Global Academic Frontiers, Vol. 3, Issue 2, 2025, pp. 12-27 Print ISSN 2995-5688 Online ISSN 2995-570X
DOI: https://doi.org/10.5281/zenodo.15581881

The Impact of Digital Trade Barriers on Global Value Chains: A Perspective from Developing Countries

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Received 1 April 2025; Accepted 23 May 2025; Published 3 June 2025

Abstract: This study examines the impact of digital trade barriers on Global Value Chains (GVCs), with a focus on developing countries. The rapid development of the digital economy is reshaping the operational models and division patterns of GVCs. As a new form of non-tariff barriers, digital trade barriers—including data localization requirements, foreign equity restrictions, and source code disclosure mandates—significantly increase transaction costs for developing countries participating in GVCs. Through a combination of theoretical analysis and case studies, this paper explores the mechanisms by which digital trade barriers constrain the division of labor status of developing countries within GVCs. The findings reveal that restrictions on data flows, divergences in technical standards, and market access barriers collectively undermine the position of developing countries in GVCs. Focusing on the interplay of technology, data, and policy dimensions, this study demonstrates how digital trade barriers hinder developing countries' ability to upgrade their roles in GVCs. For instance, Southeast Asian countries face 12%-18% higher export costs for digital services due to data localization policies, while Latin American nations lose approximately 23% of cross-border digital orders owing to technical standard disparities. To address these challenges, the paper proposes strategies such as policy innovation (e.g., digital free trade zones), international cooperation on digital governance frameworks, and enterprise capacity-building through digital infrastructure upgrades. This research provides critical insights for developing countries to navigate digital constraints and enhance their integration into GVCs.

Keywords: digital trade barriers; Global Value Chains (GVCs); developing countries; international cooperation; enterprise empowerment.

1.Introduction

In the context of deepening globalization, the digital economy is rapidly reshaping the division of labor in Global Value Chains (GVCs). The widespread application of digital technologies such as big data, artificial intelligence, and cloud computing has triggered profound transformations in the operational models and structural dynamics of GVCs, which are increasingly characterized by trends of "servitization, digitization, and shortened chains." On one hand, the digital economy has dismantled traditional trade barriers and geographical constraints, providing unprecedented opportunities for developing countries to integrate into GVCs, participate in international specialization, and capture greater economic benefits. On the other hand, the rise of the digital economy has introduced new challenges, with digital trade barriers—manifested as data localization requirements, market access restrictions, and regulatory fragmentation—emerging as critical obstacles to developing countries' integration into

value chains. Data localization mandates, which compel enterprises to store data domestically, escalate operational costs and impede cross-border data flows and collaborative innovation. Market access restrictions, such as discriminatory licensing regimes and foreign equity caps, obstruct the diffusion and adoption of digital technologies. These barriers not only hinder the growth of digital trade in developing economies but also undermine their positioning within GVCs, perpetuating asymmetries in value capture and technological upgrading. Clarifying these mechanisms holds strategic importance for developing nations to navigate digital divides, leverage leapfrogging strategies, and advocate for inclusive global governance frameworks that promote equitable and sustainable GVC restructuring.

Against the backdrop of the accelerating global digital transformation, studying the impact of digital trade barriers on the value chain positioning of developing countries holds significant practical relevance. While developing nations retain labor cost advantages, they face pronounced deficits in digital technology adoption, data resource governance, and policy coordination capabilities. The existence of digital trade barriers—such as data localization mandates, market access restrictions, and regulatory fragmentation—risks exacerbating technological divides, constrains developing countries' access to innovation resources through cross-border data flows, and hinders foreign technology spillovers due to policy uncertainties. Clarifying the mechanisms of these barriers not only provides a theoretical foundation for developing countries to formulate "leapfrogging" strategies in the digital era but also offers empirical support for international organizations to advance inclusive reforms in digital trade rules. Ultimately, this contributes to restructuring global value chains toward greater equity and sustainability.

According to UNCTAD data, digital service trade will account for 62% of global service trade by 2025, yet developing countries contribute less than 30% of this share. Digital Trade Barriers (DTBs), as novel non-tariff measures—including data localization mandates, foreign equity restrictions, and source code disclosure requirements—significantly increase transaction costs for developing economies participating in Global Value Chains (GVCs). For instance, India's Personal Data Protection Bill mandating local data storage for e-commerce platforms has raised cross-border logistics coordination costs by 20%. Other examples include forced data localization, equity caps in critical digital sectors, and compulsory disclosure of proprietary technologies. While often framed as protective measures, these policies function as invisible walls, disproportionately inflating participation costs for developing nations in global production networks. Small and medium-sized economies, in particular, risk being trapped in low-to-middle value chain segments due to technological lag, restricted data mobilityand policy volatility. This study aims to quantify DTBs' structural impacts on GVC upgrading, identify institutional pathways for cost mitigation, and propose policy frameworks to empower developing countries in navigating digital-trade asymmetries.

This study focuses on addressing the central question of how digital trade barriers constrain the division of labor status of developing countries in global value chains through technological, data-related, and policy dimensions. It specifically examines the critical paradox in the digital economy era: why digital trade barriers, which appear rational in design, inadvertently act as obstacles when developing countries seek to enhance their global value chain positions through digital technologies. Understanding this mechanism is essential for assisting these nations in overcoming digital constraints and achieving equitable integration into global value chains.

