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Digital Infrastructure, Capital Deepening, and Openness as Catalysts of Labor Productivity: Empirical Evidence from Post-Conflict Somalia (1990–2024)

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Abstract: Digital connectivity has transformed economic life in fragile states, yet its productivity effects remain poorly quantified. This study examines the long-run and short-run links between digital infrastructure, physical capital, foreign direct investment (FDI), trade openness, and labor productivity in Somalia over 1990–2024. Drawing on endogenous growth theory, neoclassical capital deepening, technology diffusion, and the General Purpose Technology paradigm, the analysis applies Augmented Dickey–Fuller and Phillips–Perron unit root tests, ARDL bounds testing, an inverse hyperbolic sine transformation for volatile FDI, Fully Modified and Dynamic OLS, residual diagnostics, and bivariate VAR Granger causality. Phillips–Perron tests establish that all variables are integrated of order one. The ARDL bounds test yields an F-statistic of 7.797, above the 1% upper bound, but the t-statistic (−1.918) fails to reject, leaving single-equation cointegration inconclusive in this small sample (T = 31); FMOLS and DOLS are therefore used as the primary long-run estimators. Both indicate that a 1% rise in mobile subscriptions raises output per worker by about 0.12% ($p < 0.001$), while gross fixed capital formation has an elasticity of 0.09–0.14% ($p < 0.001$). Net FDI has a small positive effect (≈0.013, $p < 0.01$), whereas trade openness is statistically insignificant. Granger tests show causality running from mobile subscriptions and trade openness to productivity, and from productivity to FDI, suggesting efficiency-seeking investment; capital formation shows no causality. Diagnostics reveal no first-order serial correlation or heteroskedasticity, although second-order autocorrelation and non-normal residuals persist, and recursive CUSUM indicates no significant parameter instability. The findings suggest that private-sector-led telecommunications expansion and productive capital accumulation matter more than openness alone for post-conflict recovery. Policy priorities include spectrum regulation, digital governance, infrastructure finance, and institutional rebuilding.

Keywords: Fragile states; Digital leapfrogging; Post-conflict economic reconstruction; Labor productivity; Digital infrastructure

1. Introduction

Labor productivity—defined as real gross domestic product generated per employed worker—serves as the primary engine of long-run economic growth, real wage expansion, and poverty alleviation (Romer, 1990; Solow, 1956) (International Labor Organization, 2018)In developing, fragile, and conflict-affected environments, raising labor productivity is not merely an indicator of operational efficiency; it is an essential structural requirement for state stabilization, post-war reconstruction, and economic sovereignty. Among developing nations, the Federal Republic of Somalia presents a unique developmental landscape. Following the collapse of the central government in 1991, the breakdown of formal state-administered institutions and the physical destruction of public infrastructure dismantled traditional economic arrangements. While this institutional shock devastated the country's formal industrial base and public capital assets, it fostered an unconventional economic dynamic: an unregulated, resilient, private-sector-driven economic order.

Over the past three decades, Somalia underwent an extraordinary technological and digital leapfrogging. In the total absence of legacy state-owned wireline telephone networks and traditional commercial banking branch systems, private Somali entrepreneurs established one of the most competitive, widely accessible, and lowest-cost mobile telecommunications and mobile-money ecosystems in Sub-Saharan Africa (World Bank, 2020) Today, mobile cellular subscriptions and proprietary mobile-money platforms (such as EVC Plus and ZAAD) mediate over 70% of all domestic transactions, substituting for sovereign physical currency, facilitating diaspora remittances, and streamlining basic supply chains. However, despite this dynamic digital adoption, aggregate Somali labor productivity remains constrained by severe structural vulnerabilities: an undiversified pastoral and agro-livestock economic base highly susceptible to recurrent climate shocks, extensive reliance on imported consumer staples, port-centric logistical bottlenecks, and volatile foreign capital flows.

Recent policy reports and multilateral economic assessments emphasize that post-conflict economic recovery cannot rely indefinitely on informal arrangements. Policy briefs by the African Development Bank (African Development Bank, 2022)and International Monetary Fund (International Monetary Fund, 2023) Article IV consultations highlight that while informal market mechanisms sustained basic livelihoods during state collapse, they generate severe coordination failures. Without standardized national regulatory oversight, formal contract enforcement mechanisms, and modern public infrastructure, the private sector operates within low-productivity, sub-scale equilibria. The productivity of the domestic labor force remains depressed by widespread skill mismatches, lack of accredited technical vocational training, and undercapitalized production techniques across the rural agricultural heartlands.

Academic dissertations and macroeconomic policy studies focusing on fragile African states argue that technological diffusion in post-conflict settings exhibits non-linear returns. When digital platforms and telecommunications networks are introduced into economies with underdeveloped banking and logistics systems, they yield high initial productivity returns by eliminating fundamental informational asymmetries. Farmers and pastoralists gain real-time access to market price quotations across regional trading hubs, reducing predatory intermediary markups and physical transport depreciation. Nevertheless, as highlighted in recent development policy frameworks, digital connectivity alone cannot compensate for a deficit in physical capital assets, such as power generation, paved arterial road networks, and automated port terminals.

