The Effects and Contextual Differences of Digital Technology Embeddedness on Local Public Environmental Governance Capacity

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Abstract: How digital technology is embedded within public organizations and enhances environmental governance capacity is a core issue in the field of public management in the digital era. Existing studies largely treat digitalization as an overall exogenous variable, lacking in-depth examination of the technological embedding process and contextual conditions. Drawing on technology embedding theory, this paper develops a three-dimensional analytical framework of "instrumental embedding—power embedding—capacity embedding" and introduces the TOE (Technology-Organization-Environment) framework as a contextual analytical tool. Using a sample of 104 key environmental protection cities in China from 2012 to 2022, this study empirically examines the effects and contextual variations of digital technology embedding on local public environmental governance capacity. The findings reveal that both the overall level of digital technology embedding and its three sub-dimensions have a significant positive impact on environmental governance capacity, albeit through distinct pathways: instrumental embedding improves monitoring accuracy and enforcement efficiency; power embedding restructures bureaucratic power structures through unified platforms; and capacity embedding activates multi-actor co-governance via data transparency. Technological infrastructure and fiscal capacity positively moderate the embedding effectiveness, while inter-jurisdictional competition pressure exhibits an inverted U-shaped moderating effect. Heterogeneity analysis indicates that digital technology embedding yields stronger marginal improvement effects on the southeast side of the Hu Huanyong Line, in resource-based cities, and in prefecture-level cities. This study provides a theoretical extension of the embeddedness perspective for understanding governance transformation in the digital era and offers empirical evidence for context-specific digital environmental governance.

Keywords: Technology Embeddedness; Digital Governance; Environmental Governance

1. Introduction

Against the strategic backdrop of the deep coupling between ecological civilization construction and digital government building, local environmental governance faces multiple dilemmas, including information transmission loss, departmental coordination barriers, policy implementation fluctuations, and insufficient public participation[1,2]. The embedding of digital technology offers new pathways to address these structural challenges. The application of technologies such as big data, the Internet of Things, and artificial intelligence can reshape the collection and flow of environmental information, break down fragmented governance barriers, and drive the transformation of governance models from experience-driven to data-driven[3]. However, the governance efficacy of digital technology is not automatically realized. In practice, the same technology yields divergent outcomes across different regions[4], indicating that the effectiveness of technological embedding is highly contingent on the contextual conditions of local governance ecosystems. Existing studies have predominantly focused on the application of digital technology as a tool in public administration[5], with few systematically examining the process mechanisms through which technology enters government organizations from an embeddedness perspective, and lacking empirical investigations into the preconditions

and regional heterogeneity of technology implementation[6].

This paper seeks to address two core questions: First, through which dimensions does digital technology become embedded in local government organizations and reshape environmental governance capacity? Second, what contextual conditions constrain the governance efficacy of technological embedding? To answer these questions, this paper first draws on technology embedding theory to deconstruct digital technology embedding into three dimensions—instrumental embedding, power embedding, and capacity embedding — corresponding respectively to systematic transformations in the material, behavioral, and cognitive components of organizations[7]. Second, it introduces the TOE framework to incorporate technological infrastructure, organizational resources, and external pressures into the analysis of moderating effects. On this basis, using a sample of 104 key environmental protection cities in China from 2012 to 2022, this study constructs a comprehensive index of environmental governance capacity encompassing inputs, processes, and performance, and employs a two-way fixed effects model for empirical testing.

2. Theoretical Analysis and Research Hypotheses

2.1 Theoretical Framework: Integration of Technology Embeddedness, Digital Governance, and the TOE Context

This paper constructs an integrated analytical framework based on Digital Governance Theory, Technology Embeddedness Theory, and the TOE framework (Figure 1). Digital Governance Theory provides a macro-level paradigm for understanding government transformation in the digital era. Its core premise is that government capacity is enhanced through information sharing, process reengineering, and governance synergy[8]. However, a more micro-level theoretical explanation is required to understand how technology enters organizational structures, interacts with existing institutions, and induces change.