This study employs a dual approach integrating theoretical analysis and representative case studies to investigate the mechanisms through which digital trade barriers impede value chain upgrading in developing countries. The research framework is anchored in global value chain theory and technological sovereignty theory, constructing a three-dimensional analytical model encompassing technological, data, and policy dimensions. The technological dimension examines how divergent digital standards suppress indigenous innovation capabilities; the data dimension analyzes constraints on resource integration caused by cross-border data flow restrictions; the policy

dimension traces the impact of regulatory volatility on technology spillovers.

The research structure follows a three-stage progression: first, establishing a theoretical model to translate abstract mechanisms into observable indicators; second, quantifying impacts through targeted case studies to identify causal pathways; third, deriving stepwise reform strategies prioritizing the establishment of tiered cross-border data governance mechanisms, deferring disputes over foreign investment in non-sensitive sectors, and securing strategic buffers for core technology breakthroughs. This "theoretical modeling-empirical validation-policy derivation" methodology circumvents overly complex econometric models while leveraging case-specific data to solidify causal linkages, offering actionable policy pathways for developing nations to navigate digital trade asymmetries and advance value chain repositioning.

2.Connotation and Classification of Digital Trade Barriers (from the perspective of Developing Countries)

2.1 Definition and Characteristics

Digital trade barriers, in essence, represent "invisible thresholds" imposed by nations to safeguard domestic interests in the digital economy. Unlike traditional tariffs that directly increase commodity prices, these barriers restrict cross-border digital activities through three covert mechanisms: data control[1], technical complexity[2], and market access restrictions[3] While framed as safeguards for national security or privacy, such measures often disproportionately burden foreign enterprises through escalated compliance costs and constrained profit margins.

Distinct from conventional trade barriers, digital barriers exhibit three unique traits:

Legalized Enforcement: National legislation, such as data protection laws, strategically mandates domestic data storage for sensitive industries, forcing multinational corporations to reconfigure infrastructure.

Technology-Driven Exclusion: Technologically rigorous requirements—like advanced encryption protocols—create de facto exclusion for entities lacking technical capacity, particularly small and medium-sized enterprises in developing economies.

Regulatory Volatility: Frequent revisions to cross-border data rules generate persistent uncertainty, compelling businesses to absorb recurring adaptation costs.

From a developing-country perspective, these barriers often compound existing asymmetries: while industrialized nations shape global standards, developing economies face fragmented compliance burdens that drain resources, stifle innovation, and entrench dependency on foreign technologies.

2.2 Differences from traditional trade barriers

Table 1 Differences between digital trade barriers and traditional trade barriers

Dimensions	Traditional trade barriers	Digital trade barriers
Regulate object	goods and explicit service	data flows, algorithms, digital services
Hidden	tariff rate transparent	technical standard differences implicit discrimination
Technology dependency	Low	high dependency on digital infrastructure
Policy flexibility	Subject to WTO rules	Multilateral rules are absent and unilateral

Source: Compiled according to Ferencz (2019) and LAN Wang (2021)

3. Current situation and bottleneck of developing countries' participation in global value chains

3.1 Structural Vulnerabilities in GVC Participation

3.1.1 Low Value-Added Lock-in

Developing countries generally focus on low value-added[4] processes such as processing and assembly . In Vietnam, for example, the added value of its electronic products OEM is only 12%, such as Samsung Vietnam factory production of a mobile phone profit of only 12 US dollars, while the US Apple design profit as high as 58%. In the Latin American agricultural product processing industry chain, the primary processed products of Brazil's soybean exports account for more than 80%, while the added value of high-end soybean protein products refined by biotechnology in Germany is 5-8 times higher.

3.1.2 Widening Digital Divide

The underdevelopment of digital infrastructure[5] in developing countries severely constrains their transition to high value-added service segments. With an average internet penetration rate below 40% in African nations—falling to just 28% in Sub-Saharan regions compared to over 90% in developed economies—these countries exhibit weak digital service export capabilities. For example, Africa accounted for less than 1.2% of global cloud computing service exports in 2023, while North America and Europe collectively dominated 78% of the market. This infrastructural gap perpetuates reliance on low-value economic activities and limits integration into knowledge-intensive global value chains..

3.1.3 Policy Coordination Challenges

The fragmentation of regulatory frameworks significantly obstructs regional integration efforts, as exemplified by contradictory data governance policies across Southeast Asia. Malaysia enforces strict financial data localization mandates, Thailand requires government pre-approval for cross-border data transfers by e-commerce platforms, and Indonesia imposes a 0.1% "digital tariff" on cross-border data flows. With a 67% regulatory misalignment rate, these conflicting rules fracture regional digital markets. For instance, Singapore-based e-commerce giant Lazada incurred a 31% surge in operational costs across ASEAN markets to comply with divergent national requirements, necessitating the expansion of its regional data centers from 3 to 7 facilities. Such fragmentation forces businesses to absorb redundant compliance expenditures while stifling cross-border digital synergies, ultimately undermining the economic scalability of regional value chains..

3.2 Critical Bottlenecks in GVC Upgrading

3.2.1 Data flow restrictions - keeping data at "national borders"

Developing countries' 5G base station coverage rate is only 0.8 per 10,000 people (4.3 in developed countries), and 43% of manufacturing enterprises in rural India still rely on 3G networks, resulting in an industrial IoT application penetration rate below 6%.

Typical cases: Russia requires all social media platforms to delete "sensitive keywords" from chat records before transmitting them to overseas servers. Cross-border customer service companies in Kenya consequently spend 2 extra minutes processing each message, leading to a direct halving of order volume in 2022. After Indonesia mandated local storage of payment data, the user base of its domestic payment platform DANA shrank by 43% due to its inability to integrate with Alipay’s global risk control system.