Furthermore, international policy documents concerning the Heavily Indebted Poor Countries (HIPC) Initiative, through which Somalia successfully achieved full debt relief completion point in late 2023, underscore the urgency of transitioning from external donor assistance to sustainable domestic value creation. Debt relief restores sovereign financial legitimacy and reopens access to concessional multilateral development finance from institutions like the World Bank and the International Development Association (IDA). However, absorbing these capital inflows productively requires a clear understanding of the domestic macroeconomic transmission mechanisms that link capital formation, foreign investment, and international trade to labor efficiency.

The macroeconomic challenges facing Somalia are further complicated by external terms-of-trade volatility and structural currency dynamics. Following the collapse of the central bank in 1991, the Somali Shilling experienced rapid depreciation and widespread counterfeiting, driving the private sector toward extensive dollarization and digital mobile liquidity. While dollarization stabilized domestic accounting against hyperinflation, it eliminated independent monetary policy levers and exposed domestic production to international price shocks. In this environment, labor productivity serves as the primary absorption mechanism against external macroeconomic shocks, determining whether local enterprises can survive global competition and maintain employment.

In parallel, academic analyses of state reconstruction emphasize that the spatial concentration of economic activity around major coastal ports—principally Mogadishu, Berbera, and Bosaso—creates regional productivity imbalances. The hinterlands remain largely pastoral and disconnected from international logistics corridors, while urban centers experience rapid service-sector expansion driven by telecommunications, retail, and real estate. Understanding how digital infrastructure and capital deepening interact across this divided economy is critical for designing national development plans that foster inclusive growth rather than widening regional disparities.

These structural realities raise central empirical questions for macroeconomic policy: To what extent does digital connectivity enhance aggregate labor efficiency in a rebuilding economy? Does physical capital accumulation yield significant returns to output per worker, or is its impact dampened by infrastructural and security fragmentation? What role do international trade and foreign direct investment (FDI) play in transmitting technology and managerial capabilities, or do they primarily reflect consumption-driven imports and resource-extractive enclaves?

A review of the existing productivity literature reveals three critical limitations. First, traditional empirical studies predominantly focus on advanced economies or large emerging markets (Asada, 2020; Malawi & AlMansi, 2014; Vu et al., 2026), while fragile, post-conflict economies with informal institutional arrangements remain largely overlooked. Second, existing studies frequently treat technological change as a homogeneous or residual factor, obscuring the distinct role of digital telecommunications infrastructure as a General Purpose Technology. Third, methodological approaches in small-sample time-series often overlook technical complications such as non-normal distributions, borderline cointegration bounds, and negative net foreign investment flows.

Accordingly, the central problem addressed in this study is that Somalia stands at a critical developmental crossroads: while mobile connectivity has expanded rapidly, physical capital accumulation, foreign investment, and trade integration have faced ongoing institutional frictions.

The policy challenge is therefore to identify how digital infrastructure, physical investment, and external flows interact to shape aggregate labor efficiency.

The study contributes to the development and empirical economics literature in four principal ways: (1) This study extends the empirical literature on labor productivity by examining the joint relationships between digital telecommunications infrastructure, physical capital formation, foreign direct investment and trade openness in Somalia, an economy characterized by prolonged institutional disruption and private-sector-led technological development (2) It nests digital telecommunications infrastructure, capital deepening, net FDI inflows, and trade openness within an augmented endogenous Cobb–Douglas production function; (3) It resolves finite-sample biases and degenerate ARDL t-bounds test properties by combining ARDL with Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS); and (4) It implements bivariate Vector Autoregression (VAR) Granger causality tests to establish directional feedback among variables.

2. Literature Review

2.1 Theoretical Framework: Growth, Capital Deepening, and Technology Diffusion

The conceptual baseline is grounded in the Augmented Cobb–Douglas Production Function (Ramirez, 2006; Solow, 1956)

$$\mathbf{Y_t = A_t\, K_t^{\alpha}\, L_t^{1-\alpha} \quad (0 < \alpha < 1) \quad (1)}$$

where Y_t is aggregate real output, K_t is physical capital stock, L_t is total labor input, α is the output elasticity of physical capital, and A_t is Total Factor Productivity (TFP) representing technological progress and organizational efficiency. Dividing Equation (1) by total labor input (L_t) yields output per worker—defined as Labor Productivity ($LP_t = Y_t / L_t$):

$$\mathbf{LP_t = A_t\, k_t^{\alpha} \quad (2)}$$

where $k_t = K_t / L_t$ reflects capital deepening. In the neoclassical paradigm, capital accumulation increases output per worker, but diminishing returns eventually constrain productivity growth unless sustained by technical progress.

In contrast, Endogenous Growth Theory (Romer, 1986, 1990; Lucas, 1988) endogenizes A_t, positing that technological advancements and productivity gains stem from internal economic decisions, infrastructure development, and knowledge spillovers. In this formulation, A_t is modeled as a function of external integration and technology adoption, driven by Trade Openness (TO_t), Foreign Direct Investment (FDI_t), and Digital Infrastructure (MOB_t):

$$\boldsymbol{A_t = A_0\, exp(\beta_1\, ln(TO_t) + \beta_2\, ihs(FDI_t) + \beta_3\, ln(GFCF_t) + \beta_4\, ln(MOB_t)) \quad (3)}$$

Substituting Equation (3) into Equation (2) yields the estimable log-linear baseline equation:

$$\boldsymbol{ln(LP_t) = \beta_0 + \beta_1\, ln(TO_t) + \beta_2\, ihs(FDI_t) + \beta_3\, ln(GFCF_t) + \beta_4\, ln(MOB_t) + \varepsilon_t \quad (4)}$$

where GFCF represents gross fixed capital formation as a percentage of GDP and is used as a proxy for investment intensity. Although this indicator captures the relative importance of investment in the economy, it does not directly measure the physical capital stock per worker.

