CAN DIGITALIZATION ENHANCE GOVERNMENT EFFECTIVENESS? NONLINEAR EFFECTS AND THE MODERATING ROLE OF REGULATORY QUALITY: EVIDENCE FROM ASIA AND EUROPE

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Abstract

Digitalization is widely expected to improve government effectiveness; however, empirical evidence remains inconclusive, particularly regarding the roles of institutional quality and regional heterogeneity. This study examines the relationship between digitalization and government effectiveness, with regulatory quality as a moderating factor, using panel data from 14 Asian and European countries over the period 2007–2023. A fixed-effects panel regression model is employed with a principal component analysis (PCA)-based digitalization index, incorporating both quadratic and interaction terms to capture nonlinear and conditional effects. The study contributes to the digital governance literature by jointly examining the direct, nonlinear, moderating, and regional dimensions of the digitalization–government effectiveness relationship within a unified analytical framework. The findings indicate that digitalization alone does not have a significant linear effect on government effectiveness, while its nonlinear effect is significantly negative. In contrast, regulatory quality significantly strengthens the positive impact of digitalization, with the moderating effect being more pronounced in European countries than in Asian economies. These findings suggest that the governance benefits of digital transformation depend not only on technological advancement but also on strong regulatory institutions that enable digital governance.

Keywords: Digital Governance; Digitalization; Government Effectiveness; Institutional Quality; Regulatory Quality

1. Introduction

Digital transformation has become one of the most significant drivers of governance reform in the twenty-first century (Ding et al., 2026; Pribadi et al., 2024). Governments around the world increasingly rely on digital technologies to improve administrative efficiency, strengthen transparency, and enhance the quality of public service delivery (Pribadi et al., 2024). The rapid expansion of internet access, broadband infrastructure, and digital government platforms has enabled public institutions to adopt more data-driven and responsive approaches to governance (Ding et al., 2026; Lnenicka, Luterek, et al., 2024). As a result, digitalization is now widely recognized as an important instrument for improving government performance, institutional effectiveness, and the delivery of public value (Ding et

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al., 2026; Pribadi et al., 2024). As a result, digitalization is now widely recognized as an important instrument for improving government performance, institutional effectiveness, and the delivery of public value. However, the effectiveness of digital transformation in public services depends not only on technological adoption but also on adequate digital infrastructure, human-resource capabilities, and institutional integration (Astinayanti, 2024).

The influence of digitalization on governance can be understood through several complementary theoretical perspectives. Institutional theory argues that governance outcomes depend largely on the quality of formal institutions, including regulatory frameworks and administrative capacity. Technology adoption theory further suggests that the benefits of digital technologies are realized only when organizations possess the capabilities required for effective implementation and utilization. Similarly, public value theory emphasizes that digital technologies create value by improving transparency, accountability, citizen engagement, and service responsiveness. From a public administration perspective, these theoretical perspectives collectively explain how digital transformation extends beyond technological innovation to support administrative reform, institutional capacity building, and more effective public governance. They emphasize that the success of digital governance initiatives depends not only on technological advancement but also on the ability of public institutions to develop robust regulatory frameworks, strengthen administrative capabilities, and deliver greater public value through transparent, accountable, and citizen-centered governance. Recent evidence from Indonesia further shows that the digital transformation of the public sector depends on the digital literacy and capabilities of government personnel, highlighting the importance of human and organizational capacity in translating digital technologies into effective public-sector outcomes (Iswanto et al., 2024). Collectively, these perspectives indicate that while digitalization can improve governance performance, its effectiveness is likely to depend on the institutional environment in which it is implemented, particularly the regulatory and governance arrangements surrounding digital technologies (K. Prifti et al., 2024).

Recent studies provide substantial evidence supporting the positive contribution of digitalization to governance outcomes. Recent cross-country evidence further indicates that government digitalization generates broader developmental benefits beyond public administration. Using data from 72 countries, (Ding et al., 2026) show that government digitalization enhances national innovation capability by improving the business environment, reducing corruption, and strengthening legal institutions. Digital government initiatives have been shown to improve administrative efficiency, service quality, fiscal management, and citizen satisfaction across a wide range of contexts (Hariguna et al., 2022; Khairati & Putra, 2024a; Kurniawan et al., 2023; Reynilda et al., 2025; Taufiqurokhman et al., 2025a; Zulmasyhur et al., 2024). Similarly, (Wandaogo, 2022) finds that digitalization significantly improves government effectiveness across both developing and developed countries, although the magnitude of the effect is considerably stronger in developed economies. Evidence from Indonesia similarly suggests that digital transformation enhances public service accessibility, organizational efficiency, and government responsiveness (Andrian Putro & Maricar Besa, 2025; Fitriyanti, 2024; Ismail et al., 2025). These findings indicate that digital technologies have become increasingly important in supporting effective public administration and improving governance performance.

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Beyond administrative improvements, digitalization has also been associated with broader institutional outcomes. Previous studies report that digital government initiatives strengthen transparency, increase public trust, and improve citizen participation in governance processes (Dwibin Kannapadang et al., 2025; Ramadhani et al., 2025). Evidence from Indonesia further demonstrates that digital transformation contributes to smart governance by improving public service delivery, enhancing citizen engagement, and facilitating more responsive government systems (Firmansyah et al., 2024; Priyowidodo et al., 2024). Similarly, digital transformation has been shown to strengthen transparency and improve public administration practices, thereby supporting more effective governance structures (Zulmasyhur et al., 2024). At the macro level, digital governance has been found to contribute to lower corruption levels and better governance quality across countries(Durkiewicz & Janowski, 2021; Seiam & Salman, 2024) . Likewise, research on open government data demonstrates that digital platforms can promote accountability, transparency, and civic engagement by facilitating access to public information(Lnenicka, Luterek, et al., 2024; Molodtsov & Nikiforova, 2024a; Rajamae-Soosaar & Nikiforova, 2024). Together, these studies suggest that digital transformation can generate benefits that extend beyond operational efficiency to encompass broader dimensions of governance quality.