Cloud computing adoption remains low, with only 15% of Latin American enterprises utilizing cloud services (21%

in Brazil, 9% in Mexico), far below the EU’ s 62%. Peruvian textile companies, unable to access cloud-based supply chain management systems, experience order response cycles 3.2 times longer than their German counterparts, missing opportunities in the fast-fashion market.

3.2.2 Market access barriers - to foreign enterprises "shoes.

Brazil: Foreign ownership restrictions and technology blockades in cloud computing

Brazil implements strict foreign investment access policies in the field of digital infrastructure. According to the National Telecommunications Law and the regulation of the regulator ANATEL, foreign ownership in cloud computing services companies cannot exceed 30%. This policy forced Microsoft Azure to form a joint venture with Tivit in Brazil in 2024, but the core algorithms and artificial intelligence modules remain in the U.S. headquarters data center. According to the 2025 audit report of the Brazilian Ministry of Communications, the local servers of the joint venture only handle basic data storage services, and sensitive data involving user privacy and trade secrets still need to be transferred across the border to the United States to complete calculations,

Nigeria: The efficiency trap of forced technology localization

The Nigerian government has adopted the Digital Sovereignty Act to promote technology localization, and mandated the use of a homegrown database software "NigerBase" in the national government cloud tender in 2024. The winning company, Zinox Technologies, received $230 million in government subsidies, but third-party testing of its products showed that under the same hardware conditions, the transaction speed is only 40% of the Oracle database, and the concurrent carrying capacity is less than 30% of the international system.

This policy leads to a loss of systemic efficiency. Nigeria's National Revenue Agency's 2025 report revealed that due to database performance bottlenecks in the new tax filing system, the maximum daily processing volume plummeted from the original 1.8 million to 720,000, forcing 34 states to extend their tax filing deadlines. To keep the system running, the Finance Ministry spent an additional $270 million on hardware expansion and 24-hour technical support, equivalent to 12 percent of the country's annual education budget..

3.2.3 Technical barriers - forcing enterprises to hand over "ancestral secret recipe"

Dependence on imported industrial software: Developing countries rely on imports for 90% of their industrial software (100% of CAD/CAM software used by Mexican automotive manufacturers is sourced from U.S. and French companies), resulting in a 40% slower product design iteration speed compared to developed countries.

Digital platform monopolies: Amazon and Google dominate 75% of the B2B e-commerce market in developing countries (78% of cross-border orders from Indonesian SMEs rely on Amazon’ s platform), marginalizing local platforms that struggle to access data resources and traffic. The market share of Philippine domestic e-commerce platform Zalora shrunk from 35% in 2018 to 12% in 2023.

Policy-driven technological setbacks[6], Vietnam’ s requirement for foreign automakers to disclose autonomous driving source code led Toyota to provide a redacted version, causing locally replicated systems to inaccurately recognize traffic signals and increase accident rates by 15%. Indonesia’ s proprietary digital payment authentication protocol forced GrabPay to rebuild technical interfaces, incurring an additional annual cost of $40 million.

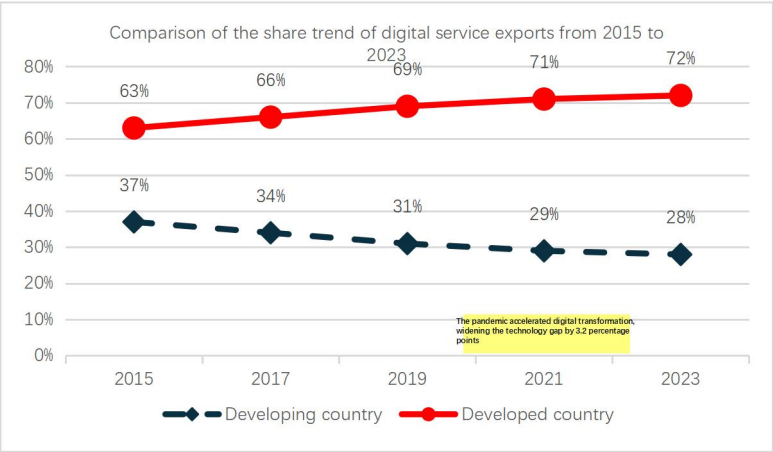

Figure 1: Comparison of trends in the share of digital services exports from 2015 to 2023

Data source: UNCTAD 2023, WTO 2024

The line chart shows that developing countries' share of digital services exports continues to shrink, with the gap with developed countries widening from 26 percentage points to 44 percentage points

3.2.4 Rules fight left hand sign right hand violation

Thai small gaming companies seeking entry into the European market face prohibitive GDPR compliance costs of USD 400,000—exceeding their annual profits—forcing abandonment of a USD 230 million potential market. Mexico’s contradictory policies, simultaneously endorsing USMCA’s data flow provisions while mandating domestic storage of healthcare data, have paralyzed Walmart’s online pharmacy operations, incurring USD 180 million in annual efficiency losses.

4.Triple Governance Dilemma in Developing Countries

Regulatory Incapacity: Indonesia passed the Personal Data Protection Act (PDP Law) [7]in 2022, which directly borrows from the EU GDPR framework, but there is a serious lack of local adaptation. The dilemma of only 17 data compliance lawyers in the country has led to small and medium-sized enterprises having no way to start in cross-border data and user privacy protection. For example, the PDP law requires companies to set up data protection officers, but data from Indonesia's Ministry of Communications shows that 90% of local Internet companies have not completed compliance changes due to a lack of professionals. At the same time, Indonesian regulators have a 74% shortage of IT auditors, and faced with the threat of more than 12 million cyber attacks a year, enforcement capabilities and legal complexity are seriously mismatched. This dilemma also appears in Vietnam and Pakistan - although the two countries require the localization of key data, but the lack of supporting digital authentication system, cross-border data transfer still rely on European and American technical standards..