2.2 Digital Infrastructure as a General Purpose Technology

The General Purpose Technology (GPT) framework explains how digital infrastructure can support productivity improvements across different sectors of the economy (Bresnahan & Trajtenberg, 1995; Helpman, 1998) Information and communication technology can reduce information asymmetries, lower communication costs, improve coordination within supply chains, and connect rural producers with urban markets(Jorgenson & Vu, 2016) In post-conflict economies, where transport infrastructure and formal financial institutions may be underdeveloped, mobile telecommunications can provide an alternative channel for communication and commercial transactions. These potential benefits, however, depend on the availability of complementary infrastructure, skills, and supportive institutions.

However, technology diffusion theory (Nelson & Phelps, 1966) emphasizes that the productivity dividend of ICT is not automatic; it requires domestic absorptive capacity. If an economy lacks complementary human capital and regulatory standards, rapid digital expansion can generate operational adjustment costs, skill mismatches, or remain confined to non-productive consumption (Ridzuan et al., 2026)

2.3 Capital Formation, FDI, and Trade Openness Dynamics

Physical investment can support labor productivity by expanding the availability of machinery, equipment, transport infrastructure, and communication facilities. Gross fixed capital formation is commonly used to capture investment activity in an economy(Msimanga & de Jongh, 2026) Similarly, foreign direct investment can contribute to productivity through technology transfer, managerial knowledge, and access to international markets(Borensztein et al., 1998) However, these benefits may be limited when foreign investment is concentrated in sectors with weak connections to the domestic economy (Anyachebelu et al., 2025)

Trade openness may improve productivity by increasing competition, encouraging firms to adopt more efficient production methods, and facilitating access to imported capital goods(Edwards, 1998; Grossman & Helpman, 1991) However, the productivity effects of trade integration may differ across countries depending on their productive capacity, export structure, and ability to benefit from international markets. In economies with limited domestic industrial capacity, import competition and external trade imbalances may constrain the benefits of openness(Adhikary, 2011; Rakshit, 2021)

2.4 Empirical Literature

Empirical investigations into the drivers of productivity in emerging and developing economies yield diverse conclusions across regions and methodological traditions.

A substantial strand of recent research documents the growth- and productivity-enhancing effects of digital transformation. (Vu et al.2026) apply an ARDL bounds testing framework to Canadian time series, demonstrating that digital transformation ($\beta = 0.214$) and R&D expenditures serve as primary drivers of long-term economic performance. Similarly, (Goldar et al. 2023)total factor productivity growth in India using time-series and sectoral panel approaches, confirming that the share of ICT capital in total fixed capital assets exerts a significant, positive influence on productivity across both manufacturing and service sectors. In advanced economies, digital networks function as complementary infrastructure that accelerates innovation, lowers transaction costs, and deepens organizational efficiency.

However, evidence from developing and transitional contexts reveals notable contradictions and structural constraints. In an analysis of Indonesia covering 1990–2024, (Ridzuan et al., 2026) find that while technological innovations (patents) and capital formation bolster economic growth, mobile cellular penetration exhibits a persistent negative long-run relationship ($\beta = -0.070$, $p < 0.001$). The authors argue that in the absence of adequate domestic human capital, institutional coordination, and workplace digital training, rapid telecommunication expansion imposes structural adjustment costs and redirects resources toward non-productive digital consumption. Similarly, (Madžar, 2023)) investigates Serbia using ARDL and ECM approaches, finding that mobile subscriptions and ICT indicators share no statistically significant long-run cointegrating relationship with worker productivity, remaining confined to short-run dynamic adjustments (ECM = -0.627).

The empirical literature on capital deepening underscores the importance of physical investment quality and gestation periods. (Msimanga & de Jongh, 2026) examine South Africa over the period 1990–2022 using dynamic ARDL and canonical cointegration regression, demonstrating that Gross Fixed Capital Formation (GFCF) is the primary statistically significant domestic driver of labor productivity ($\beta = 0.044–0.074$, $p < 0.05$). The authors establish that capital deepening lowers operational transaction costs and enables scale economies. In Chile, (Ramirez, 2006) demonstrates that private and public capital formation generate substantial positive externalities that uplift worker output over multi-period horizons. In sharp contrast, (Anyachebelu et al., 2025) find an anomalous negative long-run link between gross fixed capital formation and labor productivity in Nigeria ($\beta = -0.386$, $p < 0.01$), attributing this failure to structural resource misallocations, oil-sector enclave distortions, and weak institutional governance.

Studies evaluating external economic openness and foreign direct investment report equally divergent findings. (Asada, 2020) utilizes an ARDL framework for Vietnam, demonstrating that gross FDI inflows ($\beta = 0.085$) and capital goods imports unanimously stimulate labor productivity growth in the long run. In Jordan,(Malawi & AlMansi, 2014) report that economic globalization promotes labor productivity in the long run ($\beta = 2.268$, $p < 0.01$), but exerts a negative short-run effect ($\beta = -0.577$, $p < 0.01$), arguing that technology adoption requires time for labor re-skilling. Conversely(Adhikary, 2011)for Bangladesh and (Rakshit, 2021) for India document that trade openness can negatively affect growth when import dependency and terms-of-trade deteriorations outpace export earnings. In fragile African states, (Anyachebelu et al., 2025)note that foreign capital inflows often bypass domestic labor, reinforcing the need to evaluate country-specific structural conditions.

