Global study on the Measurement and Spatial Variation Characteristics of the Level of Development of Digital Trade

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Abstract. Digital trade has emerged as a key driver of global economic growth and the transformation of international trade structures. Drawing on data from 67 countries (2014–2022), this study develops a multidimensional evaluation system covering digital innovation, skills, trade scale, infrastructure, trust and risk, barriers, and trade environment. Using the entropy weight-TOPSIS method to measure national digital trade development levels, and integrating the Dagum Gini coefficient decomposition, spatial convergence models, and Markov chain analysis, we systematically examine its spatiotemporal dynamics. Findings reveal:(1)an overall upward trend with distinct spatial heterogeneity—Asia leads while Africa lags; (2) convergence in overall disparity, marked by declining inter-regional contributions and rising hypervariable density, reflecting intensified cross-regional interplay; (3) significant σ- and absolute β-convergence across most regions except North America and Africa, alongside pervasive conditional β-convergence; and (4) strong path dependence and stability in development states, where transitions occur only between adjacent tiers and are significantly influenced by neighboring regions' development levels.

Keywords: Digital Trade; Spatiotemporal volution; Markov Chain

1 Introduction

The global expansion of the digital economy, driven by next-generation information technologies, has positioned digital trade as a central feature of international commerce. While commonly defined as the electronic transmission of digital goods and services[1], its scope has broadened to include digitally enabled ordering, production, delivery, and cross-border data flows[2-3], offering distinct advantages in transaction costs, market reach, and matching efficiency over conventional trade.

Existing research has predominantly focused on conceptualization[1,4], measurement[5-6], and economic impacts[7-8] of digital trade. Yet, comprehensive global analyses of its spatial disparities, convergence dynamics, and evolutionary pathways remain scarce. This study therefore establishes a unified, multidimensional framework to assess digital trade development and provide deeper theoretical and policy insights.

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Specifically, this research aims to:(1)quantify global and regional digital trade development levels and trends from 2014 to 2022;(2)decompose the sources and mechanisms of spatial disparities in digital trade;(3)examine patterns of spatial convergence; and(4)trace evolutionary pathways and spatial dependencies in digital trade development.

Digital trade development relies on the synergy of internal and external conditions. Internally, it rests on two pillars: digital infrastructure as the material foundation, and digital innovation and skills as the core drivers. Externally, institutional and environmental factors—digital trade barriers, digital trust risks, and the digital trade environment—shape its progression. The scale of digital trade serves as both an outcome and a composite indicator of development. Following a "foundation–drivers–environment–outcome" logic, and informed by frameworks such as that of Feng et al.[9], this study constructs a seven-dimensional indicator system to capture the multifaceted nature of digital trade development(Table 1).Methodologically, the entropy-weighted TOPSIS method is applied to compute a composite digital trade development index, reducing information loss[10] and enabling objective weighting[11]. The Dagum Gini coefficient decomposition is used to distinguish between intra-regional, inter-regional, and transvariation contributions to overall inequality, addressing sample overlap[12]. σ- and β-convergence tests are conducted to examine spatial convergence, with control variables such as economic development and institutional quality incorporated into conditional β-convergence models(Table 2). Finally, traditional and spatial Markov chain models categorize countries into four development tiers to analyze state transition dynamics and spatial adjacency effects.Data are drawn from authoritative international sources—including the World Bank, ITU, and UNCTAD—to ensure reliability and comparability. Missing values are addressed via nonlinear interpolation, and countries with extensive data gaps are excluded, yielding a balanced panel of 67 countries for robust analysis.

