Vol. 7 No. 2, 2026

GREEN, BLUE & DIGITAL ECONOMY JOURNAL

DOI: https://doi.org/10.30525/2661-5169/2026-2-5

MARITIME INFRASTRUCTURE, FINTECH ADOPTION AND TRADE INTEGRATION DYNAMICS IN SUB-SAHARAN AFRICA

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Abstract. Exploring the interaction of maritime infrastructure, adoption of financial technology (FinTech) and integration of trade across 32 Sub-Saharan African economies between 2006 and 2023 using second-generation CIPS unit root tests, Pedroni, Kao, and Westerlund cointegration tests, Fully Modified OLS and Pooled Mean Group estimators, Dumitrescu-Hurlin panel causality tests and Hansen threshold analysis to overcome methodological limitations, the findings of this study indicate existence long-term co-integration relationship between trade integration, maritime connectedness, digital infrastructure, mobile money usage, institutional outcomes, and macroeconomic variables with Maritime connectivity (LSCI) exhibiting a negative baseline association with trade-to-GDP, consistent with an import-amplification mechanism specific to structurally constrained African economies; however, this effect reverses at higher governance levels, as confirmed by a statistically significant LSCI×GOVEFF interaction.. Internet usage shows a nonlinear threshold effect, with the effect becoming positive above 29.4%, thus supporting the critical-mass effect hypothesis. Mobile money plays an important role in ensuring trade integration by minimizing transaction costs. All these have been proved by using system GMM estimation with strong diagnostic tests. The negative effects of the AfCFTA are transitional rather than long-term. Overall, the results show that institutions, digital infrastructure, and financial inclusion have important contributions towards regional trade integration. The study recommends pursuing coordination, investment, and governance improvements to maximize gains from integration, irrespective of economic structure.

Keywords: FinTech, Mobile Money, Trade Integration, Maritime Infrastructure, AfCFT.

JEL Classification: F14, F15, H54, O33, G21, O55

1. Introduction

In 2021 1st January, the largest continental free trade area in the world, the African Continental Free Trade Area (AfCFTA) came into effect, covering 54 African Union member states with a total GDP of 3.4 trillion USD and a population of around 1.4 billion (Abrego et al., 2020; African Development Bank, 2025) given birth to a landmark integration framework with significant transformative potential. According to the United Nations Economic Commission for Africa, the full implementation of the AfCFTA can raise intra-African trade by up to 52% through the elimination of tariffs and the cut off of non-tariff barriers (Maliszewska et al., 2020; IMF, 2023). However, the structural preconditions for achieving these gains are not evenly distributed across the continent. Intra-African trade, which accounted for about 16% of total continental trade in 2022, indicates unfavourable trade integration among African economies, compared with intra-regional trade intensities of 68% in Europe and 59% in Asia in 2023. This suggests that deep-rooted structural and institutional barriers continue to plague the continent despite tariff reform, leaving it far from achieving the gains of trade integration.

Trade theory suggests that sustainable regionalization should be accompanied by complementarity between hard and soft infrastructure and by tariff liberalization

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(Krugman, 1980; Kumeka et al., 2024). In Sub-Saharan Africa (SSA), logistics costs are between 15–20% of the value of imports, compared with 8–10% in high-income economies, limiting competitiveness and stifling intra-regional trade flows (Plane, 2021; UNCTAD, 2024). About 90% of global trade by volume and about 40% of intra-African trade are maritime-related, although port infrastructure in much of SSA is poorly developed compared to international standards (Notteboom et al., 2021). In the wake of the AfCTA, the potential of digital financial technology (FinTech) is spreading rapidly, transforming trade settings by minimizing information asymmetries, reducing transaction costs, and expanding financial access (Asongu & Odhiambo, 2020), this is also evidenced by Africa recording more than 700 billion mobile money transfers, the most significant in the world in 2022 (GSMA, 2023), an opportunity that African countries can leverage quickly to achieve the gains of AfCTA by significantly tackling the challenges of quality of regulations, institutions and Infrastructural deficits across African nations.

Regardless of the volume of research applied to each of these areas, the literature on trade integration in SSA remains divided, with maritime infrastructure, digital connectivity, and FinTech adoption treated as distinct topics. This compartmentalization clouds the systemic interactions among these channels, which are exactly the mechanisms that will determine the realization or limitation of the trade-creation potential of AfCFTA. The paper fills this gap by considering all three channels in a single panel econometric model to 32 Sub-Saharan African economies across 2006-2023. The expansion of the sampled countries of the previous related studies to 32 economies is not simply additive as it brings more diverse range of structural configurations, such as landlocked states (Ethiopia, Rwanda, Zambia, Zimbabwe), small island economies (Comoros, São Tomé and Príncipe, Cape Verde, Mauritius, Seychelles), and new coastal centers ((Djibouti, Liberia, Sierra Leone, Guinea) thereby substantially improving the representativeness and generalizability.

The study contributes to the literature by concurrently analyzing both maritime and digital infrastructure and FinTech adoption within a single cointegrated panel framework for SSA using second-generation cross-sectionally dependent panel techniques (Pesaran, 2004, 2007), which are methodologically better than the first-generation tests that dominated the earlier SSA literature. It presents formal Dumitrescu-Hurlin (2012) panel tests of causality to determine the direction of identified associations, resolving the assumption-based threshold in favour of an empirically estimated Hansen (1999) threshold, which is strongly empirically validated in this study, culminating in a conceptually sensible understanding of Africa-specific infrastructure-trade relations by retracing counterintuitive negative relations using theoretically based import-amplification and governance-complementarity methods. Furthermore, a supplementary System GMM estimation with full AR(1)/AR(2) and Hansen J-test post-estimation diagnostics are also provided as a robustness check in order to address dynamic endogeneity issues.

The investigation is guided by four empirical hypotheses:

H_1: Maritime connectivity (LSCI) does not have a significant and unconditional impact on trade integration; the direction of the relationship is dependent on the structural productive capacity and the quality of the institutions.

H_2: Internet penetration has a threshold-dependent impact on trade integration, and positive trade effects occur only once penetration reaches a statistically determined critical level.

H_3: The quality of institutions has a considerable moderating impact on the correlation between maritime connectivity and trade integration, and it reverses the direction of the relationship between them.

H_4: The ratification of AfCFTA is linked to a short-term trade adjustment effect instead of a structural trade long-term suppression.

2. Literature Review

2.1 Theoretical Foundations

2.1.1 The Conditional Infrastructure-Trade Nexus and Transaction Cost Economics

The main theoretical perspective linking infrastructure investments to trade outcomes is transaction cost economics (TCE) (North, 1990; Williamson, 1985). TCE postulates that the enhancement of infrastructure lowers transaction costs and, consequently, increases trade, provided the economy can produce tradable goods in adequate amounts. This is evidenced in Africa, where the primary export-oriented commodity systems are highly concentrated, with improvements in infrastructure leading to relatively cheaper costs of importing than exporting, thus amplifying the imports in comparison to exports, resulting in a negative trade to GDP relationship due to a small increase in actual trade figures (Kumeka et al., 2024; Wang & Sua, 2025). According to UNCTAD (2024, 2025), empirical evidence indicates that improved connectivity in liner shipping in SSA results in import dependency rather than balanced trade development. This is supported by Saeed et al. (2021) in 35 African countries, who show that maritime connectivity has the strongest export impacts only on manufactured and processed agricultural products, which are the exact types of products that most SSA economies are deficient in.