In the broader African context, recent econometric investigations emphasize the moderating role of governance and institutional capacity in shaping the relationship between technology adoption and productivity. Studies examining cross-country panels in Sub-Saharan Africa highlight that mobile financial services reduce poverty and expand informal employment, but their ability to drive economy-wide total factor productivity depends on formal financial intermediation and legal contract enforcement. In economies marked by prolonged institutional disruption, digital infrastructure often functions as a coping mechanism rather than an industrial catalyst, allowing micro-enterprises to survive but generating limited large-scale manufacturing expansion.

Similarly, research on post-conflict economic recovery in East Africa indicates that the sequence of infrastructure rehabilitation matters profoundly. When investments in communication networks precede investments in basic transport and power generation, economic output becomes

skewed toward urban trade and informal services, leaving rural agricultural yields depressed. These structural imbalances emphasize the necessity of examining digital telecommunications simultaneously with physical capital formation, external trade flows, and foreign investment to capture the true multi-dimensional character of productivity growth in post-conflict states.

Overall, the empirical literature indicates that the relationship between digital infrastructure, physical investment, foreign direct investment, trade openness, and labor productivity varies across countries and economic conditions. While several studies identify positive productivity effects of digital connectivity and capital formation, other studies report insignificant or negative relationships, particularly in economies with institutional and structural constraints. These differences suggest that the productivity effects of these factors are context-specific. However, limited empirical evidence exists on how these relationships operate in fragile and post-conflict economies such as Somalia. This study addresses this gap by examining the relationship between mobile telecommunications, investment intensity, foreign direct investment, trade openness, and labor productivity in Somalia over the period 1990–2024

3. Data and Methodology

3.1 Research Design, Sample, and Data Sources

The study employs an annual time-series dataset for Somalia covering the 35-year period from 1990 to 2024. Macroeconomic and telecommunications data were extracted from the Statistical, Economic and Social Research and Training Centre for Islamic Countries (SESRIC) database, supplemented by statistical publications from the Central Bank of Somalia and the International Monetary Fund (IMF).

Table 1: Variables, Operational Measures, Sources, and Model Roles

Model Variable	Operational Measure	Source	Transformation	Model Role
lnLP	Real GDP per person employed (constant 2017 PPP US$)	SESRIC Database	Natural Logarithm	Dependent Variable
lnTO	Trade Openness: (Exports + Imports) / GDP	SESRIC Database	Natural Logarithm	External Integration
IHS_FDI	Foreign Direct Investment, net inflows (% of GDP)	SESRIC Database	Inverse Hyperbolic Sine	Technology Spillovers
lnGFCF	Gross Fixed Capital Formation (% of GDP)	SESRIC Database	Natural Logarithm	Investment Intensity

lnMob	Mobile Cellular Subscriptions per 100 people	SESRIC Database	Natural Logarithm	Digital Infrastructure

3.2 Econometric Justification of the Inverse Hyperbolic Sine (IHS) Transformation

Net foreign direct investment inflows into post-conflict Somalia experienced disinvestments and capital repatriation during periods of acute conflict and macroeconomic instability, yielding negative net values (minimum observed value of -2.270). Conventional logarithmic transformations ln(FDI) cannot handle non-positive values, leading to sample truncation and survivorship bias. Adding an arbitrary constant ln(FDI + c) introduces distortion into the parameter estimates. To preserve the complete sample and accommodate zero and negative observations, we employ the Inverse Hyperbolic Sine (IHS) transformation (Pence, 2006; Bellemare & Wichman, 2020):

$$IHS(FDI_t) = asinh(FDI_t) = ln(FDI_t + \sqrt{(FDI_t^2 + 1)}) \quad (5)$$

For positive values exceeding unity, ihs(FDI_t) ≈ ln($2FDI_t$) = ln(2) + ln(FDI_t), maintaining the standard elasticity interpretation.

3.3 Autoregressive Distributed Lag (ARDL) Model Specification

To accommodate variables integrated of order I(0) or I(1) and capture dynamic short-run and steady-state adjustments in small samples, the study utilizes the ARDL bounds testing approach (Pesaran et al., 2001). The unrestricted error correction model (UECM) of the ARDL(p, q_1, q_2, q_3, q_4) is formulated as:

$$\Delta \ln(LP_t) = c_0 + \sum \gamma_i \Delta \ln(LP_{t-i}) + \sum \theta_{1,i} \Delta \ln(TO_{t-i}) + \sum \theta_{2,i} \Delta ihs(FDI_{t-i}) + \sum \theta_{3,i} \Delta \ln(GFCF_{t-i}) + \sum \theta_{4,i} \Delta \ln(MOB_{t-i}) + \lambda_1 \ln(LP_{t-1}) + \lambda_2 \ln(TO_{t-1}) + \lambda_3 ihs(FDI_{t-1}) + \lambda_4 \ln(GFCF_{t-1}) + \lambda_5 \ln(MOB_{t-1}) + e_t \quad (6)$$

where Δ denotes the first-difference operator, c_0 is an unrestricted constant (Case 3: unrestricted intercept, no trend), γ_i and $\theta_{m,i}$ represent short-run dynamic elasticities, and $\lambda_1 \ldots \lambda_5$ represent long-run level multipliers.