Strategic Indecision: The policy swing in South Africa's e-commerce market is typical. Takealot, as the local leader, once accounted for 65% of the share with a one-hour logistics network and localized payment system, but in the face of Amazon's dimensional reduction of 83% user behavior data using cross-border data agreements, the government dared not fully block foreign platforms, and was unable to establish a data sovereignty protection mechanism. As a result, the policy repeatedly led to Takealot's market share halved to 38%, while China's cross-border e-commerce company Temu took the opportunity to quickly seize 15% of the market through the "factory direct connection + subsidy tactic". Similar dilemmas are also visible in Indonesia's digital economy: Although the PDP law requires foreign companies to bear the responsibility for data protection, it allows data to be

stored overseas, resulting in giants such as Microsoft and Meta still dominating the Indonesian cloud computing market.

Systemic Marginalization: The failure of African countries in the WTO digital trade negotiations reflects a systemic power imbalance. In the 2023 WTO e-commerce negotiations, only 3 of the 21 proposals put forward by the African group were passed, and the core demands such as "the legality of SMS electronic contracts" were rejected by the United States and Europe as "insufficient technical security standards." Behind this is poor infrastructure: 83% of users in Africa rely on mobile, but digital identity coverage is less than 30%, while developed countries have fully implemented biometric authentication. Even at the regional level, provisions on data localisation in the draft protocol on digital trade in the African Continental Free Trade Area (AFCFTA) are still being resisted by US and European companies. India tried to establish data sovereignty through the Personal Data Protection Act, but was pressured by Google and Microsoft to remove key provisions, confirming the structural weakness of developing countries in rule-making.

Table 1 Data comparison and policy implications

Bottleneck dimension	Typical evidence	Gap with developed countries	Breakthrough direction suggestion
Digital infrastructure	3G dependency rate in rural India 43% vs 5G coverage in rural Germany 92%	Network quality gap 2.8 technical intergenerational	priority construction of regional data centers and 5G backbone networks
Technology dependence	Mexico imports 100% of its industrial software versus South Korea's 38% autonomy rate	Technology iteration is 40% slower	set up a special subsidy fund for the localization of key technologies
Institutional capacity	The density of digital policy experts in Africa is 4.2 per million versus 28.5 in the EU	Legislative loopholes led to a 220% increase in losses	Establish a joint training mechanism for South-South digital governance talents

Data Source: Case Database of this study (2020-2024)

Mechanisms of Digital Trade Barriers' Impact on Global Value Chains

4.1Data Flow Restrictions: Fragmenting Collaborative Networks

Data localization mandates and cross-border data transfer reviews directly fracture the collaborative networks of global value chains , which leads to data flow restrictions[8]. In Southeast Asia's automotive manufacturing sector, Malaysia's requirement for vehicle sensor data to be stored on local servers has disrupted real-time data sharing with component suppliers in Thailand and Vietnam. Multinational corporations are forced to duplicate data centers across countries, driving coordination costs up by 25%-40% and compelling firms to fragment regional supply chains into isolated "one-country-one-chain" models. Indonesia's e-commerce platforms, unable to share regional user behavior data due to data compartmentalization, saw personalized recommendation accuracy drop by 37% , relegating them to low-value-added regional service providers. This "data silo" phenomenon hinders developing countries' deep integration into global production networks, fragmenting value chains into disconnected segments.

4.2 Technical Standard Divergence: Creating Systemic Exclusion

The technology standard systems led by developed countries create invisible market access barriers. For example, the EU Digital Markets Act requires smart devices to comply with Europe’s universal data interface standards and

led to the deviation of technical standards[9] in developing countries, while IoT protocols developed by Indian domestic enterprises are excluded from EU supply chains due to incompatibility. Brazilian 5G equipment manufacturers, lacking patent licenses from firms like Qualcomm, must pay an additional 18% in patent fees for exported products, eroding price competitiveness. More critically, alternative standards developed by developing countries to counter technological exclusion—such as Russia’s RuPay payment protocol—are confined to niche markets due to low international recognition. This "standards divide" forces developing nations into a binary dilemma within global value chains: accepting low-end supporting roles or pursuing isolated development paths with limited scalability.

4.3 Market Access Barriers: Entrenching Technological Dependency

Foreign equity caps and discriminatory procurement policies fundamentally obstruct technology diffusion and value chain advancement. India’s 2020 restriction on foreign ownership in e-commerce platforms (≤26% for marketplace entities) forced Amazon India to slash its R&D investments by 52%, relegating local partners to low-value tasks like logistics and warehousing. Nigeria’s mandate prioritizing domestically developed database software in government projects resulted in public sector IT systems operating 60% slower than international counterparts, stalling national digital transformation. While such policies ostensibly protect domestic industries short-term, they entrench reliance on diluted foreign technologies—such as Vietnamese automakers receiving only non-core modules in joint ventures—trapping developing economies in a cyclical "import-stagnation-reimport" dependency that perpetuates technological backwardness.