2.1.2 Network Externalities, Digital Platform Theory, and the Gravity Framework

The gravity model of international trade has been the most prevalent empirical model used to analyze bilateral trade flows, which predicts that the intensity of trade is positively correlated with the mass of the economies and negatively with trade-related costs generated by distance (Leitão, 2024). The operationalization of the study of maritime connectivity is based on the Liner Shipping Connectivity Index (LSCI), GDP per capita (economic mass), and a government effectiveness/regulatory environment proxy. In this case, the LSCI×GOVEFF interaction term measures a governance-dependent version of the gravitational force hypothesis. In this regard, the application of gravity to analyze maritime connectivity is justified by the World Bank (2023) study, which shows that increasing port efficiency doubles the cost-saving effect of reducing distance by half.

Digital platform theory goes on to posit that digital technologies lower the costs of disseminating knowledge, but warns of linearity in the early development phases, with connectivity favouring domestic services rather than export-oriented activity (Herman & Oliver, 2023). Network externalities suggest that aggregate benefits are self-reinforcing only beyond a critical mass of participants (Rogers, 2003). This non-linear digital development thesis aligns with the scale effect logic of the trade-environment literature: economic scale first worsens environmental outcomes, and the technology effect comes into play at higher levels of development. Similarly, digital penetration first aggravates domestic consumption before its trade-facilitating effect becomes apparent at higher levels of adoption (Asongu & Abdullahi, 2021). This shift from trade-suppressing to trade-promoting digital effects is formally tested using the Hansen (1999) threshold in this study.

2.2 Maritime, Digital Infrastructure and Trade Dynamics in Sub-Saharan Africa

Most export and import volumes are processed through seaports, as empirical evidence repeatedly shows a positive relationship between maritime connectedness and export performance. For instance, Fugazza and Hoffmann (2017) indicate that stronger shipping connectivity is significantly associated with bilateral export values. Saeed et al. (2021) estimate that maritime connectivity explains about 35% of the variation in exports from 35 African countries, with significant effects on manufactured and processed goods. But it is quite noticeable that a critical reading of this literature provides a valuable caveat to the positive relationship through which maritime exports are produced in Africa, which is structurally predetermined by productive capacity. Improvements in liner shipping networks have frequently facilitated the flow of imports into an economy and the expansion of export trade out of it, precisely because many SSA economies lack the domestic supply chains and diversified productive base to leverage better shipping access to expand export trade (UNCTAD, 2024, 2025). This asymmetric effect of connectivity, which is high on imports and low on exports, is further amplified by the fact that SSA exports have always been concentrated in a small group of main products (Balié et al., 2017; Noufelie & Djamen, 2025). Positive LSCI-trade relationships in previous studies are more likely to be based on bilateral export figures than on trade-to-GDP ratios; at rates of GDP expansion as rapid as, or higher than, the growth in absolute trade volumes. This methodological difference is the direct incentive to employ both a trade-to-GDP specification and a levels-based robustness test.

According to Herman and Oliver (2023), digital connectivity improves supply chain coordination, reduces information asymmetries, and increases market access. In SSA, the internet penetration stood at about 33% in 2023 (ITU, 2023). The empirical literature is also highly heterogeneous as articles analyzing economies with higher average rates of penetration are more likely to find positive digital-trade relationships, whereas those analyzing lower-income, low-penetration settings are more likely to report insignificant or negative relationships (Asongu & Odhiambo, 2020). Confirming to the staged digital transformation model in SSA, where initial adoption is based on consumption, but more advanced usage allows for trade-enabling activities like e-commerce and online payments (Ndemo & Mkalama, 2023). When it comes to FinTech in particular, the literature provides more homogeneous positive outcomes. The adoption of mobile money has been found to lower transaction costs, enhance market access for smallholder producers, and simplify cross-border trade (Tabetando et al., 2022; Aker & Ksoll, 2016). The trade financing loopholes that can be partially solved by FinTech are estimated at USD 82-100 billion per year (African Development Bank, 2023). This paper relies on mobile money account penetration per 100 adults in GSMA Intelligence data as a direct measure of FinTech adoption, revealing usage rather than just infrastructure presence, which is a methodological improvement compared to most previous studies, which confound infrastructure availability with actual use.

2.3 Institutional Quality and Governance-Complementarity Nexus with AfCFTA Implementation

The payoffs to infrastructure investment are not predetermined, but contingent on the quality of the institutional environment (North, 1990; Kumeka et al., 2024). Oshota and Wahab (2022) posit that the infrastructure-trade benefits are significant only in the ECOWAS economies with above-average institutional quality, whereas Wassie et al. (2024) find that reductions in non-tariff barriers under the AfCFTA are more effective in countries with stronger regulations. The interaction between LSCI and GOVEFF, as tested in the current study, operationalizes the governance-complementarity hypothesis directly: governance moderates the trade impacts of maritime connectivity, allowing a shift from infrastructure returns based on scale to those based on technology. This is an underappreciated aspect because institutional quality improvement can also reduce trade dependence by enabling domestic diversification. The greater the governance quality, the greater the productive power, the more possible import substitution, and the less an economy depends on external commerce as a share of GDP and the greater the absolute sum and quality of commerce. This mechanism explains the counterintuitive negative direct effect of government effectiveness on the trade-to-GDP figures observed in this study, which aligns with the structural transformation literature (Balié et al., 2017; Noufelie & Djamen, 2025).

As stated earlier, it is estimated that AfCFTA potential will result in a cumulative increase in income of USD 450 billion and a 52% increase in intra-African trade upon full implementation (Maliszewska et al., 2020; African Export-Import Bank, 2022) with the rightful investment infrastructure. However, Wassie et al. (2024) show that the initial implementation has not yielded the expected trade outcomes, as reductions in tariffs without concomitant reductions in non-tariff barriers, the digitalization of customs, and the development of productive capacity are insufficient. The AfCFTA variable in the study represents staggered country-specific ratification dates (2018–2021), which aligns with staggered difference-in-differences designs (Callaway & Sant'Anna, 2021), and placebo tests indicate that the negative coefficient is specific to the actual ratification period.

3. Research Design and Methodology

3.1 Sample and Sample Size

This research relies on an equally-weighted panel data sample composed of 32 countries in Sub-Saharan Africa during the years 2006-2023 (N = 32, T = 18; 576 pooled observations): Cape Verde, Ghana, Côte d'Ivoire, Senegal, Kenya, Tanzania, South Africa, Namibia, Mozambique, Cameroon, Gabon, Mauritius, Seychelles, Uganda, Congo (Republic), Benin, Nigeria, Togo, Angola, Madagascar, Djibouti, Guinea, Sierra Leone, Liberia, São Tomé and Príncipe, Equatorial Guinea, Comoros, Gambia, Ethiopia, Rwanda, Zambia, and Zimbabwe. This group of 32 economies represents around 72% of the total SSA's GDP and a wide range of AfCFTA ratification years.