Cointegration is tested under the null hypothesis of no level relationship:

$$H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = 0$$

against the alternative hypothesis:

$$H_1: \lambda_1 \neq 0 \ \&lor; \ \lambda_2 \neq 0 \ \&lor; \ \lambda_3 \neq 0 \ \&lor; \ \lambda_4 \neq 0 \ \&lor; \ \lambda_5 \neq 0$$

using finite-sample critical values from Kripfganz and Schneider (2020).

Following cointegration confirmation, the short-run dynamics are estimated via the restricted Error Correction Model (ECM):

$$\Delta \ln(LP_t) = \delta_0 + \sum \gamma_i \Delta \ln(LP_{t-i}) + \sum \theta_{1,i} \Delta \ln(TO_{t-i}) + \sum \theta_{2,i} \Delta ihs(FDI_{t-i}) + \sum \theta_{3,i} \Delta \ln(GFCF_{t-i}) + \sum \theta_{4,i} \Delta \ln(MOB_{t-i}) + \varphi ECT_{t-1} + \nu_t \quad (7)$$

where ECT_{t-1} is the lagged cointegrating residual and φ represents the speed of adjustment, required to be statistically significant and negative ($-1 < \varphi < 0$).

3.4 Methodological Triangulation: Fully Modified OLS and Dynamic OLS

In finite samples (N ≈ 31), the single-equation ARDL bounds test may exhibit degenerate test outcomes where the F-statistic rejects the null but the t-statistic fails to do so. To address this limitation, the study estimates the cointegrating vector using two robust estimators:

Fully Modified Ordinary Least Squares (FMOLS): Proposed by Phillips and Hansen (1990), FMOLS utilizes a semi-parametric transformation to purge second-order asymptotic biases arising from regressor endogeneity and residual autocorrelation:

$$\hat{\beta}_{FMOLS} = (\sum X_t X_t')^{-1} (\sum X_t y_t^+ - T \hat{\Delta}_{\varepsilon u}^+) \quad (8)$$

where y_t^+ is the modified dependent variable purged of endogeneity, and $\hat{\Delta}_{\varepsilon u}^+$ represents the non-parametric serial correlation correction factor based on a Bartlett kernel with Newey-West bandwidth.

Dynamic Ordinary Least Squares (DOLS): Developed by Stock and Watson (1993), DOLS parametrically eliminates asymptotic endogeneity by augmenting the static cointegrating regression with leads (+1) and lags (-1) of the first-differenced explanatory variables:

$$\ln(LP_t) = \beta_0 + \beta_1 \ln(TO_t) + \beta_2 ihs(FDI_t) + \beta_3 \ln(GFCF_t) + \beta_4 \ln(MOB_t) + \sum \delta_j' \Delta X_{t-j} + \nu_t \quad (9)$$

Standard errors are calculated using the Newey-West HAC covariance matrix, generating asymptotically efficient estimates in the presence of cointegration.

3.5 Bivariate Vector Autoregression (VAR) Granger Causality

To determine the direction of temporal feedback between each macroeconomic indicator and labor productivity, four bivariate VAR(2) systems are estimated:

$$[\ln(LP_t), X_t]' = [\alpha_{10}, \alpha_{20}]' + \sum A_i [\ln(LP_{t-i}), X_{t-i}]' + [\varepsilon_{1t}, \varepsilon_{2t}]' \quad (10)$$

Granger causality from X_t to $\ln(LP_t)$ is confirmed if the joint null hypothesis H_0: $\alpha_{12,1} = \alpha_{12,2} = 0$ is rejected via the Wald χ^2 test.

4. Empirical Results

4.1 Descriptive Statistics and Preliminary Diagnostics

Table 2 presents the summary statistics and distribution properties for the five variables.

Table 2: Descriptive Statistics and Distribution Diagnostics

Variable	Obs	Mean	Std. Dev.	Min	Max	p1	p99	Skewness	Kurtosis	Joint Normality [Prob > χ^2]
lnLP	34	8.805	0.303	8.384	9.254	8.384	9.254	0.125	1.524	14.160 [0.001]
lnTO	35	3.429	1.031	1.728	4.870	1.728	4.870	-0.299	1.519	15.450 [0.000]
IHSFDI	35	3.623	3.100	-2.270	7.333	-2.270	7.333	-0.311	1.477	17.860 [0.000]
lnGFCF	35	20.079	0.692	19.336	21.693	19.336	21.693	0.898	2.555	5.120 [0.077]
lnMob	34	1.890	1.620	0.000	4.007	0.000	4.007	0.119	1.419	20.430 [0.000]

Notes: Skewness and kurtosis tests report the joint adjusted $\chi^2(2)$ statistic.

The descriptive statistics confirm substantial structural shifts in post-1990 Somalia. While labor productivity (lnLP) shows steady, modest growth around a mean of 8.805, mobile connectivity (lnMob) exhibits explosive expansion from zero subscriptions to a maximum logged index of 4.007. The wide dispersion of IHSFDI (spanning from -2.270 to 7.333) reflects the volatility of foreign capital flows during periods of civil conflict and subsequent recovery.

The joint skewness and kurtosis tests reject the null hypothesis of normal distribution for lnLP ($p = 0.001$), lnTO ($p = 0.000$), IHSFDI ($p = 0.000$), and lnMob ($p = 0.000$), while lnGFCF is marginally non-normal ($p = 0.077$). The presence of non-Gaussian errors provides strong justification for deploying semi-parametric FMOLS and DOLS models alongside ARDL.