Despite these positive findings, emerging evidence indicates that digitalization alone may not be sufficient to guarantee improved governance outcomes. Recent evidence further highlights the importance of governance quality in shaping digitalization outcomes. Using panel data from Sub-Saharan African countries, (Hou et al., 2026) demonstrate that government effectiveness significantly amplifies the positive effects of digitalization, while weak governance institutions reduce its developmental benefits. Their findings suggest that institutional quality plays a critical role in determining whether digital transformation generates sustainable socio-economic improvements. Several studies emphasize that institutional and organizational conditions play a critical role in determining the success of digital transformation initiatives. (Di Giulio & Vecchi, 2023) likewise argue that the implementation of digital technologies in the public sector is often shaped by governance structures, organizational coordination, and institutional arrangements. Their findings indicate that technological innovation frequently generates implementation challenges when administrative systems are not adequately prepared to support digital transformation. Regulatory support, institutional capacity, and organizational readiness have been identified as essential factors for effective digital government implementation, while complementary governance mechanisms further strengthen digital transformation outcomes(Alfiani et al., 2024; Darusalam et al., 2023; Mindarti et al., 2024). Similarly,(Kumoro, 2026) highlights the importance of organizational learning and institutional adaptation in maximizing the benefits of digital technologies. These findings suggest that digitalization is unlikely to produce optimal governance outcomes in the absence of supportive institutional frameworks and effective regulatory environments. Similarly, (Shenkoya, 2025) finds that the digital transformation of governance may fail to improve transparency and accountability when regulatory frameworks, auditing mechanisms, and institutional controls remain weak. The study emphasizes that digital technologies alone cannot eliminate governance deficiencies without complementary institutional reforms.

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Furthermore, recent theoretical and empirical discussions suggest that the relationship between digitalization and governance outcomes may not be strictly linear. Existing evidence remains inconclusive regarding the extent to which digitalization directly improves governance performance. For example, (Dobrolyubova et al., 2019) find that although digitalization is positively associated with several dimensions of public administration, its relationship with government effectiveness is not always direct or automatic. While digital technologies can initially improve efficiency and service delivery, excessive digitalization may increase administrative complexity, generate coordination challenges, and create implementation costs that reduce marginal benefits. Consequently, the positive effects of digitalization may diminish or even reverse once digital development exceeds certain thresholds. However, empirical evidence on such nonlinear effects remains limited, particularly in cross-country governance studies.

Another important limitation of the existing literature concerns regional heterogeneity. Most previous studies focus on individual countries or global samples, providing limited understanding of how institutional differences shape the effectiveness of digital transformation across regions. Variations in regulatory quality, administrative capacity, digital maturity, and governance structures suggest that the impact of digitalization may differ substantially across institutional contexts. In particular, Asia and Europe provide a meaningful comparative setting because they represent diverse stages of digital transformation, contrasting levels of institutional development, and distinct governance models. Europe is generally characterized by more mature digital ecosystems and well-established regulatory frameworks, whereas Asian countries exhibit greater heterogeneity in digital development and institutional capacity. Comparing these two regions therefore enables a more comprehensive assessment of whether and to what extent institutional contexts condition the relationship between digitalization and government effectiveness, thereby enhancing the external validity and policy relevance of the study.

Despite the growing empirical evidence supporting the governance benefits of digitalization, recent studies increasingly suggest that digitalization alone is insufficient to guarantee improvements in government effectiveness. First, prior studies have predominantly examined the direct effects of digitalization on government effectiveness, while the possibility of nonlinear relationships has received limited empirical attention. Second, although institutional quality is widely recognized as a critical determinant of successful digital transformation, the moderating role of regulatory quality in shaping the digitalization–government effectiveness nexus remains insufficiently explored. Third, existing evidence provides limited insight into whether this relationship varies across regions characterized by different levels of institutional development and digital maturity, particularly between Asia and Europe. More importantly, these dimensions have largely been investigated in isolation rather than within a unified analytical framework. Addressing these gaps, the present study simultaneously examines the direct, nonlinear, moderating, and regional dimensions of the digitalization–government effectiveness relationship, thereby providing a more comprehensive understanding of the institutional conditions under which digitalization enhances government effectiveness.

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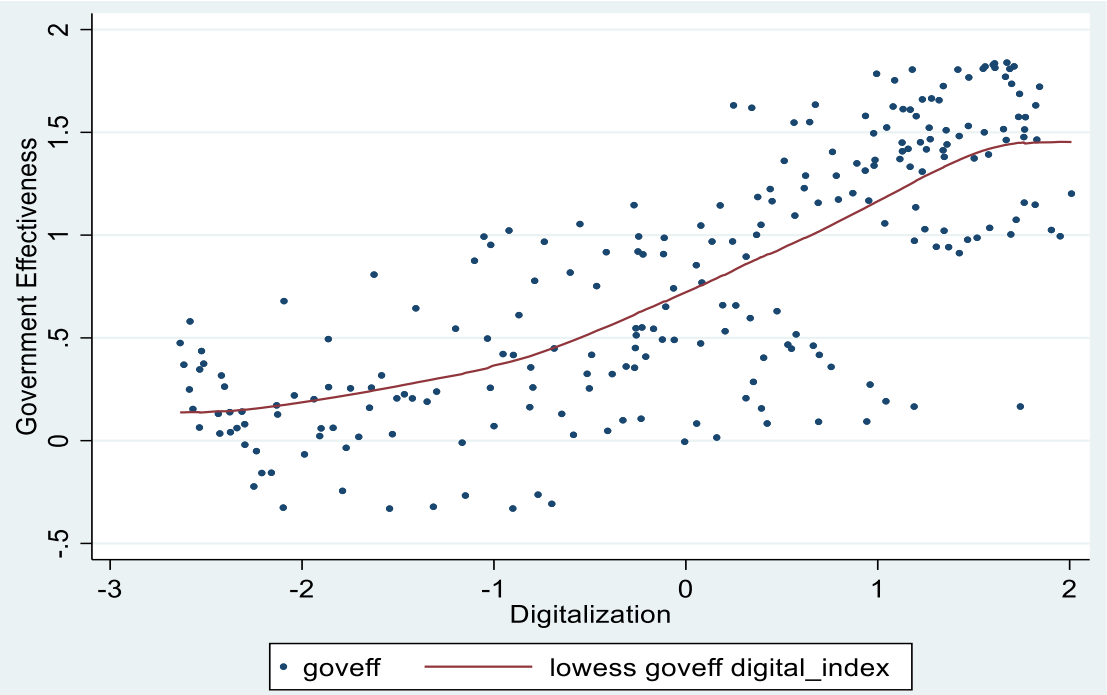

Figure 1. Preliminary Relationship Between Digitalization and Government Effectiveness: Evidence from Asian and European Countries (2007–2023)

Source: Author's elaboration based on World Bank data (World Development Indicators and Worldwide Governance Indicators, 2026

Figure 1 presents a scatter plot with a LOWESS smoothing curve illustrating the relationship between digitalization and government effectiveness across the sample countries. The visual evidence suggests a generally positive association, indicating that countries with higher levels of digitalization tend to exhibit higher government effectiveness. However, the relationship does not appear perfectly linear. The slope of the curve varies across different levels of digitalization, implying that the governance benefits of digital transformation may change as countries progress through different stages of digital development. This pattern provides preliminary evidence that the digitalization–government effectiveness nexus may be more complex than the linear relationships commonly assumed in the literature, thereby motivating the examination of nonlinear effects and the moderating role of regulatory quality in this study.