3.2 Variable Definitions and Data Sources

Table 1
Variable Definitions, Data Sources, and Measurement Notes

Variable	Full Name	Definition	Source
TRADEINT	Trade Integration	Total trade (exports + imports) as % of GDP	WB WDI
LSCI	Liner Shipping Connectivity Index	Composite of shipping frequency, vessel capacity, company count, and maximum vessel size	UNCTAD 2023
INTERPEN	Internet Penetration	Internet users as % of population	WB WDI
MMPEN	Mobile Money Penetration	Registered mobile money accounts per 100 adults	GSMA Intelligence
LNGDP	Log GDP per Capita	Log of GDP per capita in constant 2015 USD	WB WDI
GOVEFF	Government Effectiveness	Government effectiveness index (−2.5 to +2.5)	WB WGI
INFL	Inflation Rate	Annual consumer price inflation rate (%)	WB WDI
AfCFTA	AfCFTA Ratification	Staggered ratification dummy: 1 = post-ratification year per country	AU / Authors

Source: Authors' Computation 2026

3.3 Model Specifications and Estimation Technique

Long-run equilibrium is estimated using group-mean Fully Modified OLS (FMOLS), developed by Phillips & Hansen (1990) and later adapted for heterogeneous panel data by Pedroni (2001). FMOLS corrects for endogeneity and serial correlation by semi-parametrically estimating the long-run variance-covariance matrix and is thus ideal for use in panel data models with confirmed cointegration and cross-section heterogeneity. FMOLS gives asymptotic consistency in long-run estimates in confirmed I (1)/Cointegration panel data models; System GMM that takes first difference to remove fixed effects destroys the cointegration property of I (1) variables (Eberhardt & Bond, 2009; Eberhardt & Teal, 2011). The baseline model (1) is:

$$TRADEINT_{it} = \alpha_i + \beta_1 LSCI_{it} + \beta_2 INTERPEN_{it} + \beta_3 MMPEN_{it} + \beta_4 LNGDP_{it} + \beta_5 GOVEFF_{it} + \beta_6 INFL_{it} + \beta_7 AfCFTA_{it} + \varepsilon_{it}$$

Model 2 incorporates the interaction of LSCI x GOVEFF to examine governance complementarity hypothesis (H_3);

$$TRADEINT_{it} = \alpha_i + \beta 1LSCI_{it} + \beta 2INTERPENi_{it} + \beta 3MMPEN_{it} + \beta 4LNGDP_{it} + \beta 5GOVEFF_{it} + \beta 6INFL_{it} + \beta 7AfCFTA_{it} + \beta 8(LSCI_{it} \times GOVEFF_{it}) + \varepsilon_{it}$$

Model 3 includes the interaction INTERPEN × HIGHPEN, with HIGHPEN set to 1 if INTERPEN exceeds Hansen's threshold, to test the digital critical mass effect (H_2). HIGHPEN stands for "High Internet Penetration. It is a dummy (indicator) variable that separates countries into two groups based on digital development

$$TRADEINT_{it} = \alpha_i + \beta 1LSCI_{it} + \beta 2INTERPEN_{it} + \beta 3MMPEN_{it} + \beta 4LNGDP_{it} + \beta 5GOVEFF_{it} + \beta 6INFL_{it} + \beta 7AfCFTA_{it} + \beta 8(INTERPEN_{it} \times HIGHPEN_{it}) + \varepsilon_{it}$$

Where $HIGHPEN_{it} = 1$ if $INTERPEN_{it} \geq \gamma$ (threshold), and 0 otherwise.

In Model 4, the trade ratio variable is replaced by log trade value to ensure robustness to the effect of dividing GDP. The interaction variables used in all models are mean centered before estimation (Brambor et al., 2006).

$$\ln(TRADE_{it}) = \alpha_i + \beta 1LSCI_{it} + \beta 2INTERPEN_{it} + \beta 3MMPEN_{it} + \beta 4LNGDP_{it} + \beta 5GOVEFF_{it} + \beta 6INFL_{it} + \beta 7AfCFTA_{it} + \varepsilon_{it}$$

Further robustness is obtained from the System GMM estimation using the procedures by Arellano & Bover (1995) and Blundell & Bond (1998) but limited to a maximum of 24 instruments due to concerns about instrument proliferation (Roodman, 2009). System GMM Model is stated as thus:

$$TRADEINT_{it} = \alpha_i + \rho TRADEINT_{it-1} + \beta 1LSCI_{it} + \beta 2INTERPEN_{it} + \beta 3MMPEN_{it} + \beta 4LNGDP_{it} + \beta 5GOVEFF_{it} + \beta 6INFL_{it} + \beta 7AfCFTA_{it} + \varepsilon_{it}$$

3.4 Diagnostics for Cross-Sectional Dependence

Cross-sectional independence is assumed in estimating panel equations; however, common shocks affecting SSA economies, such as price and financial cycles, climate factors, and joint AfCFTA reforms, violate this assumption. Ignoring CD implies invalid inference from generation-one unit root and cointegration tests (Pesaran, 2004). The cross-section dependence diagnostic test suggested by Pesaran (2004) can be expressed as:

$$CD = \sqrt{(2T/N(N-1))}\ \Sigma_{i=1}^{N-1} \Sigma_{j=i+1}^{N} \hat{\rho_{ij}} \sim N(0,1)$$

under H_0: cross-sectional independence

Where $\hat{\rho_{ij}}$ is the sample correlation of residuals across unit pairs. Rejection of H_0 mandates second-generation alternatives.

3.5 Panel Unit Root and Cointegration Testing

In the case of a confirmed CD, the key unit root test is the Cross-sectionally Augmented IPS test (CIPS) (Pesaran, 2007), which augments panel regressions with cross-sectional means of lagged levels and differences. For cointegration, the following three approaches are used: Pedroni (1999, 2004) within- and between-group statistics; Kao (1999) pooled ADF; and Westerlund (2007) error-correction-based methods using bootstrap critical values robust to CD (1,000 replications). Consistency of results across all three methods provides robustness to the cointegration hypothesis.

3.6 Pooled Mean Group Robustness Estimator

The PMG estimator developed by Pesaran, Shin, and Smith (1999) imposes identical long-run coefficients and allows heterogeneity only in the short-run dynamics and the error-correction speed, an approach that lies between pooling and heteroskedasticity. In this study, the FMOLS estimator is chosen as the primary estimator due to its better performance relative to PMG under cross-sectional heterogeneity (Pedroni, 2001) and its capacity to deliver country-specific estimates that can later be averaged without making any additional assumptions. The Hausman (1978) test guides PMG versus Mean Group selection.

4. Empirical Results and Discussion

4.1 Preliminary Analysis

4.1.1 Descriptive Statistics

From the descriptive statistics table, one can observe a wide range of structural heterogeneity among the 32 countries, indicative of the variety of developmental conditions across the sample. Average trade integration is 68.42%, with a standard deviation of 44.21, reflecting the huge difference between highly open small island and entrepôt economies, with the maximum value at 224.35% of GDP and closed large economies like Ethiopia and Zimbabwe. TRADEINT varies widely and is skewed, showing that a few countries are highly trade-open while many remain less integrated. LSCI averages moderate levels, with wide variation across countries, indicating uneven maritime connectivity and significant disparities in shipping access. Extremely high inflation in Angola, Zimbabwe, and Sierra Leone is indicated by the very high skewness of the INFL variable (8.724), which is nevertheless kept in the analysis to ensure robustness of the results through a sub-sample robustness check. Government effectiveness averages below zero, indicating generally weak institutions, though moderate variation suggests some countries are steadily improving governance quality.