Table 1. Evaluation Indicator System for Digital Trade Development Level

Primary Indicator	Secondary Indicator	Specific Indicator	Weight	Polarity	Data Source
Digital Innovation	Digital Input	R&D expenditure (% of GDP)	0.0386	+	World Bank
	Innovation Output	Patent applications, residents	0.0128	+	
		Patent applications, non-residents	0.0207	+	
		Number of scientific and technical journal articles	0.0280	+	
Digital Skills	Talent Input	R&D researchers	0.0370	+	
		Average years of schooling	0.0414	+	UNDP
		Gross tertiary enrollment ratio	0.0407	+	World Bank
Digital Trade Scale	Digital Trade Scale	ICT goods exports (% of total goods exports)	0.0330	+	
		ICT service exports (% of total service exports)	0.0385	+	
		Share of digitally deliverable services in service exports	0.0401	+	UNCTAD
Digital Infrastructure	Tangible Infrastructure	Logistics Performance Index	0.0413	+	World Bank
		Electric power consumption	0.0364	+	
	Network Facilities	Internet penetration rate	0.0414	+	ITU

Primary Indicator	Secondary Indicator	Specific Indicator	Weight	Polarity	Data Source
		International Internet bandwidth	0.0290	+	ITU
	Communication Facilities	Fixed telephone subscriptions (per 100 people)	0.0396	+	World Bank
		Mobile cellular subscriptions (per 100 people)	0.0416	+	
	Terminal Equipment	Fixed broadband subscriptions (per 100 people)	0.0395	+	
		Active mobile-broadband subscriptions (per 100 people)	0.0410	+	ITU
Digital Trust & Risk	Security Facilities	Secure Internet servers (per 1 million people)	0.0290	+	World Bank
	Cybersecurity	Global Cybersecurity Index	0.0410	+	ITU
	Technical Regulation	Strength of auditing and reporting (index)	0.0415	+	World Bank
	Information Regulation	Depth of credit information index	0.0416	+	
Digital Trade Barriers	Digital Government	Online Service Index	0.0417	+	UN DESA
Digital Trade Environment	Transport Capacity	Liner Shipping Connectivity Index	0.0416	+	World Bank
		Container Port Performance Index	0.0417	+	
	Customs Clearance	Liner Shipping Connectivity Index	0.0397	+	UNCTAD
		Customs clearance efficiency (index)	0.0415	+	World Bank

Table 2. Description of Control Variables

Control Variable	Variable Description and Data Source
Economic Development Level	World Bank
Market Potential	World Bank
Trade Freedom	*Index of Economic Freedom*
Financial Freedom	*Index of Economic Freedom*
Government Effectiveness	*Index of Economic Freedom*
Regulatory Quality	Worldwide Governance Indicators (World Bank)
Political Stability	Worldwide Governance Indicators (World Bank)
Rule of Law	Worldwide Governance Indicators (World Bank)

2 Results and Analysis

2.1 Spatiotemporal Evolution Characteristics of Digital Trade Development Levels

From a temporal perspective (Table 3), the global average digital trade development level increased steadily from 0.3461 to 0.4295, with an annual growth rate of 2.73%. Regionally, Europe maintained the highest average, followed by Asia, while Africa consistently ranked lowest—revealing a pattern of "Asia leading, Africa lagging," consistent with Feng et al. (2022)[9]. However, kernel density analysis further shows persistent intra-regional heterogeneity across all continents, characterized by a divide between "leading" and "follower" nations. Despite its lower absolute level, Africa recorded the strongest cumulative growth (46.76%), signaling considerable catch-up potential. Across dimensions (Table 4), digital trade barriers scored highest, whereas digital innovation scored lowest, indicating that regulatory constraints and innovation gaps remain key challenges in current digital trade development.