Table 3: Pairwise Correlation Matrix

Variables	(1) lnLP	(2) lnTO	(3) IHSFDI	(4) lnGFCF	(5) lnMob
(1) lnLP	**1.000**				

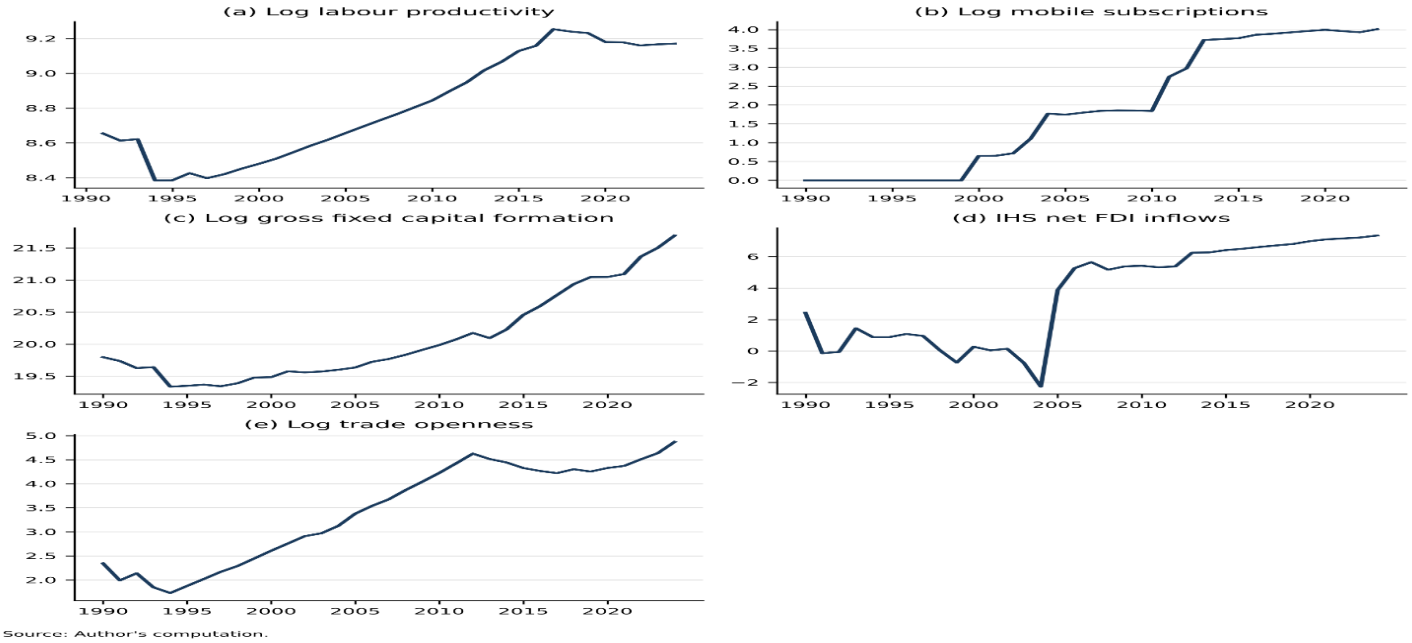
(2) lnTO	0.891* (0.000)	**1.000**			
(3) IHSFDI	0.884* (0.000)	0.878* (0.000)	**1.000**		
(4) lnGFCF	0.921* (0.000)	0.794* (0.000)	0.808* (0.000)	**1.000**	
(5) lnMob	0.962* (0.000)	0.943* (0.000)	0.873* (0.000)	0.885* (0.000)	**1.000**

*Notes: Parentheses report p-values. * denotes significance at the 1% level.*

The correlation coefficients confirm strong, statistically significant linear associations ($p < 0.001$) between labor productivity and all four explanatory variables. The exceptionally high correlation between mobile subscriptions and productivity ($r = 0.962$) preliminarily demonstrates the critical role played by telecommunications infrastructure in Somalia's informal economic expansion.

As shown in Figure 1, mobile subscriptions rise from zero, while the other series trend upward more gradually.

Figure 1: Trends of Model Variables, 1990–2024



Source: Author's computation.

Variables in natural logs: FDI is the Inverse hyperbolic sine

4.2 Unit Root and Stationarity Assessment

To determine the order of integration, Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests were implemented at levels and first differences.

Table 4: Unit Root Test Results

Variable	ADF (Levels) Without Drift [p-val]	ADF (Levels) With Drift [p-val]	PP (Levels) Without Drift [p-val]	PP (Levels) With Drift [p-val]	PP (Δ) Without Drift [p-val]	PP (Δ) With Drift [p-val]	Conclusion
lnLP	-0.247 [0.9327]	-2.910 [0.1589]	-0.210 [0.9373]	-2.904 [0.1611]	-4.557 [0.0002]	-4.583 [0.0011]	**I(1)**
lnTO	-0.772 [0.8271]	-1.441 [0.8485]	-0.187 [0.9400]	-2.135 [0.5262]	-4.710 [0.0001]	-4.604 [0.0010]	**I(1)**
IHSFDI	-1.118 [0.7079]	-2.478 [0.3392]	-0.798 [0.8196]	-3.115 [0.1027]	-6.328 [0.0000]	-6.163 [0.0000]	**I(1)**
lnGFCF	2.262 [0.9989]	-1.782 [0.7132]	2.747 [1.0000]	-1.656 [0.7697]	-3.799 [0.0029]	-6.226 [0.0000]	**I(1)**
lnMob	-0.386 [0.9124]	-2.215 [0.4816]	-0.307 [0.9245]	-2.284 [0.4430]	-5.094 [0.0000]	-5.011 [0.0002]	**I(1)**

Notes: Critical values follow MacKinnon (1996). All variables become stationary at first difference.