The scientific novelty of this study lies in its integrated examination of the direct, moderating, nonlinear, and regional dimensions of the digitalization–government effectiveness relationship. Unlike previous studies that primarily investigate linear effects or single-country contexts, this study explores whether the impact of digitalization depends on regulatory quality, whether the relationship exhibits nonlinear characteristics, and whether the magnitude of the effect varies across Asian and European countries. By incorporating these dimensions within a unified analytical framework, this study provides a more comprehensive understanding of how digital transformation influences governance performance.

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Table 1. Comparative Analysis of the Present Study and Previous Research

Study	Nonlinear Effect	Regulatory Quality as Moderator	Asia–Europe Comparison	Analytical Scope
Dobrolyubova et al. (2019)	Limited	No	No	Direct relationship between digitalization and government effectiveness
Wandaogo (2022)	No	No	Partial	Cross-country analysis of the direct effect of digitalization
Hou et al. (2026)	No	Partial	No	Institutional conditions influencing digitalization outcomes
This Study	Yes	Yes	Yes	Integrated assessment of direct, nonlinear, moderating, and regional effects within a unified panel-data framework

Source: Authors' synthesis based on the reviewed literature, 2026

Table 1 demonstrates that previous studies have primarily examined the direct relationship between digitalization and government effectiveness. In contrast, the present study provides a more comprehensive framework by integrating nonlinear effects, the moderating role of regulatory quality, and a comparative analysis between Asia and Europe.

Building upon the identified research gaps, this study makes four principal contributions to the digital governance and public administration literature. First, it extends the existing literature by examining not only the direct effect of digitalization on government effectiveness but also its potential nonlinear relationship, thereby challenging the assumption that greater digitalization necessarily generates continuously increasing governance benefits. This perspective provides a more nuanced understanding of digital transformation as a component of public-sector reform, particularly when increasing levels of technological development may generate diminishing governance returns. Second, the study provides new empirical evidence on the moderating role of regulatory quality, thereby highlighting the importance of institutional conditions in shaping digital governance outcomes. By demonstrating that the effectiveness of digitalization depends partly on the quality of the regulatory environment, the study emphasizes that technological investment must be accompanied by adequate governance capacity, regulatory coordination, and institutional support. Third, the study offers a comparative assessment of Asian and European countries, providing insights into regional heterogeneity that has received limited attention in previous studies. This comparison allows the analysis to examine whether differences in institutional maturity, administrative capacity, and regulatory environments contribute to variations in the governance returns of digitalization across regions. Finally, by integrating direct, nonlinear, moderating, and regional dimensions within a unified panel-data framework, this study offers a more comprehensive understanding of the institutional mechanisms through which digitalization may enhance government effectiveness. In doing so, it contributes to public administration scholarship by positioning digitalization not merely as a technological process, but as a broader public-sector

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transformation whose effectiveness depends on institutional capacity, regulatory quality, and the administrative context in which digital technologies are implemented.

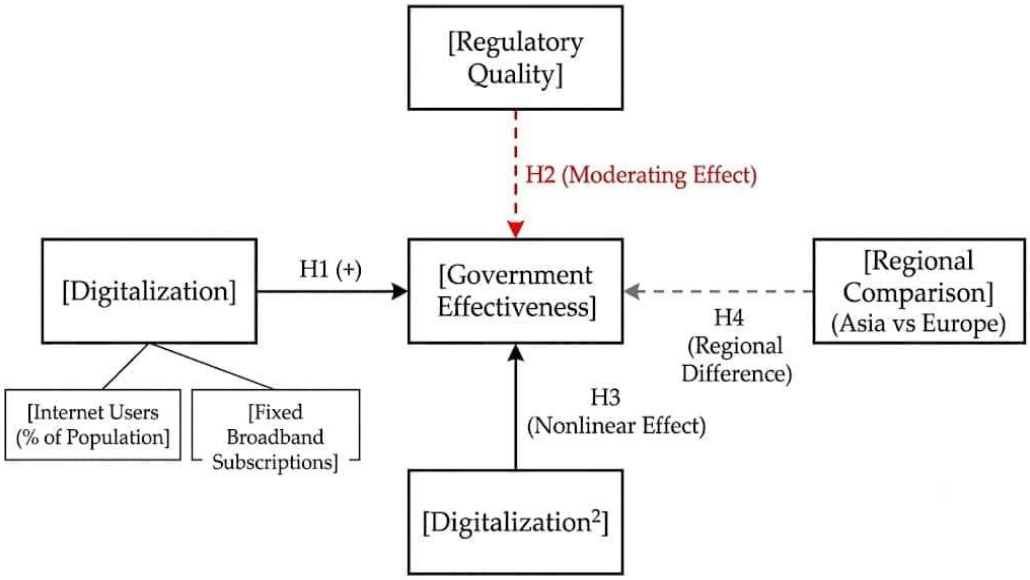

Figure 2. Proposed theoretical model and hypothesized relationships (H1–H4).
Source: Author's own elaboration, 2026

Accordingly, the following hypotheses are proposed:

H1: Digitalization has a positive effect on government effectiveness.

H2: Regulatory quality positively moderates the relationship between digitalization and government effectiveness.

H3: The relationship between digitalization and government effectiveness is nonlinear.

H4: The impact of digitalization on government effectiveness differs between Asia and Europe.

Therefore, the purpose of this study is to examine the effect of digitalization on government effectiveness, investigate the moderating role of regulatory quality, evaluate the existence of nonlinear effects, and compare the digitalization–government effectiveness relationship between Asian and European countries using panel data covering the period 2007–2023.

2. Methods

2.1 Sample, Variables, and Measurements

This study employs a panel dataset covering 14 countries from Asia and Europe over the period 2007–2023. The use of panel data enables the analysis to simultaneously exploit both the cross-sectional and time-series dimensions of the data, thereby improving estimation efficiency and controlling for unobserved country-specific heterogeneity (Baltagi, 2021).