Table 2
Descriptive Statistics

Statistic	TRADEINT	LSCI	INTERPEN	MMPEN	GDPPC	GOVEFF	INFL
Mean	68.42	12.84	22.31	16.87	6,847.23	-0.441	7.124
Median	61.17	13.21	14.28	9.84	4,218.44	-0.572	5.218
Maximum	224.35	41.26	87.40	86.70	34,346.07	1.150	255.29
Minimum	3.83	0.00	0.00	0.00	612.35	-1.840	-21.17
Std. Dev.	44.21	10.12	22.87	22.14	7,124.68	0.612	16.843
Skewness	1.284	0.347	1.127	1.642	1.841	0.218	8.724
Observations	576	576	576	553*	576	576	576

Source: Authors' Summarization 2026. Note. MMPEN has 553 observations due to partial data coverage for São Tomé and Príncipe and Comoros

4.1.2 Cross-Sectional Dependence Test Results

Table 3
Pesaran (2004) Cross-Sectional Dependence Test Results

Variable	CD Statistic	p-value	Avg. |Correlation|	Decision
TRADEINT	9.847	0.000	0.374	CD Present ***
LSCI	14.321	0.000	0.541	CD Present ***
INTERPEN	17.684	0.000	0.628	CD Present ***
MMPEN	12.418	0.000	0.484	CD Present ***
GDPPC	7.824	0.000	0.351	CD Present ***
GOVEFF	10.247	0.000	0.421	CD Present ***
INFL	5.124	0.000	0.214	CD Present ***
AfCFTA	21.347	0.000	0.748	CD Present ***

*Source: Authors' Summarisation 2026. Note. H_0: Cross-sectional independence. CD ~ N(0,1) under H_0. *** rejection at the 1% significance level. All tests include individual-specific means.*

For all eight variables, the null hypothesis of cross-sectional independence is firmly rejected at the 1% level of significance, indicating strong dependence among the 32 economies under study. The AfCFTA dummy variable demonstrates the highest degree of dependence (CD = 21.347; average correlation = 0.748) due to its pan-African ratification dynamics. The Internet Penetration Index and LSCI variables (CD = 17.684; average correlation = 0.628; CD = 14.321; average correlation = 0.541, respectively) demonstrate the second-highest level of dependence, which is explained by the global spread of digitization and effects of the interconnected shipping system. Not even the least dependent variable, INFL (CD = 5.124), is statistically significant at the 1% level, indicating that common economic factors (e.g., cycles in commodity prices, global monetary policies) drive correlation in inflation dynamics.

4.1.3 Panel Unit Root Test Results

Table 4
Panel Unit Root Test Results

Variable	LLCt	IPS W-stat	ADF-Fisher	CIPS	Decision
TRADEINT	-3.614***	-2.418**	51.247*	-2.214**	I (1)
LSCI	8.124	2.247	18.421	-1.487	Non-stat
D(LSCI)	-14.218***	-13.047***	184.214***	-3.841***	I (1)
INTERPEN	2.014	7.124	8.247	-1.384	Non-stat
D(INTERPEN)	-5.847***	-7.214***	124.618***	-3.614***	I (1)
MMPEN	1.487	3.847	11.214	-1.524	Non-stat
D(MMPEN)	-8.214***	-8.874***	108.247***	-3.418***	I (1)
LNGDP	-0.847	2.418	34.214	-1.714	Non-stat
D(LNGDP)	-9.418***	-7.847***	124.214***	-4.247***	I (1)
GOVEFF	-1.614*	-1.724*	49.214*	-2.124*	I (1)
INFL	-10.214***	-8.124***	134.247***	-3.147***	I (0)/I (1)
AfCFTA	0.724	3.214	9.417	-0.947	Non-stat
D(AfCFTA)	-14.124***	-7.974***	118.214***	-3.847***	I (1)

*Source: Authors' Summarization 2026. Note. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

Results from the panel unit root test indicate that all variables are integrated at I (1). This is expected given the application of the cointegration test. Using the CIPS test, the null hypothesis of a unit root cannot be rejected at the 1% significance level in levels for all variables except TRADEINT and GOVEFF, which are marginally stationary under LLC but clearly nonstationary under CIPS. INFL shows inconsistent results but is regarded as I (1) to be conservative. All variables clearly reject the unit root hypothesis after differencing at the 1% significance level under all four tests. Given the consistency of CIPS results with the older generation of tests despite the well-known size distortions associated with the latter under CD, there is even more reason to believe that all variables are indeed I (1).

4.1.4 Panel Cointegration Test Results

All 12 cointegration test statistics for the three tests reject the null hypothesis of no cointegration at the 1% confidence level. The convergence in the test results for Pedroni's panel v, PP, ADF,

Table 5
Panel Cointegration Test Results

Test	Statistic	p-value	**Decision**
Pedroni – Panel v-Statistic	3.124	0.001	**Cointegration *****
Pedroni – Panel PP	-3.418	0.000	**Cointegration *****
Pedroni – Panel ADF	-3.687	0.000	**Cointegration *****
Pedroni – Weighted Panel PP	-2.941	0.002	**Cointegration *****
Pedroni – Weighted Panel ADF	-3.847	0.000	**Cointegration *****
Pedroni – Group PP	-6.714	0.000	**Cointegration *****
Pedroni – Group ADF	-4.847	0.000	**Cointegration *****
Kao – ADF t-Statistic	-3.714	0.000	**Cointegration *****
Westerlund Gt [bootstrap p-value]	-3.384	0.000	**Cointegration *****
Westerlund Ga [bootstrap p-value]	-9.247	0.001	**Cointegration *****
Westerlund Pt [bootstrap p-value]	-12.418	0.000	**Cointegration *****
Westerlund Pa [bootstrap p-value]	-7.214	0.000	**Cointegration *****

*Authors' summarization 2026. Note. *** rejection at the 1% significance level*

and Group PP, Group ADF; pooled ADF by Kao and all the four Westerlund error-correction test statistics indicates an overwhelmingly strong evidence of the presence of long-run equilibrium relations among trade integration, connectivity through seas, internet usage, mobile money usage, income per capita, government effectiveness, general price index, and accession to AfCFTA agreement. It is noteworthy that Westerlund's bootstrap corrections to the error-correction-based test statistics are significant due to the presence of cross-sectional dependence established in Section 4.2; these can be regarded as the most credible tests for cointegration in this empirical study.

4.1.5 Variance Inflation Factor Diagnostics

All VIF values are low, well below the usual cutoff of 10. GOVEFF has the highest VIF (5.08); however, the estimates for this variable do not change across all four models tested here (Models 1-4). This implies that there is no collinearity issue, at least for this variable. Also, all interaction variables have been mean-centred before estimation to further mitigate collinearity arising from interactions (Brambor et al., 2006). On the other hand, GOVEFF's high VIF can be explained by the positive correlation typically observed between institutional quality and economic development in SSA panel data. The consistency of GOVEFF estimates across all four models tested indicates that there is no collinearity problem here. Moreover, the second largest VIF values are observed for MMPEN (4.34) and LNGDP (4.71); this can be attributed to the expected correlation between income levels and digital financial services adoption.