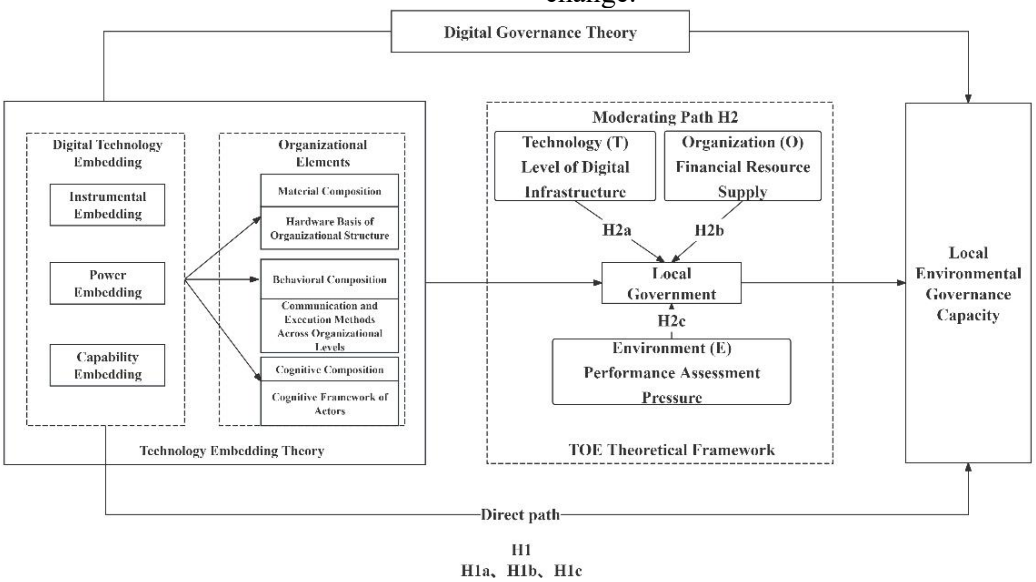

Figure 1. Analysis Framework

Technology Embeddedness Theory offers crucial support in this regard. This theory posits that technology is not an exogenous variable acting directly upon organizational structures; rather, it indirectly drives organizational change and capability reshaping by embedding itself into core organizational components—namely, the material, behavioral, and cognitive dimensions of the organization[7]. The material dimension refers to the "hardware" foundation, including institutional norms, data collection, and processing methods. The behavioral dimension involves power relations and interaction patterns among actors. The cognitive dimension pertains to actors' understanding and identification with rules, roles, and information. The introduction of digital technology transforms these three types of organizational elements, thereby altering the government's operational logic and governance capacity.

Building upon this foundation, this paper adopts the process-oriented embedding framework proposed by Gao Enxin to deconstruct the process of digital technology embedding into local government environmental governance across three dimensions: Instrumental Embeddedness, Power Embeddedness, and Capacity Embeddedness[9]. Instrumental Embeddedness emphasizes the incorporation of digital technology as a governance tool into environmental regulatory processes, primarily affecting the material dimension. Power Embeddedness highlights the restructuring of hierarchical power dynamics through digital hubs, primarily affecting the behavioral dimension[10]. Capacity Embeddedness underscores the reconstruction of governance relationships through data transparency, primarily affecting the cognitive dimension. These three dimensions correspond to different layers of organizational elements, forming a progressive logic that moves from technical tool application to power structure reconfiguration and, ultimately, to governance relationship reconstruction.

The efficacy of technology embedding is contingent upon the support of internal and external organizational contexts. The TOE framework emphasizes that the effectiveness of technological innovation depends on the synergistic alignment of three factors: technological conditions, organizational resources, and the external environment[10]. This paper utilizes the TOE framework as a contextual analysis tool to examine the moderating effects of the technological base (digital infrastructure level), organizational resources (fiscal self-sufficiency rate), and external pressure (local government competition) on the governance effects of digital technology embeddedness.