The sample includes eight Asian countries China, India, Indonesia, Japan, South Korea, Malaysia, Thailand, and the Philippines and six European countries Germany, France, Italy, Spain, Poland, and the Netherlands. These countries represent varying levels of digital development, economic performance, and institutional quality, providing a suitable context for

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comparative analysis across regions.

The dependent variable is government effectiveness (GE), obtained from the Worldwide Governance Indicators (WGI) database of the World Bank. This indicator captures the quality of public services, the competence of the civil service, and the credibility of government policies. The main independent variable is digitalization (DIG), which reflects the level of digital infrastructure and technological adoption. To account for its multidimensional nature, a composite digitalization index is constructed using Principal Component Analysis (PCA) based on two indicators: internet users (% of population) and fixed broadband subscriptions (per 100 people). The PCA results indicate that the first principal component explains approximately 91.1% of the total variance, suggesting that the index provides a reliable summary of digital development.

The use of Principal Component Analysis (PCA) is widely recommended for constructing composite indices from correlated indicators because it reduces dimensionality while retaining most of the information contained in the original variables (Baltagi, 2021). Regulatory quality (RQ) is included as a moderating variable, capturing the government's ability to design and implement sound policies and regulations. This variable is also sourced from the WGI database.

Regulatory quality represents a key institutional dimension of digital governance because effective regulatory frameworks facilitate the implementation of digital public administration and improve governance outcomes (Lnenicka, Luterek, et al., 2024; Pribadi et al., 2024). In addition, several control variables are incorporated to account for macroeconomic conditions that may influence government effectiveness. These include GDP growth (GDPgr), trade openness (Trade), and education (Education), measured by secondary school enrollment rates. All control variables are obtained from the World Development Indicators (WDI) database.

To capture nonlinear and conditional effects, the model includes the squared term of digitalization (DIG^2) and an interaction term between digitalization and regulatory quality (DIG × RQ). These transformations allow the analysis to examine both diminishing returns and the moderating role of institutional quality.

Prior to constructing the squared and interaction terms, the digitalization and regulatory quality variables were mean-centered. Specifically, the sample mean was subtracted from each variable to generate centered digitalization (cDigital) and centered regulatory quality (cRegQual). The squared term ($cDigital^2$) and the interaction term (cDigital × cRegQual) were then created using the centered variables. Mean-centering was applied to reduce potential multicollinearity between the main effects, the quadratic term, and the interaction term, while preserving the substantive interpretation of the estimated coefficients.

Table 2. Presents A Summary of All Variables, Including Their Definitions, Measurements, and Data Sources

No	Variable	Definition	Measurement	Source
1.	Government Effectiveness	Quality of public services and policy implementation	Governance index (-2.5 to +2.5)	Worldwide Governance Indicators
2.	Digitalization Index	Level of digital infrastructure and internet connectivity	PCA index based on internet users and broadband	World Development Indicators

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No	Variable	Definition	Measurement	Source
			subscriptions	
3.	Regulatory Quality	The government's ability to design and implement sound regulations	Governance index score	Worldwide Governance Indicators
4.	GDP Growth	Economic growth performance	Annual GDP growth rate (%)	World Development Indicators
5.	Trade Openness	Degree of integration into international markets	Trade (% of GDP)	World Development Indicators
6.	Education	Human capital development	Secondary school enrolment rate (%)	World Development Indicators

Source: Authors' compilation based on World Development Indicators (WDI) and Worldwide Governance Indicators (WGI), World Bank. The Digitalization Index was constructed using Principal Component Analysis (PCA).

2.2 Data Analysis Method

To examine the relationship between digitalization and government effectiveness, this study employs panel data regression techniques. The empirical analysis begins with a pooled Ordinary Least Squares (OLS) estimation as a preliminary benchmark. However, OLS does not account for unobserved heterogeneity across countries, which may lead to biased estimates. To address this issue, the study applies both Fixed Effects (FE) and Random Effects (RE) models. The Fixed Effects estimator controls for unobserved time-invariant country-specific characteristics, such as institutional structures and historical factors, that may influence governance outcomes. The Fixed Effects estimator is widely regarded as the preferred approach when unobserved country-specific effects are correlated with the explanatory variables (Baltagi, 2021). The selection between the FE and RE specifications was determined using the Hausman test, which evaluates whether the country-specific effects are correlated with the explanatory variables. The Hausman test results favored the Fixed Effects model, indicating that FE provides more consistent and reliable estimates for the analysis. The Hausman specification test is the standard econometric procedure for selecting between Fixed Effects and Random Effects estimators (Baltagi, 2021). The empirical model is specified as follows:

$$Govef f_{it} = \beta_0 + \beta_1 cDigital_{it} + \beta_2 cDigital_{it}^2 + \beta_3 cRegQual_{it} + \beta_4 (cDigital_{it} \times cRegQual_{it}) + \beta_5 GDPgr_{it} + \beta_6 Trade_{it} + \beta_7 Education_{it} + \mu_i + \varepsilon_{it} \dots\dots (1)$$

Where i denotes the country and t represents time. GE_it is government effectiveness, DIG_it is the digitalization index, and DIG_it^2 captures the nonlinear effect of digitalization. RQ_it represents regulatory quality, while (DIG_it × RQ_it) captures the moderating effect of institutional quality. GDPgr_it, Trade_it, and Education_it are the control variables representing economic growth, trade openness, and human capital, respectively. μ_i denotes country-specific fixed effects, and ε_it is the error term.

The inclusion of the squared term allows testing for nonlinear effects, while the

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interaction term enables the examination of conditional relationships between digitalization and institutional quality. To determine the appropriate estimation method, a Hausman test is conducted. The results reject the null hypothesis, indicating that the Fixed Effects model is preferred over the Random Effects specification.

To ensure the robustness of the results, diagnostic tests are performed. Multicollinearity is assessed using the Variance Inflation Factor (VIF), with results indicating no serious multicollinearity issues (mean VIF = 3.99). In addition, the model is estimated using clustered standard errors at the country level to account for heteroskedasticity and serial correlation. Cluster-robust standard errors provide more reliable statistical inference in the presence of heteroskedasticity and within-panel serial correlation (Baltagi, 2021). The main findings remain consistent across specifications, supporting the reliability of the empirical results.