The unit root tests confirm non-stationarity across all series in levels ($p > 0.10$). Upon first differencing, all variables decisively reject the unit root null at the 1% significance level under Phillips–Perron tests, verifying that the series are integrated of order one, I(1), and allowing progression to cointegration testing.

At first differences, the Phillips–Perron test rejects the unit root null at the 1% significance level for all series: ΔlnLP ($Z(t) = -4.557$, $p = 0.0002$), ΔlnTO ($Z(t) = -4.710$, $p = 0.0001$), ΔIHSFDI ($Z(t) = -6.328$, $p = 0.0000$), ΔlnGFCF ($Z(t) = -3.799$, $p = 0.0029$), and ΔlnMob ($Z(t) = -5.094$, $p = 0.0000$). The variables are uniformly integrated of order one, I(1).

4.3 ARDL Cointegration Bounds Testing

The optimal lag structure selects ARDL(2,2,2,2,0) under AIC ($R^2 = 0.8860$) and ARDL(1,2,2,1,0) under BIC ($R^2 = 0.8697$).

Table 5: ARDL Bounds Test for Cointegration

Test Statistic	Value	10% Bound [I(0) - I(1)]	5% Bound [I(0) - I(1)]	1% Bound [I(0) - I(1)]	p-value [I(0) - I(1)]	Decision
F-statistic	**7.797**	2.730 – 4.103	3.377 – 4.971	5.003 – 7.138	0.001 – 0.006	**Reject H_0 at 1%**

t-statistic	**-1.918**	-2.509 – -3.632	-2.895 – -4.091	-3.700 – -5.049	0.249 – 0.595	Fail to Reject
Conclusion	—	—	—	—	—	**Inconclusive / No Rejection (.a)**

Notes: Specification follows Case 3 (unrestricted constant, no trend) with k=4 regressors and T=31 observations. Critical values from Kripfganz and Schneider (2020).

The bounds test reveals an econometric tension: the F-statistic (7.797) strongly rejects the null of no cointegration at the 1% level, but the t-statistic (-1.918) fails to cross the critical bound. This degenerate test outcome indicates that single-equation ARDL modeling cannot definitively establish cointegration in this small sample, motivating the deployment of FMOLS and DOLS.

The calculated F-statistic of 7.797 exceeds the upper critical bound I(1) = 7.138 at the 1% level (p = 0.006). However, the calculated t-statistic of -1.918 is closer to zero than the lower bound critical value I(0) = -2.895 at the 5% level (p = 0.595). In the ARDL framework, cointegration requires both the F-statistic and the t-statistic to reject their respective bounds (Pesaran et al., 2001). Furthermore, the speed of adjustment in the AIC error correction model is statistically insignificant (ECT_{t-1} = -0.135, p = 0.360), although it achieves marginal significance in the BIC model (ECT_{t-1} = -0.242, p = 0.070).

This outcome reflects degenerate test properties arising from small-sample constraints (N = 31) and collinearity among level variables. Consequently, relying solely on single-equation ARDL would provide an incomplete basis for inference. The inconclusive ARDL bounds-test results create uncertainty regarding the existence of a stable long-run relationship among the variables. FMOLS and DOLS estimates are therefore reported as supplementary long-run estimates. However, these estimators rely on the existence of cointegration and cannot independently establish that cointegration exists. Their results should consequently be interpreted with caution.

4.4 Robust Long-Run Cointegrating Elasticities: FMOLS and DOLS

To address small-sample endogeneity and serial correlation, the cointegrating vector was estimated using Fully Modified OLS (Bartlett kernel, Newey-West bandwidth = 11.564) and Dynamic OLS (lead = 1, lag = 1, Bartlett kernel, bandwidth = 48.266).

Table 6: Comparison of Long-Run Elasticities
*Dependent Variable: **$lnLP_t$***

Regressors	Model 1: ARDL (AIC)	Model 2: ARDL (BIC)	Model 3: FMOLS	Model 4: DOLS
lnTO	-0.040 (0.234) [p=0.865]	-0.062 (0.138) [p=0.658]	-0.018 (0.023) [p=0.436]	+0.024 (0.015) [p=0.108]

IHSFDI	+0.012 (0.036) [p=0.732]	+0.023 (0.020) [p=0.256]	**+0.013**** (0.005) [p=0.010]	**+0.013***** (0.003) [p=0.000]
lnGFCF	-0.729 (1.059) [p=0.500]	-0.239 (0.259) [p=0.367]	**+0.142***** (0.027) [p=0.000]	**+0.092***** (0.014) [p=0.000]
lnMob	+0.424 (0.441) [p=0.349]	**+0.257*** (0.144) [p=0.090]	**+0.118***** (0.019) [p=0.000]	**+0.116***** (0.012) [p=0.000]
Constant	+3.041*** (0.707) [p=0.000]	+3.182*** (0.675) [p=0.000]	**+5.732***** (0.534) [p=0.000]	**+6.615***** (0.282) [p=0.000]
Model Fit (R^2)	0.8860	0.8697	**0.9405**	**0.9924**
Adjusted R^2	0.8100	0.8045	**0.9317**	**0.9831**
Observations	31	31	32	30