2.2 Direct Impact of Digital Technology Embeddedness: Three-Dimensional Mechanisms and Hypotheses

Digital technology embeddedness enhances local government environmental governance capacity through three dimensions. From the perspective of governance tools, the integration of digital technology with environmental monitoring and law enforcement enables real-time surveillance, diagnosis, analysis, and decision-making, thereby achieving precise control and scientific decision-making across the three stages of monitoring, supervision, and prevention[2]. From the perspective of power structures, unified command and dispatch platforms mitigate hierarchical attenuation and departmental barriers inherent in traditional bureaucracy through real-time data aggregation and comprehensive process tracing[11]. From the perspective of governance relationships, environmental information disclosure and data transparency dismantle the government's monopoly on information, propelling governance from unidirectional control toward multi-stakeholder co-governance[12].

2.2.1 Instrumental embeddedness: enhancing governance efficiency at the material dimension

Instrumental Embeddedness refers to the incorporation of digital technologies as governance tools into environmental regulatory processes. By deploying online monitoring equipment, mobile law enforcement terminals, and intelligent early warning systems, it alters the material dimension of the organization—transitioning information collection from manual reporting to automatic sensing and shifting business processes from fragmented execution to closed-loop management. This embedding process enhances governance capacity through three mechanisms: First, automated monitoring networks enable real-time acquisition and anomaly identification of pollution source data, significantly improving the timeliness and precision of supervision. Second, big data analytics support pollution source tracing and risk assessment, facilitating a shift from experience-driven to evidence-driven decision-making. Third, digital process reengineering creates a closed loop encompassing supervision, enforcement, and feedback, thereby reducing coordination costs and implementation deviations. Consequently, Instrumental Embeddedness systematically enhances the refinement of local government environmental governance by strengthening the information base and process standardization. Based on this, the following hypothesis is proposed:

H1a: Instrumental embeddedness of digital technology has a significant positive impact on local government environmental governance capacity.

2.2.2 Power embeddedness: restructuring authority relations at the behavioral dimension

Power Embeddedness refers to the restructuring of power operation rules within the bureaucratic

organization through digital hubs such as unified command and dispatch platforms, acting upon the behavioral dimension of the organization. Traditional environmental governance relies on vertical hierarchical command and horizontal departmental division of labor. The step-by-step reporting of information leads to hierarchical attenuation and distortion, while excessive discretionary power at the grassroots level can trigger implementation volatility. Digital platforms reconfigure control rights across three dimensions through real-time data aggregation and comprehensive online traceability: Upward centralization of information production rights reduces filtering and delays in hierarchical transmission; increased transparency of supervision and assessment rights curtails the space for strategic responses at the grassroots level; and integration of collaborative scheduling rights overcomes the fragmentation barriers of cross-departmental governance. This restructuring of power dynamics fosters a highly interconnected governance model, effectively compensating for the structural deficiencies inherent in the bureaucratic hierarchy. Based on this, the following hypothesis is proposed:

H1b: Power embeddedness of digital technology has a significant positive impact on local government environmental governance capacity.

2.2.3 Capacity embeddedness: reconstructing governance relations at the cognitive dimension

Capacity Embeddedness refers to the reshaping of governance relationships among government, enterprises, and the public through environmental information disclosure and data transparency, acting upon the cognitive dimension of the organization. In traditional closed governance models, the government's monopoly on environmental information leaves public oversight unimplemented and enterprises lacking external incentives for behavioral improvement. Capacity Embeddedness, centered on institutional arrangements such as the Pollution Information Transparency Index (PITI) and the release of online monitoring data, breaks down information barriers and shifts governance resources from exclusive government possession to multi-stakeholder sharing. On one hand, data transparency compels the government to enhance information management and public responsiveness, thereby increasing governance sensitivity and credibility. On the other hand, publicly accessible pollution and enforcement data lower the threshold for public oversight, creating a mechanism of social pressure transmission that encourages enterprises to transition from passive compliance to active responsibility fulfillment. Consequently, governance relations evolve from unidirectional control toward a multi-stakeholder co-governance model characterized by two-way empowerment. Based on this, the following hypothesis is proposed:

2.3 Moderating Effects of TOE Contexts: Boundary Conditions and Hypotheses

The governance efficacy of digital technology embeddedness is not unconditional but is significantly moderated by the technological base, organizational resources, and external pressure. Following the TOE framework, this paper proposes three moderating effect hypotheses.