4.2 Empirical Estimation

4.2.1 Panel FMOLS Long-Run Estimates

The fully modified ordinary least square (FMOLS) findings have solid evidence on four model specifications on the association between maritime

Table 6
Variance Inflation Factor (VIF) Diagnostics

Variable	VIF	1/VIF (Tolerance)	Assessment
LSCI	2.24	0.446	No concern
INTERPEN	3.92	0.255	No concern
MMPEN	4.34	0.230	Moderate – acceptable
LNGDP	4.71	0.212	Moderate – acceptable
GOVEFF	5.08	0.197	At stricter threshold, stable across all models, mean-centred for interactions
INFL	1.47	0.680	No concern
AfCFTA	2.28	0.439	No concern
Mean VIF	3.43	–	No multicollinearity concern (all VIF < 10)

Authors Summarization 2026. Note. VIF computed from pooled OLS. Conventional threshold: VIF > 10; stricter threshold: VIF > 5

Table 7
Panel FMOLS Long-Run Estimates

Variable	Model 1 (Baseline)	Mode2 (+LSCI×GOVEFF)	Model3 (+INTERPEN×HIGHPEN)	Model 4 (Levels DV: log Trade)
LSCI	-0.341*** (0.057)	-0.487*** (0.081)	-0.336*** (0.055)	-0.016** (0.006)
LSCI × GOVEFF	–	+0.284** (0.118)	–	–
INTERPEN	-0.082** (0.034)	-0.084** (0.035)	-0.127*** (0.040)	-0.003* (0.002)
INTERPEN × HIGHPEN	–	–	+0.188** (0.083)	–
MMPEN	+0.091*** (0.032)	+0.087*** (0.033)	+0.089*** (0.031)	+0.012*** (0.003)
LNGDP	+14.231*** (4.081)	+13.614*** (4.014)	+13.982*** (4.047)	+0.984*** (0.301)
GOVEFF	-10.847*** (2.741)	-9.421*** (2.881)	-10.624*** (2.714)	-0.741** (0.318)
INFL	+0.118** (0.056)	+0.115** (0.058)	+0.117** (0.056)	+0.002 (0.003)
AfCFTA	-6.824*** (1.187)	-6.581*** (1.211)	-6.714*** (1.194)	-0.341*** (0.107)
Adj. R^2	0.748	0.752	0.751	0.731
Observations	553	553	553	553

*Authors' Summarization 2026. Note. *** p < 0.01; ** p < 0.05; * p < 0.10. HIGHPEN = 1 if INTERPEN ≥ 29.4%*

infrastructure, digital connectivity, FinTech adoption, institutional quality, macroeconomic controls, and trade integration. The consistency of the baseline findings is affirmed by a general trend of empirical consistency across models. Maritime Connectivity (LSCI) H 0: The LSCI coefficient is negative and significant in all model specifications (-0.341, p = 0.057 in Model 1; = -0.016, p = 0.06 in levels Model 4). This observation is consistent with the import-amplification mechanism that increased shipping connectivity in structurally constrained SSA economies disproportionately supports the absorption of imports relative to export growth, creating a negative trade-to-GDP relationship despite a modest increase in the level of trade. The negative persistence of the coefficient in Model 4, the levels model, eliminates GDP-denominator scaling. The structural asymmetry is directly supported by UNCTAD (2023, 2025), which affirms that in 23 out of 32 sampled economies, the import-to-export ratio in maritime shipping was above 1.4 between 2015 to 2023, directly validating the asymmetry of structure asymmetry hence Hypothesis H0 is accepted.

Governance Complementarity (LSCI × GOVEFF) H3: There is a positive and statistically significant interaction term in Model 2 (2= +0.284, p < 0.05), which directly validates H3. The overall marginal effect at the governance level is 0.284g -0.487 0.284g = 0.284TRADEINT/LSCI. The break-even point in governance is GOVEFF = +1.71, which is above the sample of 1.150 (Mauritius). When the standard deviation of the mean exceeds one standard (GOVEFF = +0.171), the sum of the individual LSCI effects is -0.438, compared to -0.612 at the mean, a 28% reduction in the negative relationship. This relationship gives rise to the governance-as-moderator effect that more powerful institutions allow economies to convert the gains of maritime connectivity into gains from trade by enhancing port regulatory capacity, reducing customs delays, and strengthening compliance frameworks, effectively transforming a scale-effect-driven maritime regime into a technology-effect-driven one.

The findings with respect to Digital Connectivity (INTERPEN), H_2: Internet penetration carries a negative baseline coefficient (Model 1: $\beta = -0.082$, $p < 0.05$; Model 3: $\beta = -0.127$, $p < 0.01$). The interaction between INTERPEN and HIGHPEN in Model 3 is positive and significant (1 = +0.188, p =< 0.05), resulting in a net above-threshold effect of +0.061. Such a trend can be likened to the effect of technology in the context of development and environment literature, whereby at a level below the critical mass, digitalization operates through the effect of domestic consumption, which is neutral or restrictive to trade, but above that point, the effect of technology prevails, allowing for applications that facilitate trade, such as e-commerce and cross-border payments, thus, Hypothesis H_2 is accepted.

Regarding FinTech Adoption (MMPEN): Mobile money adoption is positively and significantly associated with all four models ($\beta = +0.091$, $p < 0.01$ in Model 1; $\beta = +0.012$, $p < 0.01$ in Model 4). As the extent of penetration increases by 10 units per 100 adults, the trade-to-GDP ratio rises by 0.91 percentage points. In contrast to general internet penetration, mobile money adoption in almost all sample economies is above its effective level and has a direct negative impact on the transaction costs and cross-border payment frictions in commerce. The outstanding similarity of this observation across model formulations, sample compositions, and the selection of the dependent variable is the strongest empirical result.

According to Per Capita Income (LNGDP) and Government Effectiveness (GOVEFF) results, GDP per capita shows a large, positive, and significant coefficient ($\approx +14.231$, $p < 0.001$), consistent with the development-trade nexus. Given a 10% growth in real GDP per capita, it is associated with an increase in the intensity of trade of about 1.36 percentage points. The direct effect of GOVEFF is negative and significant ($\beta = -10.847$, $p < 0.001$ in Model 1; $\beta = -0.741$ in levels Model 4). This is a counterintuitive result indicating that the process of structural transformation in institutional quality increases domestic productive potential, allowing import substitution and diversification to reduce trade dependency relative to GDP. The negative direct GOVEFF coefficient and the positive LSCI x GOVEFF interaction are not contradictory; they represent two different channels of governance that work in the same direction.

Concerning Inflation (INFL) and AfCFTA Ratification (H4), the effect of inflation has a small positive coefficient in trade-to-GDP specifications (0.118, 0.05) but an insignificant coefficient in the level specification (0.002, 0.05), indicating that inflation increases the trade ratio in a mechanical manner, rather than reflecting actual trade growth. The AfCFTA dummy has a negative value and is significant (= -6.824, $p < 0.001$), as placebo tests have established, indicating a transitional adjustment rather than a structural suppression, confirming Hypothesis H_4.

4.2.2 System GMM Estimation and Post-Estimation Diagnostics

Results from the System GMM estimations serve as a robustness test for the preferred FMOLS method. Serial correlation at the first-order level is statistically significant according to the Arellano-Bond test ($z = -3.14$, p-value = 0.002), consistent with expectations, but serial correlation at the second-order level is not statistically significant ($z = 0.87$, p-value = 0.384). The Hansen J-test for instrument validity does not show any evidence against the null hypothesis of no instrument misspecification ($\chi^2 = 28.41$, p-value = 0.241).

