.014
	(1.998)	(0.824)	(0.243)
Controls	YES	YES	YES
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Observations	29288	29288	29288
Adj.R^2	0.422	0.446	0.422

7. Conclusions and policy implications

Based on the quasi-natural experiment of the "Internet + Government Services" pilot program launched in 2016, this paper uses data from Chinese listed firms from 2012 to 2023 to examine the impact of digital government construction on corporate ESG performance and the underlying mechanisms. The findings demonstrate that digital government construction significantly improves corporate ESG outcomes. After conducting parallel trend tests, placebo tests, PSM-DID matching, alternative variable specifications, and a series of robustness checks, the results remain consistent. The mechanism analysis further reveals that digital government enhances corporate ESG performance primarily by promoting green technological innovation, upgrading human capital structures, reducing information asymmetry, and lowering agency costs. Moreover, the positive effect of digital government on ESG performance is more pronounced among state-owned enterprises, firms with lower financing constraints, larger enterprises, and those located in regions where local governments exhibit stronger environmental attention. Further dimension-specific analysis shows that the coefficients of digital government construction on the environmental, social, and governance dimensions are all positive, but only the effect on the environmental dimension is statistically significant. This suggests that the overall improvement in corporate ESG performance is mainly driven by firms' enhanced environmental performance.

These findings suggest that digital government construction can substantially enhance corporate ESG performance, providing important policy insights for improving digital governance systems and advancing sustainable development.

First, policymakers should systematically advance the construction of digital government platforms to enhance information transparency and governance efficiency. Policymakers should accelerate the development of digital government infrastructure by integrating critical corporate information—such as environmental emissions, social responsibility, and governance structures—into comprehensive public databases. This would reduce regulatory costs for both governments and markets and enable deeper integration between policy instruments and corporate ESG practices. Importantly, digital government should be regarded not merely as an incremental improvement but as a systemic transformation of governmental functions and governance models. Leveraging digital technologies across economic regulation, social governance, public service delivery, and ecological protection can promote both integrated coordination and differentiated service provision, ultimately improving firms' overall ESG performance.

Second, the deep application of digital governance in corporate environmental, social, and governance domains should be strengthened. Digital modules such as environmental monitoring, green finance, and labor rights protection should be fully embedded into digital governance frameworks, thereby reinforcing the government's guiding and incentivizing role in driving firms' sustainable development. By improving human capital structures and resource allocation efficiency, digital governance can stimulate firms' intrinsic motivation for green innovation and social responsibility. Furthermore, the orderly opening of government data should be promoted to encourage the participation of investors, consumers, and social organizations in supervision, thereby fostering joint governance between government regulation and societal oversight. In this way, digital government can not only improve corporate social responsibility but also facilitate green transformation and high-quality development.

Third, differentiated regulation and targeted policy support should be promoted to strengthen the synergy between digitalization and ESG performance. Policy design should take into account differences in ownership type, financing constraints, firm size, and local government environmental attention. In regions or industries dominated by state-owned enterprises, characterized by relatively loose financing conditions, or with high levels of governmental environmental concern, policymakers should prioritize the integration of digitalization and green development to create demonstration effects and replicable models. These can amplify the positive effects of digital government on corporate ESG outcomes. At the same time, additional policy support and resource allocation should be directed toward small and medium-sized enterprises (SMEs) to help them overcome financial and capability constraints, improve ESG performance, and avoid marginalization in the sustainable development process due to the high costs of digital and green transformation.

Author contributions

All authors contributed equally to the data analysis, research design and writing of the paper. All authors have read and approved the final manuscript.

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Use of AI tools declaration

The authors declare they have not used artificial intelligence (AI) tools in the creation of this article.

Conflict of interest

All authors declare that they have no conflicts of interest in this paper.

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The data is available from the corresponding author upon request.

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