2.3.1. Moderating effect of technological context

The technological base constitutes the physical support and operational environment for digital technology embeddedness. Robust digital infrastructure—including high-speed broadband networks, mobile communication base stations, and government cloud platforms—reduces latency in environmental monitoring data transmission, enhances the stability and coverage of online monitoring systems, and supports the implementation of advanced applications such as AI-assisted law enforcement. When local governments possess favorable technological conditions, monitoring tools within Instrumental Embeddedness operate more efficiently, unified platforms within Power Embeddedness facilitate smoother coordination, and information disclosure within Capacity Embeddedness achieves broader reach. There exists a significant complementary effect between technological infrastructure and digital technology embeddedness. Based on this, the following hypothesis is proposed:

H2a: The more developed the technological base, the stronger the promotional effect of digital technology embeddedness on local government environmental governance capacity.

2.3.2 Moderating effect of organizational context

Fiscal resources serve as the organizational guarantee for the sustained advancement of

digital technology embeddedness. The deployment of digital systems involves not only upfront hardware procurement and software development but also ongoing operational maintenance, personnel training, and technological iteration. Local governments with higher fiscal self-sufficiency possess more abundant discretionary financial resources, enabling stable budgetary support for the routine operation of digital governance systems and preventing issues of "building without using" or "using without sustaining" due to funding shortages. Moreover, ample fiscal capacity implies stronger mobilization capabilities for cross-departmental coordination and institutional support, which facilitates the organizational restructuring required for Power Embeddedness. Based on this, the following hypothesis is proposed:

H2b: The stronger the fiscal capacity, the stronger the promotional effect of digital technology embeddedness on local government environmental governance capacity.

2.3.3 Moderating effect of environmental context

Local government competitive pressure constitutes the external institutional constraint on digital technology embeddedness. Under China's "promotion tournament" system, local officials simultaneously face dual performance pressures from both economic growth and environmental protection. Moderate competitive pressure can incentivize local governments to proactively adopt digital technology as a governance tool to enhance performance, thereby amplifying the governance efficacy of technology embeddedness. However, when competitive pressure exceeds a critical threshold, the attentional resources of local governments become disproportionately occupied by short-term economic objectives. In such cases, the application of digital technology tends to exhibit formalistic tendencies—emphasizing platform construction over substantive application—thereby weakening the actual effectiveness of technology embeddedness. Accordingly, the moderating effect of competitive pressure is expected to exhibit non-linear characteristics. Based on this, the following hypothesis is proposed:

H2c: Local government competitive pressure exerts an inverted U-shaped moderating effect on the governance efficacy of digital technology embeddedness, wherein moderate pressure enhances the effect, while excessive pressure diminishes it.

3. Research Design

3.1 Sample Selection and Data Sources

This study takes key environmental protection cities in China as the research object. The PITI has been jointly released by the Institute of Public and Environmental Affairs (IPE) and the Natural Resources Defense Council (NRDC) since 2009. Covering 120 key cities nationwide, it is currently the most authoritative third-party evaluation indicator in the field of environmental information disclosure in China. Based on data availability, this study selects 104 cities at the prefectural level and above that consistently appeared in the PITI evaluation from 2012 to 2022, constructing a balanced panel dataset with a total of 1,040 observations. The data are primarily sourced from the China City Statistical Yearbook, China Environmental Statistical Yearbook, provincial and municipal statistical yearbooks, the official website of the Ministry of Ecology and Environment, and local government work reports. Missing data for certain observations are supplemented using linear interpolation.

3.2 Variable Measurement

3.2.1 Dependent variable: local government environmental governance capacity (EGC)

Drawing on the research of He[2], a comprehensive indicator system is constructed across three dimensions: environmental governance input, governance process, and governance performance. The input dimension includes the proportion of environmental protection expenditure and the proportion of environmental protection personnel. The process dimension measures the intensity of environmental regulation using the proportion of environment-related statements in local government work reports. The performance dimension covers indicators such as industrial wastewater discharge, the proportion of days with good air quality, the harmless treatment rate of domestic waste, and the centralized treatment rate of sewage. The entropy weight method is employed to objectively assign weights to the indicators and synthesize them into a comprehensive index.