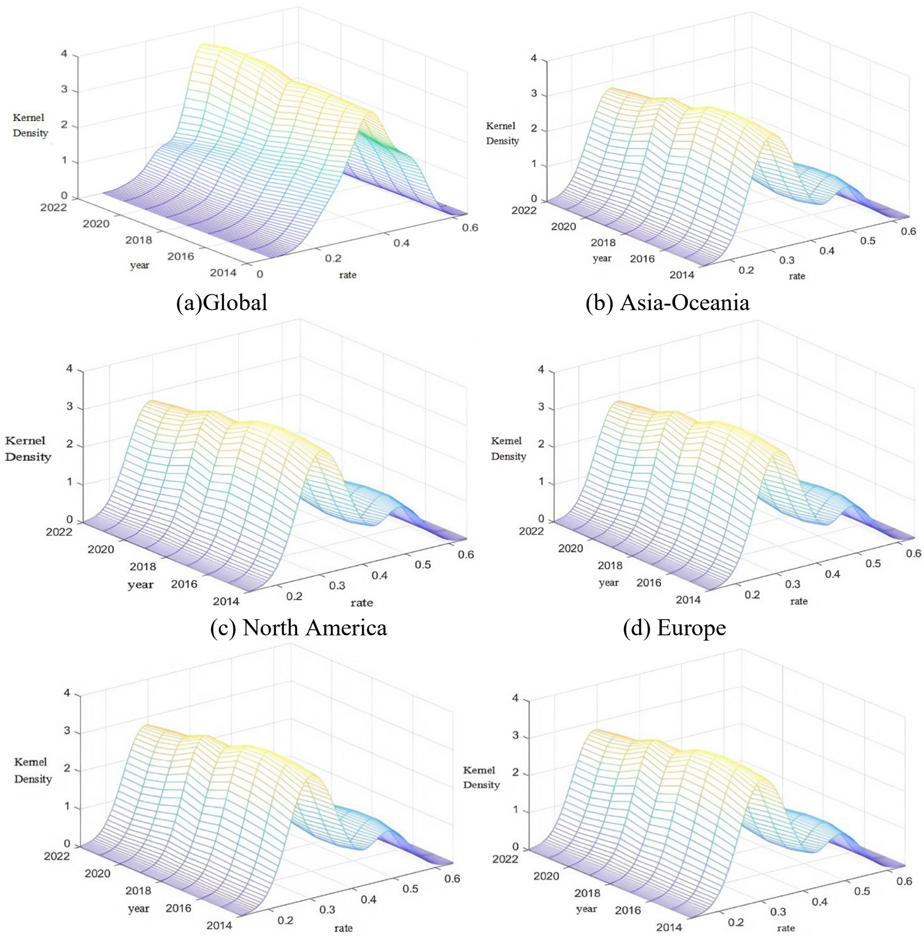
Table 3. Mean Values of the Global and Regional Digital Trade Development Index

Region	2014	2015	2016	2017	2018	2019	2020	2021	2022
Global	0.3461	0.3536	0.3612	0.3688	0.3760	0.3831	0.3982	0.4141	0.4295
Asia-Oceania	0.4101	0.4159	0.4185	0.4291	0.4365	0.4400	0.4522	0.4677	0.4829
Europe	0.4229	0.4288	0.4372	0.4435	0.4521	0.4584	0.4707	0.4845	0.502
South America	0.3361	0.3457	0.3542	0.3599	0.3655	0.3713	0.3884	0.4057	0.4199
Africa	0.2415	0.2526	0.263	0.2729	0.2844	0.2984	0.3195	0.3391	0.3545
North America	0.3201	0.3248	0.3331	0.3384	0.3417	0.3475	0.3603	0.3737	0.388

Table 4. Mean Values of Primary Indicator Development Indices for Global and Regional Digital Trade

Region	Digital Innovation	Digital Skills	Digital Trade Scale	Digital Infrastructure	Digital Trust & Risk	Digital Trade Barriers	Digital Trade Environment
Global	0.1582	0.4001	0.1923	0.3801	0.4957	0.7077	0.3840
Asia-Oceania	0.1875	0.47975	0.19725	0.4263	0.5606	0.7979	0.4399
Europe	0.2382	0.5335	0.2474	0.4678	0.5126	0.771	0.4457
South America	0.0996	0.3608	0.1942	0.364	0.4825	0.7689	0.3339
Africa	0.0844	0.2179	0.1112	0.2589	0.4202	0.5073	0.3126
North America	0.1518	0.3287	0.2065	0.3372	0.4379	0.6033	0.3317