3. Results and Discussion

3.1: Results

Table 3 reports the descriptive statistics for the variables used in the empirical analysis. Government effectiveness (goveff), the dependent variable, records a mean value of 0.784 with a standard deviation of 0.617, indicating moderate cross-country variation in governance performance, with values ranging from −0.33 to 1.839. The digitalization index, constructed using principal component analysis and standardized around zero, has a mean of 0 and a standard deviation of 1.35, with a range between −2.635 and 2.01, suggesting substantial differences in the level of digital development across the countries and years included in the sample. Regulatory quality (regqual) shows an average value of 0.679 and a standard deviation of 0.681, reflecting notable heterogeneity in institutional quality among the sampled economies. Regarding the control variables, GDP growth (gdpgr) averages 2.455 percent with a relatively high standard deviation of 3.539, indicating considerable fluctuations in economic performance, with values ranging from −11.393 to 13.555 percent. Trade openness (trade) has a mean of 77.78 percent of GDP and a standard deviation of 37.74, with values spanning from 24.39 to 192.47 percent, highlighting substantial variation in international economic integration. Finally, the education variable records a mean of 97.14 and a standard deviation of 16.23, with values ranging from 59.15 to 138.77, indicating differences in educational attainment across the sample. Overall, the descriptive statistics reveal sufficient variability across both institutional and macroeconomic variables, supporting their suitability for panel econometric analysis.

Table 4. Correlation Matrix and Multicollinearity Diagnostics

Variables	(1)	(2)	(3)	(4)	(5)	(6)	VIF
(1) goveff	1.000						
(2) digital index	0.763***	1.000					4.862
(3) regqual	0.858***	0.809***	1.000				5.901
(4) gdpgr	-0.307***	-0.317***	-0.418***	1.000			1.196
(5) trade	0.288***	0.172***	0.304***	-0.039	1.000		1.107
(6) education	0.535***	0.694***	0.730***	-0.306***	0.112	1.000	2.314
digital index^2							6.531

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Variables	(1)	(2)	(3)	(4)	(5)	(6)	VIF
(digital × regqual)							5.992
Mean VIF = 3.986							
*** $p < 0.05$							

Source: Author's Calculation, 2026

Table 4 presents the pairwise correlation matrix along with variance inflation factor (VIF) statistics to assess potential multicollinearity among the explanatory variables. The results show a strong and positive correlation between the digitalization index and government effectiveness ($r = 0.763$, $p < 0.01$), suggesting that higher levels of digital development are generally associated with better governance performance. Similarly, regulatory quality exhibits a very strong positive correlation with government effectiveness ($r = 0.858$, $p < 0.01$), indicating that countries with stronger regulatory frameworks tend to achieve higher levels of government effectiveness. The digitalization index is also highly correlated with regulatory quality ($r = 0.809$, $p < 0.01$), which may reflect the complementary relationship between technological development and institutional capacity. In contrast, GDP growth shows a negative correlation with government effectiveness ($r = -0.307$, $p < 0.01$) and with digitalization ($r = -0.317$, $p < 0.01$), suggesting that short-term economic fluctuations do not necessarily align with improvements in institutional performance. Trade openness and education display positive correlations with government effectiveness, although the relationship with trade is relatively moderate. Despite the presence of several relatively high correlations, the multicollinearity diagnostics indicate that it is not a serious concern. The VIF values for all variables remain below the commonly accepted threshold of 10, with the highest value observed for the squared digitalization term (6.531), followed by the interaction term between digitalization and regulatory quality (5.992) and regulatory quality itself (5.901). The mean VIF of 3.986 further confirms that multicollinearity is within acceptable limits, indicating that the explanatory variables can be jointly included in the regression models without causing significant estimation bias.

Table 5. Principal Component Analysis for the Digitalization Index

Panel A. Eigenvalues and Explained Variance

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	1.823	1.646	0.911	0.911
Comp2	0.177	—	0.088	1.000

Panel B. Factor Loadings (Eigenvectors)

Variable	Comp1	Comp2	Unexplained
Internet Users	0.707	0.707	0
Broadband Subscriptions	0.707	-0.707	0

Source: Author's Calculation, 2026

Notes: *The first principal component explains 91.1% of the total variance, indicating that the constructed digitalization index captures the majority of the variation in the underlying digital infrastructure indicators.*

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Table 5 reports the results of the principal component analysis (PCA) used to construct the digitalization index based on two standardized indicators: internet users and broadband subscriptions. Panel A shows that the first principal component has an eigenvalue of 1.823 and explains 91.1% of the total variance. In comparison, the second component has a much smaller eigenvalue of 0.177 and accounts for only 8.8% of the variance. This substantial difference indicates that the first component captures the overwhelming majority of the information contained in the original variables, making it an appropriate summary measure of digital development. Panel B presents the factor loadings, where both internet users and broadband subscriptions load equally and positively on the first component (0.707), suggesting that they contribute symmetrically to the underlying digitalization dimension. The high and balanced loadings further indicate that both indicators represent closely related aspects of digital infrastructure. Given that the first principal component explains more than 90% of the total variance, it is retained as the composite digitalization index used in the subsequent econometric analysis, ensuring that the constructed index effectively summarizes the variation in the underlying digital infrastructure indicators across the sample.

Table 6. Baseline FE Model of Full Sample

goveff	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
cdigital	.024	.018	1.32	.188	-.012	.061	
cdigital2	-.061	.018	-3.30	.001	-.097	-.024	***
cregqual	-.246	.075	-3.27	.001	-.395	-.098	***
(cdigital × cregqual)	.297	.054	5.50	0.00	.19	.403	***
gdpgr	.0004023	.003	0.13	.898	-.006	.007	
trade	.0004845	.001	0.48	.632	-.002	.002	
education	-.002	.002	-1.51	.133	-.005	.001	
Constant	.882	.163	5.43	0.00	.562	1.203	***
Mean dependent var	0.804	SD dependent var				0.602	
R-squared	0.304	Number of obs				213	
F-test	11.980	Prob > F				0.000	
Akaike crit. (AIC)	-275.144	Bayesian crit. (BIC)				-248.254	

**** p<.01, ** p<.05, * p<.1*

Source: Author's Calculation, 2026

Table 6 presents the results of the baseline fixed effects (FE) model examining the relationship between digitalization and government effectiveness while controlling for regulatory quality and key macroeconomic variables. The coefficient of the digitalization index (cdigital) is positive but statistically insignificant, suggesting that the direct linear effect of digitalization on government effectiveness is not strong when considered alone. However, the squared term of digitalization ($cdigital^2$) is negative and highly significant ($p < 0.01$), indicating the presence of a nonlinear relationship between digitalization and governance outcomes. This result suggests that the impact of digitalization may initially improve governance performance but eventually exhibits diminishing returns at higher levels of digital development. Regulatory