3.2.2 Core independent variables

(1) Instrumental embeddedness (tool)
Measured based on the annual assessment results of the "Ecological Environmental Protection Law Enforcement Drill" organized by the Ministry of Ecology and Environment. Scoring rules are as follows: 1 point if the province is awarded "Outstanding Collective"; 3 points if the municipal-level bureau is awarded; 2 points if a district/county-level unit is awarded; and 1 point if any individual is recognized as "Outstanding Individual." The cumulative score reflects the depth of application of digital law enforcement tools.
(2) Power embeddedness (power)
Proxied by whether the local government has established and put into operation a unified ecological and environmental command and dispatch platform. Determined through manual retrieval of government official websites, work reports, and bidding announcements. A value of 1 is assigned if the platform has been established and is operational; otherwise, 0.
(3) Capacity embeddedness (capacity)
Directly measured using the annual PITI score of each city. The index systematically evaluates the level of environmental information disclosure across five dimensions: regulatory information, self-monitoring, interactive response, emission data, and environmental impact assessment information. A higher score indicates a deeper degree of capacity embeddedness.
(4) Comprehensive digital technology embeddedness index (dtei)
The entropy weight method is used to synthesize the above three sub-dimensional indicators into a comprehensive index, which is employed for testing moderating effects.

3.2.3 Moderating variables
Technological Context is measured by the level of digital infrastructure. An index is constructed by integrating indicators such as broadband internet access, the number of mobile base stations, and the development of government cloud platforms.
Organizational Context is measured by the fiscal self-sufficiency rate, defined as the ratio of local general public budget revenue to local general public budget expenditure.
Environmental Context is measured by local government competitive pressure, calculated as the difference between the city's GDP (Gross Domestic Product) growth rate and the average GDP growth rate of all prefectural-level cities within the same province.

3.2.4 Control variables
Control variables include the level of economic development (log of per capita GDP), population density (permanent residents per unit area), industrial structure (value added of the secondary industry as a proportion of GDP), degree of openness (actual foreign investment as a proportion of GDP), and urbanization rate (urban population as a proportion of total population). Variables are presented in Table 1.

Table 1. Selection of Variables and Measurement Indicators

Category	Variable	Description
Dependent Variable	EGC	Comprehensive index constructed from panel data
Independent Variables	Tool	Scored based on the assessment results of the Ecological Environmental Protection Law Enforcement Drill
	Power	Whether a unified ecological and environmental command and dispatch platform has been established and put into operation
	Capability	PITI
Moderating Variables	T	Digital infrastructure level
	O	Fiscal self-sufficiency rate, measured as the ratio of local general public budget revenue to local general public budget expenditure, and transformed using natural logarithm
	E	Difference between the city's GDP growth rate and the average growth rate of all prefectural-level cities within the same province
Control Variables	GDP	Per capita Gross Regional Product
	Pop	Number of permanent residents per square kilometer
	Industry	Value added of the secondary industry / Gross Regional Product
	Open_ratio	Actual foreign investment of the prefectural-level city in the current year / Gross Regional Product
	Urban	Urban population / Total population

3.3 Model Specification

To test Hypothesis H1 proposed above, a linear regression model is first constructed to examine the relationship between the level of digital technology embeddedness—as well as its three sub-dimensions—and local government environmental governance capacity. Considering the lagged effect of digital technology embeddedness on governance capacity, EGC_{it} denotes the environmental governance capacity of prefectural-level city I in year t, $Tool_{it-1}$ denotes the degree of Instrumental Embeddedness of city i in year t-1; $Power_{it-1}$ denotes the degree of Power Embeddedness in year t-1. $Capability_{it-1}$ denotes the degree of Capacity Embeddedness in year t-1. $Control_{it}$ represents the set of control variables; η_i denotes city fixed effects; μ_t denotes time fixed effects; and ε_{it} is the random error term.