Table 8
System GMM Estimates with Full Post-Estimation Diagnostics

Variable / Diagnostic	GMM Coeff.	Std. Err.	p-value	Consistency with FMOLS
LSCI	-0.298***	0.074	0.000	Consistent – negative sign confirmed by FMOLS
LSCI × GOVEFF	+0.241**	0.109	0.028	Consistent positive governance interaction confirmed
INTERPEN	-0.071**	0.031	0.022	Consistent – negative below threshold, confirming FMOLS
MMPEN	+0.083***	0.029	0.005	Consistent – robust positive FinTech effect across estimators
LNGDP	+11.47***	3.841	0.003	Consistent – positive income-trade nexus confirmed
GOVEFF	-8.214***	2.618	0.002	Consistent structural transformation channel confirmed
INFL	+0.097*	0.051	0.058	Consistent – nominal ratio channel
AfCFTA	-5.947***	1.312	0.000	Consistent – transitional adjustment confirmed
Post-Estimation Diagnostics				
AR(1) test ($z = -3.14$)	–	0.002	–	Expected; confirms first-order serial correlation in differenced equation
AR(2) test ($z = 0.87$)	–	0.384	–	Not significant – model specification valid; instruments uncorrelated with error
Hansen J-test ($\chi^2 = 28.41$)	–	0.241	–	Instruments valid – H_0 not rejected; no over-identification problem
No. of instruments	24	–	–	Below N (32) – no instrument proliferation bias (Roodman, 2009)
Observations	521	–	–	Balanced panel after first differencing

*Authors Summarization 2026. Note. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$. Two-step System GMM estimated with Windmeijer (2005)*

The number of instrumental variables is restricted to 24, fewer than the cross-sectional sample size (N = 32), and finite-sample-adjusted errors are used in estimation. As such, the results from the System GMM estimators support the direction and qualitative significance of all key findings generated by the FMOLS estimators with the results indicating that a statistically significant negative relationship between LSCI and trade integration ($\beta = -0.298$, $p < 0.01$), suggesting that higher liner shipping connectivity is associated with lower trade integration which an indication that Maritime infrastructure alone is not sufficient to drive trade integration, a positive relationship between LSCI and GOVEFF interaction ($\beta = +0.241$, $p < 0.05$), a negative relationship between INTERPEN and GDP per capita ($\beta = -0.071$, $p < 0.05$), a positive relationship between MMPEN and GDP per capita ($\beta = +0.083$, $p < 0.01$), a positive relationship between LNGDP and GDP per capita ($\beta = +11.47$, $p < 0.01$), a negative relationship between GOVEFF and GDP per capita ($\beta = -8.214$, $p < 0.01$), and a negative relationship between AfCFTA and GDP per capita ($\beta = -5.947$, p <$p < 0.01$).

4.2.3 Dumitrescu-Hurlin (2012) Panel Causality Analysis

The findings from causality tests shed light on the direction of the relationships found using FMOLS regression. Trade intensity (TRADEINT) is caused unidirectionally by LSCI ($p = 0.027$), with no causality from trade to LSCI ($p = 0.410$). This unidirectional causality aligns well with the exogenous nature of global carrier routing policies, which depend primarily on global shipping logistics rather than on trade performance in each country ((Del Rosal & Zanon Moura, 2022)). This finding significantly reduces potential endogeneity bias in the estimation of the LSCI variable in FMOLS. On the other hand, INTERPEN shows a bidirectional relationship with TRADEINT ($p < 0.10$), reflecting the interdependence between the evolution of investment in digital infrastructure and trade expansion. As trade expands, more investment in digital infrastructure is required; at the same time, improved digital infrastructure creates room for further trade expansion. Similarly, MMPEN and TRADEINT show bidirectional causality ($p < 0.05$), showing the coexistence of FinTech and trade in each other's development. Moreover, GOVEFF causes TRADEINT unidirectionally ($p = 0.034$), with no causality from trade to GOVEFF ($p = 0.539$).

4.2.4 Hansen (1999) Panel Threshold Estimation

The interval estimate for the threshold value is found using the likelihood ratio test. Control variables (LSCI, MMPEN, LNGDP, GOVEFF, INFL, AfCFTA) are used in both regimes. Hansen (1999) considers a sharp shift between the regimes, whereas in reality, there may be a smooth transition; thus, STR (Teräsvirta, 1994) is a preferred extension.

The empirically determined critical mass is very close to the benchmark of 30% established by Asongu and Abdullahi (2021). This independently validates the critical mass hypothesis while proving that the non-linearity is driven by empirical evidence, not an arbitrary assumption. The estimated INTERPEN coefficient in Regime 1 (N=421) is significantly negative ($\beta_1 = -0.127$, $p<0.01$), indicating that the effect of digital infrastructure below the critical mass is more oriented towards domestic consumption than trade-related purposes. The estimated INTERPEN

Table 9
Dumitrescu-Hurlin (2012) Panel Granger-Predictive Causality Test Results

Causal Direction	W-bar	Z-bar	p-value	Decision
LSCI → TRADEINT	2.847	2.214	0.027	Granger-predictive **
TRADEINT → LSCI	1.341	0.824	0.410	No causality
INTERPEN → TRADEINT	2.124	1.742	0.081	Granger-predictive *
TRADEINT → INTERPEN	2.687	2.041	0.041	Granger-predictive **
MMPEN → TRADEINT	3.214	2.847	0.004	**Granger-predictive *** **
TRADEINT → MMPEN	2.411	1.987	0.047	Granger-predictive **
GOVEFF → TRADEINT	2.584	2.114	0.034	Granger-predictive **
TRADEINT → GOVEFF	1.127	0.614	0.539	No causality

*Authors' Summarization 2026. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$*

Table 10

Hansen (1999) Panel Threshold Estimation

Parameter	Estimate	Confidence Interval/p-value
Threshold estimate (γ^): INTERPEN	29.4%	95% CI: [26.8%, 32.1%]
F-statistic (threshold significance)	18.42***	Bootstrap p-value: 0.002
Regime 1: INTERPEN < 29.4% (N = 421)	β_1 = -0.127***	Std. Err.: 0.040; p < 0.01
Regime 2: INTERPEN ≥ 29.4% (N = 132)	β_2 = +0.061**	Std. Err.: 0.029; p < 0.05
Wald test: $\beta_1 = \beta_2$	F = 24.17***	p-value: 0.000; regime homogeneity rejected

*Authors' Summarization 2026. Note. Bootstrap F-statistic uses 1,000 replications. *** p < 0.01; ** p < 0.05. The Hansen (1999) threshold test yields a threshold estimate of 29.4% internet penetration (95% CI: 26.8% - 32.1%), which is statistically significant at the 1% level (F = 18.42, bootstrap p = 0.002)*

coefficient in Regime 2 (N=132) is significantly positive (β_2 = +0.061, p<0.05), suggesting that once the critical mass of digital penetration is reached, the effect becomes positive and trade-related. The hypothesis that regime coefficients are identical is rejected at the 1% level by the Wald test (F=24.17, p=0.000), formally confirming the existence of the structural break. Out of the 32 sample countries, only Mauritius, Seychelles, South Africa, Kenya, and Ghana exceed the critical mass of 29.4%.

4.2.5 PMG Robustness Estimator and Coefficient Divergence Analysis

Table 11 displays the PMG output, with a negative, statistically significant ECT coefficient (-0.317), indicating a valid cointegration relationship with a speed of adjustment of approximately 31.7% per year. Hausman test (H = 10.14, p = 0.181) rejects the superiority of MG over PMG for efficiency reasons.

The negative and significant error correction term (ECT = -0.317, p < 0.01) indicates the presence of a valid cointegration relationship, where about 31.7% of disequilibrium from the long-run equilibrium is corrected each year. Findings for the dependent variables LSCI, MMPEN, and AfCFTA are qualitatively consistent with FMOLS in both the long- and short-run models. INTERPEN was statistically insignificant in the PMG long-run model, which can be attributed to the averaging effect of economies above and below the threshold, given the homogeneity constraint. The GOVEFF coefficient estimate is also smaller than that of the FMOLS model due to heterogeneity in the sample.

4.2.6 Cross Estimator Consistency: FMOLS versus PMG

Consistency testing is conducted through the consistency of signs and significance levels PMG long-run coefficients from Table 11. Exclusion of island economies: Mauritius, Seychelles, Cape Verde, Comoros, São Tomé and Príncipe.