Kernel density estimation reveals distinct distribution dynamics in digital trade development (Figure 1). Globally, the density curve shifted slightly leftward before 2018 and then moved markedly rightward with a higher, narrower peak—indicating accelerated post-2018 growth and narrowing cross-country disparities, all while preserving a unimodal, non-polarized distribution. Regionally, all continents exhibited a "prominent main peak with a trailing tail," reflecting persistent divergence between leaders and laggards within each region. Europe and Asia showed right-shifted, elevated peaks, signaling stronger overall performance and internal clustering; Africa's left-shifted, elongated tail corresponded to lower average levels and greater internal heterogeneity. Over time, peak narrowing and tail flattening across most regions suggest a gradual easing of intra-regional imbalance.



(a)Global (b) Asia-Oceania

(c) North America (d) Europe

(e) South America (f) Africa

Fig. 1. Kernel Density Plots of Global and Regional Digital Trade Development Levels

2.2 Regional Disparity in Digital Trade Development Levels and its Sources

The decomposition results of the Dagum Gini coefficient(Figure 2) reveal that the global overall Gini coefficient for digital trade development level decreased from 0.1491 to 0.1098 during the sample period, indicating a significant reduction in disparities among countries. The average contribution rate of inter-regional differences (56.84%) is the highest, constituting the primary source of overall disparity. This finding aligns with the assessment by Liu Min et al.(2021)[13] regarding inequality within the global digital trade network. Furthermore, the Dagum decomposition reveals a rise in the contribution rate of transvariation density, providing empirical evidence for the enhanced intersecting and overlapping influences among regions. This suggests that the interactivity of digital trade extends beyond simple binary disparities. Specifically, the disparity between Asia and North America is the largest among all regional pairs, yet it also shows the most pronounced decline.

2.3 Spatial Convergence Test of Digital Trade Development Levels

The results of the σ-convergence test (Figure 3) indicate that the coefficients of variation for the global aggregate, Asia, Europe, and South America exhibit a declining trend, demonstrating σ-convergence and a gradual narrowing of disparities. In contrast, the coefficients of variation for North America and Africa show a fluctuating upward trend, failing to present convergence characteristics and instead indicating a trend of widening divergence. Notably, within these regions, the digital trade development level of the United States ranks among the highest globally, while those of Algeria and Honduras are at the lowest global tiers, revealing a significant polarization phenomenon. This underscores the need to pay attention to the unique impediments present in such highly polarized regions. The results of the β-convergence test (Table 5) reveal that, at the global level, the β coefficient is significantly negative at the 1% level, confirming the existence of both significant absolute β-convergence and conditional β-convergence. At the regional level, Asia, Europe, and North America exhibit absolute β-convergence. After controlling for relevant variables, all regions demonstrate significant conditional β-convergence, with an accelerated convergence speed, indicating that each region is progressing towards its respective steady-state level of development. This finding corroborates the potential for "latecomer catch-up" in the diffusion of digital trade as a new developmental driver[14].