(1) The relationship between Instrumental Embeddedness and local government environmental governance capacity is examined using the following regression specification. If the coefficient of Instrumental Embeddedness satisfies. If $\beta_1 > 0$, Hypothesis H1a is supported.

$$EGC_{it} = \beta_0 + \beta_1 Tool_{it-1} + \beta_n Control_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (1)$$

(2) The relationship between Power Embeddedness and local government environmental governance capacity is examined using the following regression specification. If the coefficient satisfies. If the coefficient satisfies $\beta_1 > 0$, Hypothesis H1b is supported.

$$EGC_{it} = \beta_0 + \beta_1 Power_{it-1} + \beta_n Control_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (2)$$

(3) The relationship between Capacity Embeddedness and local government environmental governance capacity is examined using the following regression specification. If the coefficient satisfies $\beta_1 > 0$, Hypothesis H1c is supported.

$$EGC_{it} = \beta_0 + \beta_1 Capability_{it-1} + \beta_n Control_{it} + \eta_i + \mu_t + \varepsilon_{it} \quad (3)$$

To verify the moderating effects of the technological context, organizational context, and environmental context on the relationship between digital technology embeddedness and local government environmental governance capacity, this paper draws on established methodological approaches. Specifically, we introduce the levels of digital infrastructure, fiscal self-sufficiency rate, and local government inter-jurisdictional competitive pressure—along with their respective interaction terms with the comprehensive digital technology embeddedness index (DTEI)—into the model. This allows us to separately analyze the influence of these three contextual factors on the governance efficacy of digital technology embeddedness. The specific models are specified as follows:

$$EGC_{it} = \beta_0 + \beta_1 DTEI_{it-1} + \beta_2 T_{it-1} + \beta_3 (DTEI_{it-1} \times T_{it-1}) + \beta_n Control_{it} + \mu_i + \lambda_i + \varepsilon_i \quad (4)$$

$$EGC_{it} = \beta_0 + \beta_1 DTEI_{it-1} + \beta_2 O_{it-1} + \beta_3 (DTEI_{it-1} \times O_{it-1}) + \beta_n Control_{it} + \mu_i + \lambda_i + \varepsilon_i \quad (5)$$

$$EGC_{it} = \beta_0 + \beta_1 DTEI_{it-1} + \beta_2 E_{it-1} + \beta_3 (DTEI_{it-1} \times E_{it-1}) + \beta_n Control_{it} + \mu_i + \lambda_i + \varepsilon_i \quad (6)$$

$DTEI_{it-1}$ denotes the comprehensive digital technology embeddedness index of city i in year t-1; T_{it-1} represents the digital infrastructure level of the city, O_{it-1} represents the fiscal self-sufficiency rate of the local government of city i in year t-1, E_{it-1} represents the inter-jurisdictional competitive pressure faced by the local government. The coefficients of the interaction terms $DTEI_{it-1} \times T_{it-1}$, $DTEI_{it-1} \times O_{it-1}$ and $DTEI_{it-1} \times E_{it-1}$ reflect how differences in local government contexts moderate the relationship between digital technology embeddedness and local government environmental governance capacity.

4. Empirical Results and Analysis

4.1 Baseline Regression Results

Table 2 reports the baseline regression results of digital technology embeddedness on local government environmental governance capacity. Column (1) shows that the coefficient of the comprehensive digital technology embeddedness index is 0.007, statistically significant at the 1% level, indicating that the overall level of digital technology embeddedness significantly enhances local government environmental governance capacity. Columns (2) through (4) respectively test the effects of the three sub-dimensions: the coefficient of Instrumental Embeddedness is 0.005 ($p < 0.01$), the coefficient of Power Embeddedness is 0.009 ($p < 0.05$), and the coefficient of Capacity Embeddedness is 0.005 ($p < 0.05$). All are significantly positive,

supporting H1a, H1b, and H1c.

In terms of coefficient magnitude, Power Embeddedness exhibits the largest marginal effect, indicating that the restructuring of bureaucratic power represented by the unified command and dispatch platform plays the most prominent role in enhancing environmental governance capacity. The effects of Instrumental Embeddedness and Capacity Embeddedness are relatively similar, jointly constituting the foundational support for digital technology empowerment. Among the control variables, the level of economic development is consistently significantly positive, while industrial structure (the proportion of the secondary industry) is significantly negative, consistent with theoretical expectations.