Another critical difference is the sign of the LNGDP (+14.231 vs -24.847). However, after splitting the sample into two, LNGDP is reduced to +12.41 (p < 0.01) in FMOLS and -11.24 (p = 0.087) in PMG. Note that, after splitting the sample, the PMG estimate is now statistically close to zero rather than statistically significant and negative. This suggests that the sign difference can be explained by the inclusion of small islands with disproportionately high GDP levels but low physical trade. In this setting, PMG tends to yield a misleading result when homogeneity is imposed

Table 11

Pooled Mean Group (PMG) Estimation Results

Variable	LR Coeff.	LR Std. Err.	SR Coeff.	SR Std. Err.
ECT (−1)	–	–	-0.317***	0.072
LSCI	-0.524***	0.087	-0.018	0.197
INTERPEN	-0.049 (ns)	0.056	0.214	0.584
MMPEN	+0.071**	0.030	+0.107*	0.063
LNGDP	-24.847***	10.124	+61.247***	15.841
GOVEFF	-1.124 (ns)	4.214	6.847	6.217
INFL	-1.084***	0.247	0.271	0.208
AfCFTA	-7.412***	1.547	-1.147	1.891

*Authors' Summarization 2026. Note. *** p < 0.01; ** p < 0.05; * p < 0.10; ns = not significant*

Table 12

Cross-Estimator Consistency: FMOLS versus PMG Long-Run Coefficients

Variable	FMOLS Coeff.	PMG LR Coeff.	Consistent?	Reconciliation Notes
LSCI	-0.341***	-0.524***	**Yes**	Same negative sign; magnitude difference attributable to PMG homogeneity restriction
AfCFTA	-6.824***	-7.412***	**Yes**	Core finding confirmed across both estimators
MMPEN	+0.091***	+0.071**	**Yes**	Positive FinTech-trade association robustly confirmed
GOVEFF	-10.847***	-1.124 (ns)	Partial	Same direction: magnitude diverges; island economy exclusion reduces FMOLS to −7.12
INTERPEN	-0.082**	-0.049 (ns)	Partial	Same direction: PMG insignificance reflects threshold averaging within homogeneity constraint
INFL	+0.118**	-1.084***	Diverges	FMOLS: nominal ratio channel; PMG: real appreciation channel; both support stabilisation policy
LNGDP	+14.231***	-24.847***	Diverges	Resolved by island economy sub-sample analysis (Table 14); not a fundamental misspecification

Authors' Summarization 2026. Note. FMOLS coefficients from Model 1 (baseline)

across all 32 units (Eberhardt & Teal, 2011). On the contrary, averaging the country-specific coefficients using the FMOLS group mean is robust to such outliers. As for the INFL coefficient difference, the divergence results from the fact that FMOLS and PMG capture different effects. While the former captures the trade effect in the short and medium term, the latter captures the real appreciation effect within the same period under homogeneity.

4.2.7 AfCFTA Placebo Tests and Sub-Sample Robustness Checks Analysis

Table 13 presents the Placebo tests assigning AfCFTA = 1 for all countries from the placebo year onwards, ignoring staggered ratification. The actual test uses country-specific staggered ratification dates per country-level AU ratification records.

For the three artificial treatment years (2017, 2018, and 2019), the placebo AfCFTA tests have coefficients of -1.624, -1.887, and -1.412, respectively, all of which are far from statistically significant (minimum p-value = 0.201). This starkly contrasts with the coefficient obtained for the actual staggered AfCFTA regime (-6.824; $p < 0.001$), thereby verifying the existence of an AfCFTA-specific effect that was neither previously trending nor affected by other simultaneous shocks. The relative magnitude difference between placebo coefficients and the true AfCFTA coefficient (which is fourfold higher) is convincing evidence in favour of the proposed identification strategy. This provides direct confirmation of Hypothesis H_4: the AfCFTA coefficient is due to adjustment effects and not a result of trade restrictions.

4.2.8 FMOLS Long-Run Coefficients

The robustness tests consistently accept the stability and reliability of the baseline FMOLS results. The omission of island economies, high-inflation outliers, or the post-2021 period does not alter the signs and significance patterns of all statistically significant coefficients. The fact that the GOVEFF coefficient is attenuated moderately in the case that the economies of the islands are omitted (between -10.85 and -7.12) does indicate the compositional origin of the FMOLS-PMG divergence without compromising the direction or the significance of the association. The levels specification verifies that the negative LSCI sign and the negative INTERPEN sign persist in absolute terms of trade values, thereby establishing beyond any doubt that GDP-denominator effects

Table 13

AfCFTA Placebo Test Results (FMOLS)

Treatment Assignment	AfCFTA Coefficient	Std. Error	p-value	Significant?
Placebo: 2017	-1.624	1.584	0.287	No
Placebo: 2018	-1.887	1.561	0.201	No
Placebo: 2019	-1.412	1.617	0.364	No
Actual staggered AfCFTA ratification	**-6.824*** **	1.187	0.000	**Yes** ***

*Authors' Summarization 2026. Note *** $p < 0.01$*

Table 14
Robustness Check Results (FMOLS Long-Run Coefficients)

Specification	LSCI	INTERPEN	MMPEN	LNGDP	GOVEFF	INFL	AfCFTA
Baseline (N=553)	-0.341***	-0.082**	+0.091***	+14.23***	-10.85***	+0.118**	-6.82***
Excl. Island economies (N=468)	-0.314***	-0.074**	+0.084***	+12.41***	-7.12***	+0.104**	-5.94***
Pre-2021 subsample (N=432)	-0.328***	-0.087**	+0.098***	+13.87***	-10.21***	+0.111**	–
Excl. high-inflation outliers (N=541)	-0.337***	-0.079**	+0.094***	+14.08***	-10.47***	+0.047	-6.71***
Levels DV: log(trade value)	-0.016**	-0.003*	+0.012***	+0.984***	-0.741**	+0.002	-0.341***

Authors' Summarization 2026. Note. * *p* < 0.10; ** *p* < 0.05; *** *p* < 0.01

are eliminated. The most consistent observation across all specifications is the positive MMPEN coefficient (ranging from +0.084 to +0.098 in terms of trade-to-GDP); mobile money adoption is the strongest promoter of trade integration in the research.

4.3 Discussion of Findings

Empirical results from the current research offer a subtle, context-specific view of the infrastructure-trade nexus in Sub-Saharan Africa (SSA), showing that the efficacy of maritime and digital investments is intrinsically conditional and not automatic in line with the submissions of Fagbemi et al. (2024), who emphasize that the impact of trade-related mechanisms is highly dependent on institutional quality. The adverse baseline effect of maritime connectivity on trade integration contradicts traditional trade theory but is quite consistent with the structural realities of SSA economies. Efficiency in port operations and maritime connectivity usually reduces transport costs and promotes international trade; yet, in most developing countries, this manifests as stimulating imports rather than promoting exports, as the country lacks sufficient production capabilities and comparative advantage (Sahoo et al., 2025). This indicates low industrial potential, weak value chains, and a high degree of commodity dependence. Therefore, rather than indicating inefficiency, the negative LSCI coefficient reflects a transitional development process, in which infrastructure continues to affect productive capacity. This pattern is evident in Sub-Saharan Africa, where the expansion of ports and enhanced efficiency in maritime operations have typically been associated with higher volumes of imports, especially of manufactured products, without a corresponding diversification of exports in nations such as Nigeria, Angola, and Mozambique (Gbadeyanka, 2018). Nevertheless, the positive and meaningful relationship between maritime connectivity and governance points out the crucial policy lever. Those countries with a relatively stronger institutional structure, including Mauritius and, to a lesser degree, Ghana and Kenya, are better positioned to translate connectivity into trade benefits. These are clear signs of efficiency in customs, regulation, and port management. It is very clear from the statement above that infrastructure reforms without governance reforms yield little or no trading gains. The same problem is evident in the case of AfCFTA's implementation, where non-tariff barriers have continued to constrain trade even after tariff reductions.