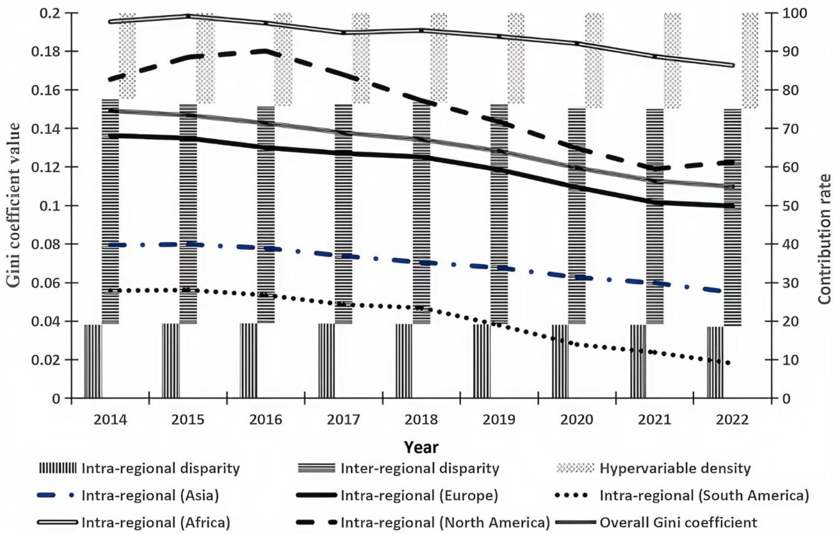


Fig. 2. Dagum Decomposition of the Gini Coefficient

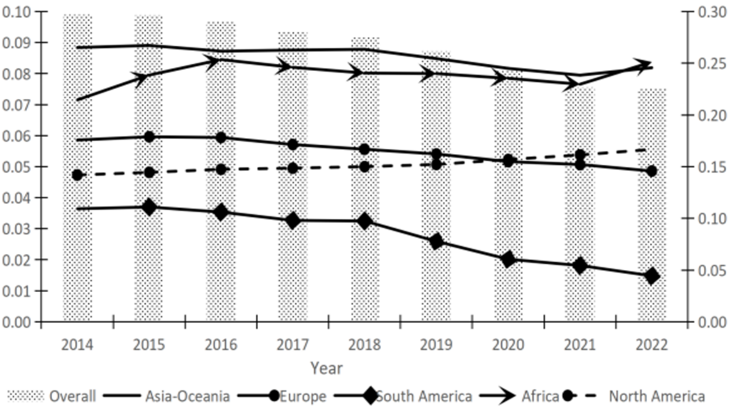


Fig. 3. Results of the σ-Convergence Test

Table 5. Results of the β-Convergence Test

	Absolute β-Convergence						Conditional β-Convergence					
	Global	Asia-Oceania	Europe	South America	Africa	North America	Global	Asia-Oceania	Europe	South America	Africa	North America
Model	SEM	SEM	SDM	SEM	OLS	SEM	SEM	SDM	SDM	SDM	SDM	OLS
β	-0.221 ***	-0.299 ***	-0.368 ***	0.521 *	0.029	-0.509 ***	-0.243 ***	-0.366 ***	-0.426 ***	-0.580 ***	-0.636 ***	-0.281 *
Controls							YES	YES	YES	YES	YES	YES
Constant					0.101 ***							3.578 ***
Conv. Speed	0.028	0.039	0.051	-0.047	-0.003	0.079	0.031	0.051	0.062	0.096	0.112	0.037
LM-error	518.012 ***	44.157 ***	175.699 ***	7.932 ***	0.075	13.509 ***	170.442 ***	13.479 ***	32.155 ***	6.689 ***	19.821 ***	0.427
LM-lag	135.947 ***	27.746 ***	94.440 ***	4.086 **	1.869	6.716 **	78,984 ***	22.460 ***	36.124 ***	10.038 ***	23.756 ***	1.339
Robust-LM -error	385.018 ***	16.903 ***	81.795 ***	4.968 **	6.108	7.592 ***	94.391 ***	1.323	3.599 *	1.183	5.397 **	0.510
Robust-LM -lag	2.95*	0.49	0.54	1.12	7.90	0.80	2.93*	10.30 ***	7.57 ***	4.53 **	9.33 ***	1.42
Hausman Test	21.18 ***	12.52 ***	25.25 ***	19.66 ***	1.94*	13.02 ***	71.25 ***	180.67 ***	147.69 ***	134.32 ***	127.28 ***	55.65 ***
Wald Test	206.49 ***	103.93 ***	113.63 ***	18.95 ***	14.76 ***	43.06 ***	83.45 ***	24.47 ***	39.01 ***	4.40 ***	8.41 ***	14.1 9***
Ind. Fixed	130.07 ***	81.23 ***	68.45 ***	24.02 ***	46.19 ***	464.74 ***	30.26 ***	35.04 ***	9.90 ***	26.74 ***	13.25 ***	9.42 ***
Time Fixed	1646.94 ***	834.93 ***	881.63 ***	124.91 ***	120.08 ***	335.86 ***	83.45 ***	517.18 ***	339.73 ***	73.65 ***	83.40 ***	104.77 ***
LR-SDM-SAR	0.63	1.05	3.89**	1.34		0.59	10.55	19.47**	21.89**	33.77***	24.90***	
LR-SDM-SEM	0.56	0.67	3.73*	0.59		0.38	10.60	18.98**	21.89**	20.88**	21.27**	
R^2	0.053	0.046	0.193	0.947	0.941	0.198	0.170	0.074	0.0570	0.037	0.344	0.437