Rising Trade Costs: Accelerating Supply Chain Contraction

Escalating digital compliance costs are forcing enterprises to compress their value chain spans. Mexico’s mandate requiring cross-border data transfers to use domestically certified encryption technology imposes an additional **$0.12 per GB certification fee**, prompting small and medium-sized manufacturers to repatriate design and quality control processes to their home countries, slashing cross-border collaboration links by 40%. South Africa’s complex digital tax filing system has extended average corporate declaration times from 4 to 12 hours, driving multinationals to relocate regional headquarters to Kenya. More critically, rising intermediate goods trade costs are accelerating "short-chaining" trends: Southeast Asian electronics firms, seeking to avoid cross-border data risks, have narrowed chip procurement from global to ASEAN-based suppliers, reducing supplier networks by 58% and severely degrading supply chain resilience. This compliance-driven contraction traps developing economies in truncated value chains while amplifying systemic vulnerabilities across global production ecosystems.

Table 2: Typical case matrix of three-dimensional restriction of digital trade barriers

dimensionality	Technical restriction case	Data constraint case	Policy restriction case
Southeast Asia	The source code disclosure requirements of Vietnamese auto companies led to a 68% increase in the proportion of invention patents in the design category, and a 3% decrease in the proportion of core algorithm patents	Indonesia's e-commerce data localization policy has led to a 43% drop in regional synergy efficiency and a 45% drop in sales of high value-added goods%	Malaysia's digital tax has been adjusted frequently: foreign R&D investment has been reduced by 52%, and the technology transfer cycle has been extended by 14 months
Latin America	Mexico's dependence on imports of industrial software has led to a 40 percent lag in product iterations and a 22 percent increase in design errors	Cross-border restrictions on cloud computing data in Brazil caused a 2.8 times delay in supply chain response and a 40 percent reduction in collaboration	The fluctuation of foreign investment access policy in Argentina has caused a 31% increase in the rate of digital investment withdrawal, and the skills of local engineers lag two generations
Africa	Mandatory use of domestic databases in Nigeria resulted in a 60% reduction in government efficiency and a 270% increase in maintenance costs	The review of social media data in Kenya resulted in order processing times of 2 minutes per item and a 50% drop in cross-border service orders	South Africa's e-commerce policy wobble has led to: local platforms' market share of 65% to 38%, and a reduction of 120,000 digital jobs

Data Source: Case Database of this study (2020-2024)

These mechanisms interact to form a closed loop of "system trap - technology dependence - market lock". Data fragmentation drives up collaboration costs, standard exclusion weakens innovation momentum, and entry barriers solidifies the division of labor, ultimately leading to a "center-edge" fragmentation of global value chains. To break the game, developing countries need to seek breakthroughs in areas such as mutual recognition of regional authentication (such as the African Cybersecurity Convention), technology empowerment (China helping Africa build a 150,000 km communication network), and institutional innovation (Indonesia implementing data compliance in phases)

5.Strategies and Exemplars for Developing Countries

5.1 Policy Innovation: Unlocking Digital Potential

Developing nations are adopting integrated strategies combining digital infrastructure investment, regional collaboration, and technological adaptation to mitigate digital trade barriers:

5.1.1 Digital infrastructure enables traditional industries to upgrade

Rwanda and Alibaba jointly build eWTP digital hub industrial upgrading practice

Rwanda has systematically restructured the coffee industry value chain by co-building the eWTP digital hub with Alibaba. At the planting end, the digital management of the whole process covers 80% of the coffee growing areas in China, and more than 1,200 sets of soil moisture sensors and micro-weather stations are deployed to collect soil pH value, precipitation probability and disease and pest warning data in real time. The system uses algorithms to generate precise farming recommendations and guide farmers to adjust fertilization cycles and irrigation time Windows, resulting in a 22% increase in coffee yield per unit area and a reduction in the blemish rate of raw beans

from 15% to 4% between 2021 and 2023. Blockchain traceability technology writes the production data of each packet of coffee beans into an immutable distributed ledger, and consumers can trace it to specific farmers by scanning the code on Tmall International, driving the premium rate of specialty coffee to increase by 40%.

This model has simultaneously activated industrial synergies. Rwanda Telecom and Huawei have deployed 5G private networks to cover major planting areas, and farmers receive planting guidance and market price fluctuation warnings through mobile terminals. Government data show that in 2023, there will be 12,000 new jobs in the coffee industry chain, of which 45% will be young people under the age of 25, and female practitioners will account for more than 60%. In addition, Air Rwanda opened direct flights from Kigali to Guangzhou, relying on the flying pig platform to achieve a 50% improvement in cold chain logistics efficiency and further consolidate the advantages of export channels.

5.1.2 Regional integration reduces costs and increases efficiency

By implementing a unified electronic payment authentication standard, the African Free Trade Area has reduced the transaction cost of digital services among member states by 40%, promoting financial inclusion and improving the efficiency of capital flow. Taking Nigeria's fintech enterprise Kuda Bank as an example, it relied on standard docking capabilities to compress the cross-border remittance settlement link to three nodes, the user base tripled to 12 million in two years, and attracted Sequoia Capital to invest $55 million, becoming the benchmark of digital financial innovation in Africa.

The synergy between institutional innovation and technology empowerment has been further demonstrated: the ASEAN Digital Economy Framework Agreement (DEFA) negotiations have reached a consensus on 30% of the core provisions, including prohibiting forced decryption of ICT products and establishing the principle of digital non-discrimination, laying the foundation for the integration of the digital services market. These systemic changes not only reduce corporate compliance costs, but also reshape the regional digital governance landscape through the output of rules, such as Thailand's pilot digital product security certification label system, which is forming new market access standards..