Table 2. Baseline Regression Results

Model / Variables	(1)	(2)	(3)	(4)
	EGC			
L.DTEI	0.007***			
	(0.002)			
L.Tool		0.005***		
		(0.001)		
L.Power			0.009**	
			(0.004)	
L.Capacity				0.005**
				(0.002)
Controls	Yes	Yes	Yes	Yes
Individual Fixed	Yes	Yes	Yes	Yes
Time Fixed	Yes	Yes	Yes	Yes
Cons	-2.206***	-0.428	-0.487	-0.267
	(0.594)	(0.775)	(0.543)	(0.553)
Observations	1040	1040	1040	1040
R^2	0.469	0.470	0.465	0.464

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Robust standard errors clustered at the city level are reported in parentheses.

4.2 Analysis of Moderating Effects

Table 3. Moderating Effects of Technological Context and Organizational Context

Model / Variables	(1)	(2)
	EGC	
L.DTEI	0.006**	0.005*
	(0.003)	(0.003)
L.T	-0.036**	
	(0.018)	
L.O		-0.018***
		(0.006)
L.DTEI*L.T	0.043*	
	(0.023)	
L.DTEI*L.O		0.002*
		(0.001)
Controls	Yes	Yes
Cons	-2.062**	-1.710**
	(0.833)	(0.743)
Observation	1040	1040
R^2	0.487	0.500

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Robust standard errors clustered at the city level are reported in parentheses.

Table 3 reports the results of the moderating effect tests for the Technology context and Organization context. In Column (1), the interaction term between digital technology embeddedness level and digital infrastructure level has a coefficient of 0.043, statistically significant at the 10% level, confirming H2a. In Column (2), the interaction term with fiscal self-sufficiency rate has a coefficient of 0.002, statistically significant at the 10% level, confirming H2b. These results indicate that a well-developed technological base and abundant fiscal resources can effectively amplify the governance efficacy of digital technology embeddedness, both serving as organizational safeguards for technology empowerment.

Table 4 shows the moderating effect of the environmental context. The results show that the interaction term between digital technology embeddedness level and the quadratic term of competitive pressure has a coefficient of -0.001, statistically significant at the 5% level. This

indicates that the moderating effect of competitive pressure exhibits an inverted U-shaped characteristic. Calculation reveals that the inflection point of competitive pressure is approximately 0.5. When competitive pressure is below the inflection point, the governance effect of digital technology embeddedness strengthens as pressure increases; beyond the inflection point, the effect diminishes as pressure increases. H2c is thus confirmed.

Table 4. Moderating Effects of Environment Context

Model / Variables	(3) EGC
L.DTEI	0.009***
	(0.006)
$L.E^2$	0.000
	(0.001)
L.DTEI*L.E	0.001
	(0.001)
$L.DTEI*L.E^2$	-0.001**
	(0.001)
Controls	Yes
Cons	-1.985**
	(0.832)
Obeservation	1,040
R^2	0.486

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Robust standard errors clustered at the city level are reported in parentheses.

4.3 Heterogeneity Analysis

This study conducts grouped regressions across three dimensions—region, resource endowment, and administrative hierarchy—to further reveal the contextual dependence of digital technology governance effects.

In terms of regional heterogeneity, results grouped by the Hu Huanyong Line show that both the comprehensive digital technology embeddedness index and its three sub-dimensions are significantly positive in cities on the southeastern side, whereas none are significant in cities on the northwestern side. This disparity stems from the more developed digital infrastructure and stronger factor agglomeration capacity in the southeastern region, which amplify the scale and spillover effects of technology embedding.

Regarding resource endowment heterogeneity, the coefficient of digital technology embeddedness level in resource-based cities is 0.017 ($p < 0.01$), which is substantially larger than that in non-resource-based cities, where the coefficient is not statistically significant. Across the three dimensions, Instrumental, Power, and Capacity Embeddedness are all significantly positive in resource-based cities, whereas only Capacity Embeddedness shows marginal significance in non-resource-based cities. This indicates that digital technology exerts a stronger marginal improvement effect in regions with weaker governance foundations, serving the function of addressing deficiencies.