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01.*

2.4 Evolution Path Analysis of Digital Trade Development Levels

The construction of traditional and spatial Markov transition probability matrices reveals (Table 6): (1) Path Dependence and Stability. Regardless of whether spatial factors are considered, the diagonal transition probabilities all exceed 71%, indicating that countries' digital trade development types exhibit strong stability and "path dependence" characteristics. (2) Gradual Transition. State transitions occur only between adjacent types, with no evidence of leapfrogging transitions. Countries with low and medium-low levels exhibit higher probabilities of transitioning upward. (3) Spatial Spillover Effects. The spatial Markov chain analysis reveals a significant spatial adjacency effect. When neighboring countries are of a higher development type, the probability of a country transitioning upward increases significantly, indicating the presence of positive spatial spillovers. If the development types of neighboring countries differ substantially (e.g., adjacency between Type I and Type IV), the spillover effect is not obvious, potentially constrained by technological gaps and knowledge absorption capacity.

Table 6. Markov Transition Probability Matrix

<table>
<tr><th colspan="2">Spatial Lag Type</th><th>Type</th><th>I</th><th>II</th><th>III</th><th>IV</th><th colspan="2">Type</th><th>I</th><th>II</th><th>III</th><th>IV</th></tr>
<tr><td rowspan="16">With Spati-al Lag</td><td rowspan="4">I</td><td>I</td><td>0.9024</td><td>0.0976</td><td>0</td><td>0</td><td rowspan="16">With -out Spa- ti-al Lag</td><td rowspan="4">I</td><td rowspan="4">0.8663</td><td rowspan="4">0.1337</td><td rowspan="4">0</td><td rowspan="4">0</td></tr>
<tr><td>II</td><td>0</td><td>0.8261</td><td>0.1739</td><td>0</td></tr>
<tr><td>III</td><td>0</td><td>0</td><td>0.8571</td><td>0.1429</td></tr>
<tr><td>IV</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td rowspan="4">I I</td><td>I</td><td>0.8793</td><td>0.1207</td><td>0</td><td>0</td><td rowspan="4">II</td><td rowspan="4">0</td><td rowspan="4">0.7130</td><td rowspan="4">0.2870</td><td rowspan="4">0</td></tr>
<tr><td>II</td><td>0</td><td>0.7719</td><td>0.2281</td><td>0</td></tr>
<tr><td>III</td><td>0</td><td>0.0714</td><td>0.7857</td><td>0.1429</td></tr>
<tr><td>IV</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td rowspan="4">III</td><td>I</td><td>0.7333</td><td>0.2667</td><td>0</td><td>0</td><td rowspan="4">III</td><td rowspan="4">0</td><td rowspan="4">0.0303</td><td rowspan="4">0.7778</td><td rowspan="4">0.1919</td></tr>
<tr><td>II</td><td>0</td><td>0.5625</td><td>0.4375</td><td>0</td></tr>
<tr><td>III</td><td>0</td><td>0.02</td><td>0.78</td><td>0.2</td></tr>
<tr><td>IV</td><td>0</td><td>0</td><td>0.0357</td><td>0.9643</td></tr>
<tr><td rowspan="4">IV</td><td>I</td><td>1</td><td>0</td><td>0</td><td>0</td><td rowspan="4">IV</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0.0133</td><td rowspan="4">0.9867</td></tr>
<tr><td>II</td><td>0</td><td>0.3333</td><td>0.6667</td><td>0</td></tr>
<tr><td>III</td><td>0</td><td>0</td><td>0.7143</td><td>0.2857</td></tr>
<tr><td>IV</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
</table>