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quality (cregqual) appears with a negative and statistically significant coefficient; however, this effect should be interpreted jointly with the interaction term between digitalization and regulatory quality, which is positive and highly significant ($p < 0.01$). The positive interaction coefficient indicates that the effectiveness of digitalization in improving government performance increases in countries with stronger regulatory frameworks, highlighting the complementary role of institutional quality in translating digital investments into better governance outcomes. In contrast, the control variables GDP growth, trade openness, and education do not show statistically significant effects in the baseline specification. Overall, the model explains approximately 30.4% of the within-country variation in government effectiveness ($R^2 = 0.304$), and the F-test confirms that the model is jointly significant ($p < 0.001$), suggesting that the included variables collectively contribute to explaining variations in governance performance across the sample.

Table 7. Robustness Model (cluster SE) of Full Sample

goveff	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
cdigital	.024	.034	0.71	.491	-.05	.098	
cdigital2	-.061	.03	-2.03	.064	-.125	.004	*
cregqual	-.246	.134	-1.84	.089	-.536	.043	*
(cdigital × cregqual)	.297	.085	3.51	.004	.114	.479	***
gdpgr	.0004023	.003	0.15	.879	-.005	.006	
trade	.0004845	.001	0.35	.734	-.003	.003	
education	-.002	.003	-0.74	.471	-.009	.004	
Constant	.882	.316	2.79	.015	.2	1.565	**
Mean dependent var		0.804	SD dependent var			0.602	
R-squared		0.304	Number of obs			213	
F-test		3.079	Prob > F			0.042	
Akaike crit. (AIC)		-277.144	Bayesian crit. (BIC)			-253.615	

**** p<.01, ** p<.05, * p<.1*

Source: *Author's Calculation, 2026*

Table 7 reports the robustness results using clustered standard errors to account for potential heteroskedasticity and within-panel correlation. The findings remain broadly consistent with the baseline fixed effects model, supporting the robustness of the main conclusions. The coefficient of the digitalization index (cdigital) remains positive but statistically insignificant, indicating that the linear effect of digitalization alone does not significantly influence government effectiveness. However, the squared term of digitalization ($cdigital^2$) retains a negative coefficient and remains weakly significant at the 10% level ($p < 0.1$), providing additional evidence of a nonlinear relationship between digitalization and governance outcomes. Regulatory quality also shows a weakly significant negative coefficient, but this effect should again be interpreted in conjunction with the interaction term. Importantly, the interaction between digitalization and regulatory quality remains positive and highly significant ($p < 0.01$), confirming that the positive impact of digitalization on government

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effectiveness becomes stronger in countries with higher regulatory quality. This result reinforces the argument that digital transformation alone is insufficient and that supportive institutional frameworks are necessary to realize its governance benefits fully. The control variables GDP growth, trade openness, and education remain statistically insignificant, suggesting that short-term macroeconomic conditions and trade integration do not directly drive variations in government effectiveness within the sample. Overall, the model remains jointly significant (Prob > F = 0.042) and continues to explain about 30.4% of the variation in government effectiveness, indicating that the main empirical findings are stable under alternative error specifications.

Table 8. Regional comparison (Asia vs Europe)

Variable	fe_asia	fe_europe
cdigital	0.131	-0.007
cdigital2	0.012	-0.035
cregqual	-0.275	-0.188
(cdigital × cregqual)	0.198	.38891004**
gdpgr	0.001	0.001
trade	0.000	-0.001
education	-0.001	0.003
_cons	0.306	0.810

*Legend: * p<0.05; ** p<0.01; *** p<0.001*

Source: *Author's Calculation, 2026*

Table 8 presents the regional comparison between Asian and European countries using fixed-effects estimations. The results reveal notable differences in the relationship between digitalization, regulatory quality, and government effectiveness across the two regions. In the Asian sample, the coefficient of the digitalization index is positive (0.131), suggesting that higher levels of digital development are associated with improvements in government effectiveness. However, the effect is not statistically significant. The squared term of digitalization is also positive but small (0.012), indicating no clear evidence of a nonlinear relationship in the Asian context. Regulatory quality appears with a negative coefficient (−0.275). Still, the interaction term between digitalization and regulatory quality is positive (0.198), implying that stronger regulatory institutions may enhance the potential governance benefits of digitalization in Asian countries, even though the effect is not statistically significant. In contrast, the European results show a slightly negative coefficient for the digitalization index (−0.007) and a negative coefficient for its squared term (−0.035), suggesting a potential diminishing effect of digitalization at higher levels of technological development. Most importantly, the interaction between digitalization and regulatory quality is positive and statistically significant (0.389, $p < 0.01$) in Europe, indicating that digital transformation contributes more strongly to government effectiveness when supported by high-quality regulatory institutions. The control variables GDP growth, trade openness, and education do not exhibit statistically significant effects in either region. Overall, these findings suggest that while digitalization alone does not guarantee improvements in governance, its effectiveness is

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strongly conditioned by institutional quality, with the complementary role of regulatory frameworks appearing particularly pronounced in European countries.

3.2 Discussion

The findings of this study provide important insights into the complex relationship between digitalization and government effectiveness across Asian and European countries. The results reveal that the impact of digital transformation is not uniformly positive but follows a nonlinear pattern. While initial improvements in digital infrastructure and internet connectivity contribute significantly to better governance outcomes, the marginal benefits of digitalization decline as digital development reaches higher levels. This finding challenges the widespread assumption that expanding digital technologies automatically leads to continuous improvements in government performance. Instead, the results suggest that digitalization functions as an enabling mechanism whose effectiveness depends on institutional readiness, administrative capacity, and regulatory support.

A possible explanation for this nonlinear relationship is that digital transformation generates increasing governance benefits only up to a certain threshold. Beyond this point, governments may face challenges associated with system complexity, interagency coordination, cybersecurity risks, data governance requirements, and rising implementation costs (Homburg et al., 2025). Consequently, additional investments in digital technologies may produce diminishing returns if institutional capabilities fail to evolve at the same pace. This interpretation is consistent with (Zhao & Ren, 2026), who identify an inverted U-shaped relationship between digitalization and green innovation, demonstrating that moderate levels of digital transformation enhance organizational performance while excessive digitalization may reduce efficiency. Similar evidence is provided by (Huang, 2025), who reports nonlinear effects of digital transformation on operational efficiency in the insurance sector, while (Fuseini, 2026) finds threshold effects in the interaction between ICT infrastructure and governance quality across African countries. Together, these studies support the argument that the benefits of digitalization are conditional and vary according to the level of technological and institutional development.