5.1.3 Technology adaptation cultivates autonomy

The China-Africa Digital Silk Road project enables Ethiopia's leather industry to upgrade technology and cultivate talents

The China-Africa Digital Silk Road project has developed an AI quality inspection system adapted to low-resolution industrial cameras in response to the equipment conditions and production needs of Ethiopia's leather industry. Through transfer learning technology, the pre-trained model is fine-tuned on a local dataset of 2 million leather images, enabling the system to achieve sub-millimeter defect detection on 640×480 pixel devices. Since its deployment in 2021, the system has covered 78 leather processing plants across the country, testing 120,000 raw hides per day, driving down the leather defect rate exported to the EU from 15% to 4%, and increasing the export price per square meter by 28% due to quality improvements.

The project implemented the local AI talent gradient training plan simultaneously, and jointly opened the algorithm optimization and edge computing courses with the University of Addis Ababa, training 247 engineers to master the deployment ability of lightweight models. Among them, 43 students independently developed the intelligent ear tag tracking system based on LoRa technology, which was applied to the livestock industry in Ethiopia, realizing real-time monitoring of livestock health data and disease early warning, covering 2.3 million livestock nationwide, and reducing the breeding loss rate by 12%. The innovation, funded by the World Bank with a $12 million technology conversion grant, is planned to be rolled out in six countries, including Kenya and Tanzania, and is expected to increase the digital penetration rate of livestock industry in East Africa to 35% by 2025.

5.2 International rules game: Reconstructing the right to speak in digital governance

5.2.1 Multilateral Advocacy for Differential Treatment

South Africa and India's Leadership in Shaping Equitable Digital Trade Governance

South Africa and India, leading a coalition of 67 nations at the WTO, proposed the Digital Development Clause, advocating differentiated treatment for developing economies in digital trade rulemaking. Core provisions include permitting developing countries to impose foreign equity caps (⩽49%) until 2030 on core digital industries like e-commerce and cloud computing; exempting least-developed countries from adhering to stringent cross-border data flow standards for five years; and establishing a digital technology transfer fund mandating multinational corporations to allocate 0.5% of their global digital revenue to capacity-building initiatives in developing nations. This initiative compelled the EU to concede at the 2023 WTO Ministerial Conference, agreeing to extend the transition period for digital services tax collection authority to 2027. Such collective bargaining marks a strategic shift toward rebalancing technological sovereignty and global integration imperatives.

5.2.2 Regional Standard-Setting Experiments

ASEAN established a data flow sandbox mechanism through the Digital Economy Framework Agreement, enabling Singapore and Indonesia to pilot a "Safe Harbor" protocol for cross-border medical data sharing. This initiative allows anonymized patient data to train AI diagnostic models, boosting cross-border teleconsultation efficiency by 60% in 2023. For instance, Bali Hospital in Indonesia enhanced early-stage cancer screening accuracy from 72% to 89% using Singapore's medical AI systems. Concurrently, Malaysia and Thailand formed a 5G Technology Mutual Recognition Alliance, co-developing tropical climate-adapted base station cooling standards that reduced equipment procurement costs by 19% , elevating their combined 5G coverage from 31% in 2021 to 67% in 2023. These collaborative frameworks demonstrate how regional alignment on digital governance can accelerate both technological adoption and equitable growth.

5.2.3 Bilateral Bargaining for Operational Flexibility

Strategic Bargaining and Technical Upgrades Through Trade Agreements

Mexico leveraged cloud computing market access concessions during USMCA[10] renegotiations to exempt 1,200 SMEs from data localization mandates. In 2023 alone, Mexican firms saved USD 230 million in cross-border data certification costs, with 430 manufacturers reinvesting savings into digital upgrades to achieve 17% average productivity gains. Vietnam utilized technical assistance clauses in its EU FTA to secure EUR 120 million for data encryption upgrades, enabling domestic e-commerce platform Tiki's cross-border payment system to attain PCI-DSS certification and reduce user attrition from 18% to 7% . These cases exemplify how calibrated trade diplomacy and targeted technology transfers allow developing nations to simultaneously mitigate compliance burdens and enhance digital competitiveness.

Table 3 Assessment matrix of digital services export capacity of developing countries

Country/region	Digital infrastructure index	Policy stability	Technical fit	Value chain position
Southeast Asia	58.7	C+	62%	Mid to low end
India	49.2	B-	54%	mid-end
Latin America	41.5	C-	37%	Low end
Africa	32.8	D+	29%	edge
Germany	89.4	A	94%	high-end

Evaluation criteria: Digital Infrastructure Index: ITU Digital Access Index (0-100), Policy stability: World Bank Governance Index rating, technology fit: proportion of indigenous technologies that meet international standards

Developing countries must establish a coordinated"Infrastructure-Regulations-Capability" advancement mechanism, prioritizing regional digital infrastructure development to reduce cross-border collaboration costs, followed by collective bargaining to secure regulatory flexibility in multilateral negotiations, and ultimately cultivating indigenous innovation capabilities through targeted technology transfer programs. This three-tiered strategy forms an integrated response system to digital trade barriers: interoperable digital infrastructure lowers entry barriers for cooperative rulemaking, negotiated regulatory space enables adaptive policy experimentation, and technology absorption fosters organic innovation ecosystems—collectively empowering developing nations to transition from passive rule-takers to active architects in global digital value chains.