2.5 Research Limitations and Future Prospects

This study still possesses certain limitations that warrant further investigation: (1) Sample Scope: While the research encompasses major economies, it does not include all countries. Consequently, the generalizability of the conclusions may be subject to subtle influences. (2) Mechanism Depth: Although this paper confirms the existence of spatial spillover effects, the decomposition of specific spillover channels—such as technology diffusion and investment linkages—remains an area for deeper exploration. Subsequent research could employ more refined models and data to further elucidate the micro-level dynamic mechanisms underlying spatial spillovers and convergence.

3 Conclusions and Implications

3.1 Research Conclusions

This study establishes a multidimensional evaluation framework to assess digital trade development across 67 countries (2014–2022). The main findings are: (1) while global digital trade development shows steady progress, significant regional imbalances persist, characterized by a “Europe and Asia leading, Africa lagging” pattern; (2) overall disparities have narrowed, driven mainly by declining inter-regional differences, though rising hypervariable density points to stronger cross-regional interaction; (3) σ- and absolute β-convergence are observed in most regions except North America and Africa, while conditional β-convergence is evident across all regions after controlling for relevant factors, reflecting noticeable catch-up dynamics; (4) digital trade development displays strong path dependence and spatial interdependence, evolving through gradual adjacent-state transitions where higher-level neighbors exert positive spillovers—effects that diminish as developmental gaps widen.

3.2 Implications

Based on the findings, the following policy recommendations are proposed:

(1)Establish a Multilevel International Rule Coordination System.Encourage the creation of "digital regulatory pilot zones" within regional frameworks such as RCEP and DEPA to develop replicable models of mutual recognition and compliance facilitation, thereby accelerating global regulatory harmonization.

(2)Adopt a Dual-Track "Hardware-Software" Strategy for Differentiated Support.Address structural gaps in lagging regions through a dedicated "Digital Trade Development Fund" targeting critical physical infrastructure, complemented by locally tailored digital skills programs developed in partnership with educational and technological institutions to build endogenous capacity.

(3)Enhance Domestic Regulatory Clarity and Institutional Innovation.Governments should establish cross-departmental coordination mechanisms, streamline compliance procedures for data and digital products, and issue transparent regulatory guidelines. Proactive policy disclosure and tools such as regulatory sandboxes should be employed to foster innovation within a secure framework.

(4)Strengthen Regional Cooperation Through Strategic Spatial Spillover Design.Research confirms significant positive spatial spillovers in digital trade development, though excessive developmental disparities may inhibit their effectiveness. Regionally tailored strategies should therefore focus on three approaches:First, foster "gradient synergy" clusters among geographically proximate economies at similar development levels—such as within ASEAN or the EU—by advancing deeply integrated digital markets to maximize spillover benefits.Second, implement targeted "Digital Bridge" programs between adjacent regions with pronounced development gaps, such as Europe and Africa. Collaborative efforts should concentrate on digital infrastructure, skills development, and regulatory capacity building to enhance local absorption capabilities and translate geographic proximity into tangible developmental synergies.Third, establish regional monitoring and evaluation systems to regularly assess spatial spillover effects, identify emerging "growth poles" and lagging areas, and support evidence-based regional policy formulation.

(5)Build an Enforceable Global Digital Trust Framework.Advance internationally recognized certifications for data security and digital identity, while supporting organizations such as ITU and ISO in developing unified standards for digital transaction traceability and consumer privacy protection.

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