However, the present findings also differ from several previous studies that report a predominantly positive and linear relationship between digitalization and government effectiveness. For instance, (Wandaogo, 2022) concludes that digitalization consistently enhances government effectiveness across both developed and developing countries, while (Dobrolyubova et al., 2019) report generally positive associations between digital government initiatives and public sector performance. The divergence between these findings and the results of the present study may be attributed to differences in model specification, sample composition, and analytical design. Unlike previous studies that primarily estimate linear relationships, this study explicitly incorporates both a quadratic term and an interaction term, allowing the identification of nonlinear dynamics and the conditional role of regulatory quality. These findings suggest that the governance benefits of digitalization are not universal but depend on the interaction between technological advancement and the institutional environment in which digital transformation is implemented.

The most important finding of this study concerns the moderating role of regulatory

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quality. The empirical results indicate that digitalization contributes more effectively to government effectiveness when accompanied by strong regulatory institutions. This finding is consistent with recent perspectives on public governance, which emphasize that adopting emerging technologies requires appropriate regulatory, accountability, and institutional arrangements to generate sustainable public value (Goossens et al., 2025). This finding supports the institutional complementarity perspective, which argues that technology and institutions are mutually reinforcing rather than independent drivers of governance performance. From a broader theoretical perspective, these findings also reinforce the core propositions of Institutional Theory, Technology Adoption Theory, and Public Value Theory. Institutional Theory suggests that organizational outcomes are shaped not only by technological resources but also by the quality of institutional arrangements that govern their implementation. Likewise, Technology Adoption Theory emphasizes that the benefits of digital technologies depend on complementary organizational capabilities and supportive institutional environments rather than technology alone. Furthermore, Public Value Theory argues that digital transformation creates sustainable public value only when technological innovation is accompanied by transparent governance, effective accountability mechanisms, and citizen-oriented public service delivery (Afandi et al., 2025) . The present findings therefore provide empirical support for these theoretical perspectives by demonstrating that regulatory quality constitutes a critical institutional condition through which digitalization translates into improved government effectiveness. Digital technologies can improve transparency, administrative efficiency, and public service delivery, but these benefits depend on the existence of effective regulations, accountability mechanisms, and administrative capabilities. In the absence of such conditions, digital initiatives may fail to generate meaningful governance improvements or may even create new governance challenges. This interpretation is further supported by (Darusalam et al., 2023) who find that government digitalization improves transparency, accountability, and service quality in Indonesia, yet does not automatically reduce corruption, collusion, and nepotism. Their findings suggest that digital transformation must be accompanied by effective monitoring mechanisms, institutional safeguards, and regulatory controls to generate broader governance improvements. This is consistent with (Seiam & Salman, 2024), who show that digital governance contributes more effectively to governance quality in countries with stronger institutions. Likewise, (Osinubi & Simatele, 2026) demonstrate that weak governance systems significantly constrain the developmental benefits of digitalization in African countries. Similar conclusions are reached by (Kai et al., 2026), who find that digitalization produces stronger economic outcomes in ASEAN countries when supported by high institutional quality, and by (Mastac et al., 2026), who argue that digitalization acts as an institutional amplifier, strengthening existing governance structures rather than replacing them.

The regional comparison further highlights the importance of institutional context. European countries generally appear to derive greater governance benefits from digitalization than their Asian counterparts. This difference is unlikely to be explained solely by technological infrastructure, as many Asian countries have achieved substantial progress in internet penetration and broadband expansion. Instead, the results suggest that institutional maturity and regulatory effectiveness play a decisive role in determining the success of digital

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transformation. More specifically, the moderating role of regulatory quality appears to be stronger in European countries, where more mature regulatory frameworks, higher administrative capacity, and stronger institutional coordination enable governments to translate digital investments into more effective governance outcomes. In contrast, although many Asian countries have made substantial progress in expanding digital infrastructure, considerable variation in institutional capacity, regulatory consistency, and implementation effectiveness may limit the extent to which digitalization improves government effectiveness. These findings suggest that the governance returns to digital transformation depend not only on the availability of digital technologies but also on the institutional context within which they are implemented, highlighting the importance of region-specific governance and regulatory conditions.

This finding also supports the conclusions of (Syamsuddin et al., 2025) , whose systematic review demonstrates that the governance benefits of digital transformation vary considerably across countries depending on institutional and administrative conditions. Similarly, (Hariguna et al., 2022) argue that digital technologies create public value only when governments possess the organizational capabilities required to effectively utilize digital systems. European countries have generally invested in digitalization alongside broader governance reforms, administrative modernization, and regulatory strengthening. Estonia represents a particularly relevant example. Often recognized as a global leader in digital government, Estonia has successfully integrated digital identity systems, e-governance platforms, and open-data initiatives within a robust institutional framework developed over several decades (Rajamäe-Soosaar & Nikiforova, 2024). This combination of technological innovation and institutional development has enabled Estonia to achieve high levels of government efficiency, transparency, and public trust. The broader European experience also supports evidence from open government initiatives. (Lnenicka, Nikiforova, et al., 2024) show that open government data programs improve transparency and service quality across European countries, while (Molodtsov & Nikiforova, 2024) demonstrate that well-developed digital platforms enhance citizen participation and government accountability.

The findings are also consistent with(Sharaf Addin, 2025), who reports significantly higher levels of government effectiveness across Europe compared to many developing regions. (Wandaogo, 2022) similarly finds that digitalization significantly improves government effectiveness in both developed and developing countries. However, the study reports that the magnitude of this effect is considerably stronger in developed economies, suggesting that institutional maturity and complementary socio-economic conditions influence the effectiveness of digital transformation. Furthermore, (Chen, 2025) finds that Europe outperforms Southeast Asia in digital public service outcomes due to higher levels of digital readiness, digital literacy, and institutional capacity. These findings suggest that the effectiveness of digitalization depends not only on access to technology but also on the ability of governments to manage and regulate digital transformation effectively.