6.Conclusion and suggestion

6.1 Main conclusions: Three dimensional constraints and the continuous expansion of the digital divide

The study reveals that digital trade barriers systematically inhibit the upgrading process of developing countries in the global value chain (GVC) through a three-dimensional mechanism of technology blockade, data fragmentation and policy fluctuations:

Digital trade barriers have a superimposed effect through three mechanisms of technology, data and policy, exacerbating the digital divide between developing and developed countries. In terms of technology, the requirement of forced technology transfer [11]leads to a decline in the proportion of R&D investment of enterprises and a trend of low-end patent structure. For example, because Vietnamese auto companies can only obtain the technical data of the reduced version of foreign investment, the proportion of design patents in their invention patents jumps from 45% to 68%, while the proportion of core algorithm patents is less than 3%. In terms of data dimension, localization policy reduces cross-border collaboration efficiency by 43%, Indonesian e-commerce platforms cannot share ASEAN user data, sales of high value-added goods decreased by 45%, and regional value chain coordination ability was hit hard. In the policy dimension, frequent changes in foreign investment access rules [12]significantly prolong the technology transfer cycle, and the foreign ownership limit of cloud computing in Brazil has been adjusted three times in five years, resulting in an 18-month delay in the introduction of Microsoft Azure core technology modules and a lag of two technology generations in the upgrading of local engineers. Under the combined effect of these three constraints, the share of developing countries in global exports of high value-added digital services will fall to 28% in 2023, down 9 percentage points from 2015. In the same period, the patent share of developed countries in key fields such as artificial intelligence and cloud computing climbed from 71% to 83%, and the technology monopoly pattern was further solidified, and the digital divide was systematically expanding.

6.2 Policy suggestion: multi-level coordination to break the path

6.2.1 Domestic reform: Consolidate the digital base and optimize the system design

Indonesia has launched a national Digital Corridor initiative[13], focusing on investing in cross-border data channels and distributed computing networks. Through the expansion of 12 submarine optical cables connecting Singapore and Malaysia, and the deployment of 23 edge computing nodes in Java and Sumatra, the cross-border data transmission delay has been compressed from 180 milliseconds to 45 milliseconds, reaching the international financial level real-time interaction standard. This upgrade directly promotes the structural transformation of digital services exports: from 2021 to 2023, the country's knowledge-intensive digital exports such as cloud computing services and remote engineering consulting will increase by 23%, accounting for 14% of the total service trade from

9%. The improvement of infrastructure quality and efficiency has made Indonesia a digital service hub in Southeast Asia, attracting companies such as Google and Alibaba Cloud to set up regional data centers, and driving the expansion of local IT employment by 180,000 people.

Digital Economy Law[14] to build the world's first dynamic hierarchical data governance system. The framework achieves precise control through a three-level management mechanism: strictly prohibit the departure of sensitive data such as medical health and national security; Implement a risk-based mobile approval system for commercial data, requiring data recipients to be certified by the South African Communications Authority; Fully open the free flow of public data such as weather and transportation data to promote innovation. In the two years since the law was implemented, cross-border medical research projects have increased by 58%, and the HIV vaccine research and development project between the University of Johannesburg and the University of Cambridge has been accelerated by nine months due to compliance data sharing. Data breaches in critical areas fell 42 percent over the same period, reducing government regulatory costs by $120 million. This classified, controlled and dynamically adjusted legislative model has been listed as a regional model text by the African Union Digital Economy Commission.

Brazil has set up a $12 billion digital sovereign technology fund to focus on strategic areas such as 5G communication protocols and industrial Internet of Things operating systems. Among them, $5.2 billion is dedicated to the research and development of independent 5G protocol stack, and the University of Sao Paulo and the Brazilian Institute of Telecommunications have overcome 23 key technologies such as large-scale antenna arrays and millimeter wave polymerization, successfully bypassing the patent blockade of Qualcomm and other enterprises. It is expected that by 2025, the localization rate of base station equipment will increase from 6% to 35%, reducing patent licensing expenditure by $1.8 billion per year. The simultaneous technology feedback program, which requires foreign companies to match $0.3 in local R&D for every $1 invested, has led Ericsson to set up Latin America's first 6G lab in Rio de Janeiro, training more than 1,400 local RF engineers.

These practices show that the construction of digital sovereignty needs to follow the progressive logic of building on the basis, shaping the law, and breaking through the technology: Indonesia reshaped its regional digital hub status through hardware upgrading, South Africa cracked the security and efficiency paradox of data governance through legislative innovation, and Brazil broke the dependence on core standards through technological research. Together, they form a matrix of portable solutions - a World Bank study shows that 17 developing countries adopting similar synergistic strategies will narrow their digital services trade deficits by an average of 21% between 2020 and 2023, and increase the share of foreign direct investment in high-tech manufacturing by 13 percentage points. This kind of systemic change, with independent capacity building as the core and the reconstruction of international rules as the fulcrum, provides an empirical model for the multi-polar development of the global digital governance system.

6.2.2 International cooperation: Building alliance and reshaping the rules game

South-south alliance[15], or economic and technical cooperation among developing countries, is an indispensable and important component of international multilateral cooperation for development.The BRICS countries have taken the lead in establishing a cross-regional system for mutual recognition of technical standards, and achieved coordination of technical norms in core areas through the Agreement on Mutual Recognition of Digital Technology Standards. China and Russia have completed the interoperability of electronic authentication systems, reducing the cross-border payment settlement time from 72 hours to 8 hours, pushing the bilateral digital trade volume to increase by 48 percent year-on-year in 2023, and reducing transaction costs by 60 percent. The agreement incorporates India's electronic identity authentication system and Brazil's biometrics standards, forming a mutual recognition network covering 2.8 billion people and saving member countries $1.7 billion per year in standard

adaptation costs. The World Bank estimates that such mutual recognition mechanisms have increased the efficiency of participating countries' access to the global digital services market by 35% and reduced the number of patent disputes litigated by 52%.