Regarding administrative hierarchy heterogeneity, ordinary prefectural-level cities experience significant positive impacts from all three dimensions, with Power Embeddedness exhibiting the largest coefficient. Provincial capital cities show significance only in Capacity Embeddedness. None of the three dimensions are significant in municipalities directly under the central government. This finding corroborates the pattern that the higher the administrative hierarchy and the more mature the governance system, the weaker the marginal benefit of digital technology embeddedness.

4.4 Robustness Tests and Endogeneity Treatment

To ensure the reliability of the conclusions, several robustness tests are conducted. First, the dependent variable is replaced: principal component analysis is used to reconstruct the environmental governance capacity index, and the conclusions remain consistent. Second, all continuous variables are winsorized at the 1% level. Third, samples from municipalities directly under the central government are excluded. Fourth, the sample period is shortened to 2012–2018 to exclude potential interference from major public health events. In all these tests, the signs and significance levels of the core explanatory variables do not undergo substantive changes.

To mitigate endogeneity bias arising from reverse causality and omitted variables, the system Generalized Method of Moments (System GMM) is employed for estimation. Both the AR(2) test and the Hansen test are passed, indicating that the instrumental variables are valid. After controlling for the lagged term of the dependent variable, the coefficients of the digital technology embeddedness level and its three sub-dimensions remain significantly positive,

confirming the robustness of the conclusions.

5. Conclusions and Policy Implications

5.1 Research Conclusions

Based on technology embeddedness theory, this paper constructs a three-dimensional analytical framework of "Instrumental Embeddedness—Power Embeddedness—Capacity Embeddedness." Using a sample of 104 key environmental protection cities in China from 2012 to 2022, it empirically examines the impact of digital technology embeddedness on local government environmental governance capacity and its contextual differences. The main conclusions are as follows:

First, the overall level of digital technology embeddedness significantly enhances local government environmental governance capacity, and the three dimensions operate through differentiated pathways. Instrumental Embeddedness improves monitoring precision and enforcement efficiency through the deployment of digital tools. Power Embeddedness restructures the bureaucratic power hierarchy and mitigates hierarchical attenuation through unified platforms. Capacity Embeddedness activates multi-stakeholder co-governance through data transparency. Among these, Power Embeddedness yields the largest marginal effect, highlighting the central role of digital hubs in organizational change.

Second, the governance efficacy of digital technology is significantly moderated by TOE contexts. Technological base and fiscal capacity positively moderate the embedding effect, serving as foundational safeguards for technology empowerment. Local government competitive pressure exhibits an inverted U-shaped moderating effect: moderate pressure stimulates innovative momentum, whereas excessive pressure leads to attentional displacement and efficacy attenuation.

Third, significant heterogeneity exists in the governance effects of digital technology embeddedness. The marginal improvement effect is more pronounced in cities southeast of the Hu Huanyong Line, in resource-based cities, and in ordinary prefectural-level cities. This suggests that digital technology possesses a "late-mover advantage" in regions with weaker governance foundations and can serve to bridge regional disparities in governance capacity.

5.2 Policy Implications

Based on the research findings, the following policy recommendations are proposed: First, strengthen digital infrastructure and promote intelligent monitoring and law enforcement, while avoiding the formalistic tendency of "emphasizing construction over application." Second, advance inter-departmental collaboration through unified platform development, integrating fragmented monitoring data and enforcement resources into a cohesive governance force. Third, deepen environmental information disclosure, establish digital channels for public participation, and foster a multi-stakeholder co-governance framework. Fourth, advance digital reforms in accordance with local conditions, increase resource allocation toward resource-based cities and ordinary prefectural-level cities to leverage the marginal advantages of digital technology, and simultaneously guide local government competition appropriately to prevent strategic responses induced by excessive pressure.

5.3 Research Limitations and Future Directions

This study has the following limitations: First, the measurement of digital technology embeddedness is constrained by data availability; future research could integrate methods such as big data text mining to enhance precision. Second, the potential negative effects of digital technology, such as "digital burden," have not been thoroughly examined; subsequent studies could further explore the double-edged sword effects of technology embeddedness. Third, micro-level mechanisms await deeper investigation through case analysis.

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