In contrast, the weaker relationship observed in several Asian countries appears to reflect institutional and governance constraints rather than technological deficiencies. Nevertheless, these gains remain dependent on administrative coordination and institutional effectiveness, particularly in ensuring the quality and effectiveness of digitally delivered public services

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(Astuti & Khusna, 2025; Priyowidodo et al., 2024). Countries such as Indonesia have achieved substantial progress in digital public services and e-government initiatives. For example, (Priyowidodo et al., 2024) document how digital transformation in Surabaya City improved public participation and governance processes through smart government initiatives. Nevertheless, these gains remain dependent on administrative coordination and institutional effectiveness. Similarly, (Taufiqurokhman et al., 2025) find that digital governance models can improve public service effectiveness in developing countries, although outcomes vary considerably according to governance capacity and implementation quality. However, existing studies indicate that the effectiveness of these reforms remains constrained by implementation challenges, regulatory inconsistencies, and varying levels of administrative capacity (Andrian Putro & Maricar Besa, 2025; Fitriyanti, 2024b; Ismail et al., 2025) . Related evidence from (Khairati & Putra, 2024; Kurniawan et al., 2023; Reynilda et al., 2025) suggests that digital platforms improve administrative efficiency, fiscal management, and citizen satisfaction; however, these benefits are often conditional upon effective institutional coordination and regulatory oversight. Similar patterns can be observed in other developing contexts. For example, (Zemene et al., 2026) show that despite significant investments in digital transformation, many public institutions in Ethiopia remain at an intermediate stage of digital maturity, highlighting the importance of organizational capabilities, continuous monitoring, and institutional learning. These examples suggest that investments in digital infrastructure alone are insufficient to guarantee improvements in governance performance.

Overall, the findings contribute to the growing literature on digital governance by demonstrating that the relationship between digitalization and government effectiveness is conditional, nonlinear, and institutionally dependent. While previous studies have primarily focused on the direct effects of digital transformation, this study provides evidence that regulatory quality fundamentally shapes both the magnitude and sustainability of digitalization outcomes. The findings therefore extend existing research by showing that digital technologies generate the greatest governance benefits when supported by strong institutions capable of managing technological change. Recent evidence from (Ding et al., 2025) further indicates that government digitalization contributes to broader national outcomes by improving the business environment, strengthening legal institutions, and reducing corruption. Their findings suggest that digital transformation can act as a catalyst for institutional and economic development when embedded within an effective governance framework. This result is further supported by(Alfiani et al., 2024), who identify institutional readiness, regulatory support, and organizational capacity as fundamental prerequisites for successful e-government implementation in developing countries. Likewise, (Kumoro, 2026) demonstrates that organizational learning significantly strengthens the effectiveness of digital government initiatives, suggesting that technological investments alone cannot guarantee governance improvements.

From a theoretical perspective, the findings make several important contributions to the digital governance and public administration literature. First, the study extends the existing literature by demonstrating that the relationship between digitalization and government effectiveness is not purely linear but exhibits nonlinear characteristics, thereby challenging technology-deterministic assumptions that greater digitalization invariably leads to better

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governance outcomes. Second, the findings provide empirical evidence that regulatory quality functions as a critical institutional condition through which digital transformation enhances government effectiveness, reinforcing the view that technology and institutional capacity are complementary rather than independent drivers of governance performance. Finally, by integrating direct, nonlinear, moderating, and regional dimensions within a unified empirical framework, this study advances a more comprehensive understanding of the institutional mechanisms that shape digital governance across different national contexts.

From a policy perspective, the findings suggest that governments should move beyond infrastructure-centered digital strategies and adopt integrated digital governance policies that combine technological investment with regulatory reform, institutional capacity building, administrative modernization, and effective governance mechanisms. Policymakers should prioritize strengthening regulatory quality, enhancing administrative capabilities, promoting organizational learning, and establishing robust monitoring and accountability systems to ensure that digital transformation delivers sustainable governance improvements. Importantly, the findings challenge the technology-deterministic view that digital infrastructure alone is sufficient to improve government effectiveness. Instead, they support an institutional-development perspective in which digitalization serves as a complementary enabler whose effectiveness depends on the quality of the institutional environment. This interpretation is consistent with evidence from ASEAN (Kai et al., 2026), Africa (Fuseini, 2026; Osinubi & Simatele, 2026), and Europe (Mastac et al., 2026), all of which demonstrate that institutional quality ultimately determines whether digital transformation translates into sustained improvements in government effectiveness and public sector performance.

4. Conclusion

These findings make both theoretical and practical contributions to the literature on public administration and digital governance. Theoretically, the study extends the conventional view of digitalization as a direct driver of government effectiveness by demonstrating that its governance effects are nonlinear and institutionally conditional. In particular, the positive and significant interaction between digitalization and regulatory quality indicates that the effectiveness of digital transformation depends not only on the availability of digital technologies but also on the institutional environment in which these technologies are implemented. The regional comparison further suggests that the digitalization–government effectiveness relationship is heterogeneous across institutional contexts. Taken together, these findings support a more conditional framework of digital governance in which technological development, institutional quality, and governance capacity operate jointly rather than independently.

The findings also provide several stakeholder-specific policy implications. For national governments, investment in digital infrastructure should be accompanied by institutional reforms, regulatory capacity building, and long-term strategies for integrating digital technologies into public-service delivery. For public administrators and civil servants, digital transformation should be supported through continuous digital skills development, organizational adaptation, and the effective integration of digital systems into administrative processes rather than through technology adoption alone. For regulatory agencies,

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strengthening regulatory quality should be treated as a central component of digital transformation, particularly through transparent, predictable, and adaptive regulatory frameworks that can support technological innovation while maintaining institutional accountability. For digital governance policymakers, digitalization strategies should be designed according to institutional capacity and the level of digital maturity, with greater emphasis on governance readiness, regulatory coordination, and monitoring of digital transformation outcomes. For researchers and academic institutions, future studies should expand country coverage, employ broader and multidimensional measures of digitalization and institutional quality, and apply advanced econometric approaches to investigate further potential endogeneity, nonlinear dynamics, and the long-term effects of digital transformation on governance outcomes.

Overall, the evidence suggests that digitalization should not be treated as an automatic pathway to better government effectiveness. Its governance benefits are more likely to materialize when appropriate institutional and regulatory conditions accompany technological investments. This perspective provides a more nuanced understanding of digital governance and offers a basis for policymakers to move beyond technology-centered strategies toward institutionally grounded digital governance.

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