Sixty-seven developing countries led by South Africa and India jointly submitted the "Digital Development Provisions" at the 13th Ministerial Conference of the WTO, systematically advocating the restructuring of technology transfer and digital tax rules. The core provisions require companies in developed countries to transfer 0.5 percent of global digital business revenue to developing countries and establish a $20 billion digital development fund. Through the inter-regional linkage pressure of the African Union and ASEAN, the proposal forces the EU to extend the transition period for the collection of digital services tax from 2025 to 2027, winning a four-year window for developing countries to catch up on key technologies. At the same time, for the first time, "digital capacity building" is included in the WTO subsidy exception clause, allowing member states to provide financial subsidies of up to 30% for local cloud computing and AI training data centers. This game of rules has increased the participation of developing countries in negotiations on 23 key issues, such as digital tariffs and data sovereignty, from 18% to 41%.

The ASEAN Framework Agreement on the Digital Economy creates the world's first regional sandbox mechanism for data flow and establishes a hierarchical and classified cross-border data pilot system. Singapore and Indonesia jointly carried out a medical data sharing pilot, using dynamic desensitization technology to achieve cross-border anonymization of patient data for AI diagnosis and treatment model training, which increased the response speed of transnational remote consultation by 60%, and the accuracy rate of early lung cancer screening from 72% to 89%. Malaysia and Thailand jointly developed the tropical climate adaptability 5G base station standard, through the sharing of test data and joint certification system, the deployment cost of 5G equipment will be reduced by 19%, and the 5G population coverage of the two countries will jump from 31% to 67% in 2023. Such regional synergies will enable ASEAN digital services trade to grow at an average annual rate of 24% between 2021 and 2023, outpacing the global average by 9 percentage points.

Developing countries are reshaping the power structure of global digital governance through the three-dimensional linkage of mutual recognition of standards, negotiation of rules and regional coordination. According to the United Nations Conference on Trade and Development, between 2020 and 2023, the proportion of international digital technology standards developed by developing countries will rise from 12% to 21%, and the number of joint patent applications in key areas such as cloud computing and the Internet of Things will increase by 137%. This change not only enhances the capacity of technological sovereignty, but also gives rise to a new model of multilateral cooperation - the African Free Trade Area and the South American Union for Progress have established a fast track for mutual recognition of digital rules, and 18 common standards will be mutually recognized across the continent by 2023. The World Trade Organization predicts that by 2030, developing countries will have a substantial share of the initiative in global digital rule-making to 38%, fundamentally changing the unipolar domination of governance.

6.2.3 Enterprise empowerment: activate micro-entities and break through market barriers

Developing countries are compensating for the impact of digital trade barriers through enterprise empowerment[16] Through the National Digital Trade Promotion Plan, Malaysia has systematically guided small and medium-sized manufacturers to access international digital platforms such as Alibaba International Station and Amazon Global Store. The program provides subsidies for the standardization of data interfaces to help companies gain real-time access to global consumer demand heat maps and inventory warning data. Participating Penang electronic component manufacturers have compressed product iterations from 18 months to nine months through platform demand forecasting, while using dynamic pricing modules to achieve an 18% increase in premium rates and an increase in gross export margins to Europe to 32% by 2023. At present, 4,700 smes across the country have

completed the digital transformation of their platforms, reducing the average order response speed by 40%, and increasing the on-time compliance rate of cross-border logistics to 92%.

The Ethiopian Leather Industry Alliance has joined forces with Addis Ababa University in Asia and the China-Africa Digital Silk Road project to build a blockchain data collaboration platform covering the whole industrial chain. The platform synchronizes the latest quality inspection standards of the EU REACH regulation in real time, the design trend data of Milan Fashion Week, and accesses the German TUV certification system. Through the dual-track operation of machine vision quality inspection equipment and blockchain traceability, the defect rate of leather exports to the EU has been reduced from 15% to 4%, and the export unit price has been increased by 28%. In 2023, the proportion of local deep-processed products exceeded 40%, driving the overall added value of the industry to increase by $120 million. The intelligent leather cutting system jointly developed by the members of the alliance has been exported to Kenya and Tanzania through the technology authorization model, creating a new model of regional technology spillover.

The Mexican Digital Trade Agency set up a cross-border compliance service center to integrate 28 international digital regulations such as GDPR and CCPA, and develop automated compliance diagnosis tools. The center provides smes with full process services from data encryption transformation to legal document generation, and the enterprise compliance certification cycle has been reduced from 14 months to 5 months. After participating in the support of Monterrey auto parts suppliers, through the EU data protection certification, the export cost of digital supply chain management services to Germany has been reduced by 38%, and in 2023, there are 12,000 new orders from BMW, Volkswagen and other enterprises, and the proportion of digital service revenue has jumped from 7% to 22%. 83% of smes across the country have obtained at least one international compliance certification through the center, and the cross-border digital services trade deficit has narrowed by 19 percentage points.

The triple constraint mechanism of digital barriers revealed in this study essentially reflects the deep contradiction of the global digital governance system - the structural conflict between technology monopoly and digital sovereignty. The way to break the game in developing countries not only needs to catch up at the technical level, but also needs to build a three-dimensional response system that includes' digital infrastructure - institutional innovation - rule game '. As Mexico's negotiating strategy of offering market access in exchange for technology exemptions shows, policy wisdom can be more strategically valuable than technological breakthroughs in the restructuring of global value chains in the digital age."

Fundings: Key Project of Philosophy and Social Sciences Planning in Zhejiang Province for 2025: Theoretical Mechanism, Effect Testing, and Legal Path Research on the Impact of Digital Tax on Common Prosperity in Zhejiang Province (25NDJC028Z). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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