The sequencing of internet penetration is supported by its nonlinear effects, as digital infrastructure becomes development-enhancing only after a critical threshold is reached. Empirical evidence shows that at low levels of internet penetration, its impact remains insignificant, but becomes positive and stronger beyond identified thresholds. This reflects the stage-dependent nature of digital adoption, where early phases are constrained by the digital divide and limited user capability, restricting productive and trade-oriented use. At these early stages, internet usage is largely confined to existing social and communication networks, limiting its contribution to broader economic and trade activities (Zhang, Li, Mao, & Wang, 2023; Zhang, Ma, Tian, & Dong, 2023; Chen & Ye, 2021). Therefore, trade gains from digitalization have not been realized in many SSA countries with low digital penetration rates. On the other hand, South Africa and Kenya are examples of digitally developed economies where the greater penetration enables e-commerce, logistics coordination, and cross-border business. This example emphasizes the importance of expanding digital transformation from accessibility to include digital literacy and regulation as well. Probably the policy implication most relevant is the unanimously positive effect of mobile money adoption on trade integration. Mobile money also works well in low-income, low-infrastructure settings, unlike general internet infrastructure. It has already been clear in East Africa that lowering transaction costs, improving cross-border payments, and incorporating informal sectors into formal trade systems are key. There is a positive two-way causality between mobile money and trade, creating a virtuous cycle that drives the development of both trade and financial inclusion. This will definitely be an essential aspect of trade facilitation in Sub-Saharan Africa.

The negative AfCFTA coefficient indicates short-term adjustment costs rather than policy failure. As a matter of fact, trade liberalization tends to destabilize established market structures in the short run before bringing long-term benefits. Transitional effects include initial revenue losses, changes in compliance requirements, and competition exerted on domestic companies. The placebo effect demonstrates that this phenomenon is not incidental but relates to the actual implementation period. This is consistent with initial experience across the continent, in which the gains of AfCFTA are skewed by unfinished reforms in logistics, customs, and productive capacity (Lunenborg & Roberts, 2021). Generally, the results underline that trade integration in SSA is not limited by infrastructure shortages per se, but by the absence of complementary systems that can translate infrastructure into actual economic outcomes in governance, digital maturity, and financial inclusion.

5. Conclusion and Recommendations

5.1 Conclusions

This paper has explored the long-run relationship between maritime infrastructure, FinTech adoption, and trade integration in 32 Sub-Saharan African economies from 2006 to 2023 using a methodologically comprehensive panel design that incorporates CIPS unit root tests, Pedroni/Kao/Westernlund cointegration, FMOLS and PMG long-run estimators, and Dumitrescu-Hurlin, coming up with four coherent and policy-relevant conclusions.

Maritime connectivity does not necessarily facilitate trade integration in SSA. The LSCI is negatively and statistically significant in the long run across all model specifications and robustness diagnostics, supporting the structural fact that, in productive-capacity constrained economies, better shipping networks are disproportionately used to absorb imports rather than to expand exports. The fact that the negative coefficient of LSCI remains in the levels specification despite this mechanism indicates that the levels specification is not based on GDP-denominator effects. Dumitrescu-Hurlin tests of causality also support the hypothesis that the relationship between LSCI and TRADEINT is unidirectional, consistent with the exogeneity of maritime network investment.

Digital connectivity and trade integration exhibit a nonlinear relationship. This empirical evidence supporting the critical mass theory comes from Hansen (1999), who endogenously determined a threshold of 29.4% internet penetration (95% confidence interval: [26.8%, 32.1%]). Below this threshold, trade intensity is positively related to internet penetration; above it, the relationship becomes positive, with a 1% increase in internet penetration associated with a 0.061% increase in the trade/GDP ratio. According to the findings, only five out of 32 sample economies have crossed this threshold to date (2023).

Institutional quality emerges as a critical structural moderator of infrastructure returns. The governance-complementarity relationship, as evidenced by the LSCI×GOVEFF correlation, indicates that more well-governed economies have significantly smaller negative maritime trade relationships. The Dumitrescu-Hurlin findings show that governance causally precedes trade integration, thereby establishing its position as a structural determinant. The direct negative impact of GOVEFF on the trade ratio is a channel of structural change, namely, improvements in institutional quality that strengthen domestic productive capacity, facilitate import substitution and diversification, decrease trade dependence, and enhance trade quality.

The most direct FinTech proxy, mobile money adoption, is statistically significant and strongly promotes trade integration across all model specifications, sub-samples, and estimators, as shown by the System GMM robustness check (0.083, $p < 0.01$) and supported by full AR and Hansen J-test diagnostics. The two-way causality between MMPEN and TRADEINT indicates the virtuous FinTech-trade reinforcement cycle. The negative AfCFTA coefficient, confirmed by sound placebo tests as a transitional adjustment effect, indicates that the early implementation period creates predictable short-run disruption costs that are bound to turn around as the agreement matures.

5.2 Policy Recommendations

The investment in ports should be matched with supply-side growth in manufacturing promotion, agricultural value-addition, and export diversification, so that maritime connectivity drives export growth rather than import deepening. The governments and regional organizations must resist the tendency to treat maritime connectivity as an isolated intervention and should explicitly co-plan infrastructure investment with supply-side development policies, defining the segments of the value chain where local productive capacity can be built in realistic ways.

Economies with a digital threshold of 29.4% or lower should accelerate internet adoption and implement enabling policies, such as cross-border e-commerce laws, the formalization of digital businesses, and digital trade financing, to redirect use toward export-focused activities. The economies that are always above the threshold (Mauritius, Seychelles, South Africa, Kenya, Ghana) must focus on the quality of connections rather than on expanding access.

AfCFTA institutions ought to make infrastructure funding conditional on institutional performance standards, such as efficiency in customs, regulatory transparency, and anti-corruption efforts, to ensure that connectivity resources are deployed in enabling environments that can bring to bear their trade-creating potential.

The expansion of the Pan-African Payment and Settlement System (PAPSS) must be extended beyond its current coverage; mobile money regulatory harmonization and interoperability must be incorporated into trade facilitation action plans. The positive MMPEN-TRADEINT relationship is very robust, providing a solid evidence base for focusing on digital financial inclusion in trade policy, ensuring that the FinTech ecosystem is a fundamental trade tool.

The negative AfCFTA coefficient indicates foreseeable adjustment costs; complementary non-tariff barrier reduction, customs digitalization, and development of productive capacity should be preserved during the transitional process while patiently implementing AfCFTA.

5.3 Limitations and Future Research

Future studies should consider the causal effects of AfCFTA, which can be directly estimated using difference-in-differences, exploiting the staggered ratification of the AfCFTA (Callaway & Sant'Anna, 2021). Future studies could also decompose trade directly to test the asymmetric LSCI hypothesis by separating export-to-GDP and import-to-GDP models using bilateral data from COMTRADE. To ensure improvements to AfCFTA measurement, Trade-weighted implementation indices or implementation scores for individual protocols would capture the extent of implementation beyond mere ratification.

AI Disclosure: Grammarly was used for grammatical editing. No AI tools were used in methodology design, model construction, result interpretation, or conclusion formulation.

Conflict of Interest: The authors declare no financial, personal, or professional conflicts of interest.

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Received on: 22th of April, 2026
Accepted on: 12th of June, 2026
Published on: 24th of July, 2026