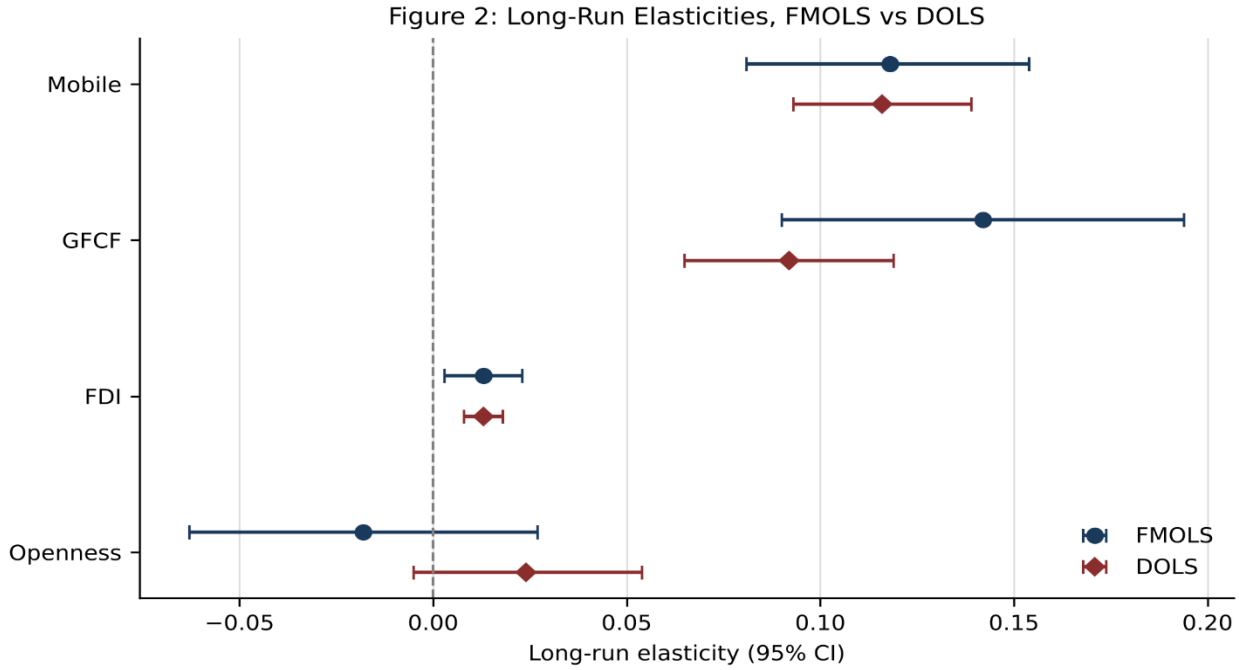
*Notes: Standard errors are in parentheses; p-values are in brackets. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.*

The robust estimators demonstrate that digital connectivity (lnMOB) and domestic capital formation (lnGFCF) are highly significant, positive determinants of Somali labor productivity ($p < 0.001$), with output elasticities of approximately 0.12% and 0.09%–0.14%, respectively. Foreign direct investment produces a stable, positive long-run gain ($\beta = 0.013$, $p < 0.01$), whereas trade openness exerts no statistically significant long-run impact.

The FMOLS and DOLS models exhibit high explanatory power ($R^2 = 0.9405$ and 0.9924, respectively) and yield stable parameter estimates:

1. ***Digital Infrastructure (lnMOB):*** Positive and highly significant at the 1% level across both models ($\beta = 0.118$, $z = 6.300$, $p = 0.000$ in FMOLS; $\beta = 0.116$, $z = 9.800$, $p = 0.000$ in DOLS). A 1% increase in mobile subscriptions per 100 people permanently raises labor productivity by approximately 0.12%.
2. ***Gross Fixed Capital Formation (lnGFCF):*** Exerts a strong, positive, and statistically significant impact on labor productivity ($\beta = 0.142$, $z = 5.350$, $p = 0.000$ in FMOLS; $\beta = 0.092$, $z = 6.620$, $p = 0.000$ in DOLS). Capital deepening represents the single largest output elasticity in the model.
3. ***Foreign Direct Investment (IHSFDI):*** Displays an identical, statistically significant positive coefficient ($\beta = 0.013$, $p = 0.010$ in FMOLS; $\beta = 0.013$, $p = 0.000$ in DOLS).
4. ***Trade Openness (lnTO):*** Remains statistically insignificant in the long run ($\beta = -0.018$, $p = 0.436$ in FMOLS; $\beta = 0.024$, $p = 0.108$ in DOLS).

figure2 plots the long-run elasticities from FMOLS and DOLS with their 95% confidence intervals. Mobile subscriptions(about0.12(, capital formation(0.09 to 0.14) and(FDI) are positive and clearly separated from zero, while the trade openness interval crosses zero in both estimators



Author's computation Note: Points are long-run elasticities; bars are 95%confidence intervals

4.5 Short-Run Dynamics and Model Diagnostics

Table 7 summarizes the short-run dynamics from the ARDL error-correction models and post-estimation diagnostics.

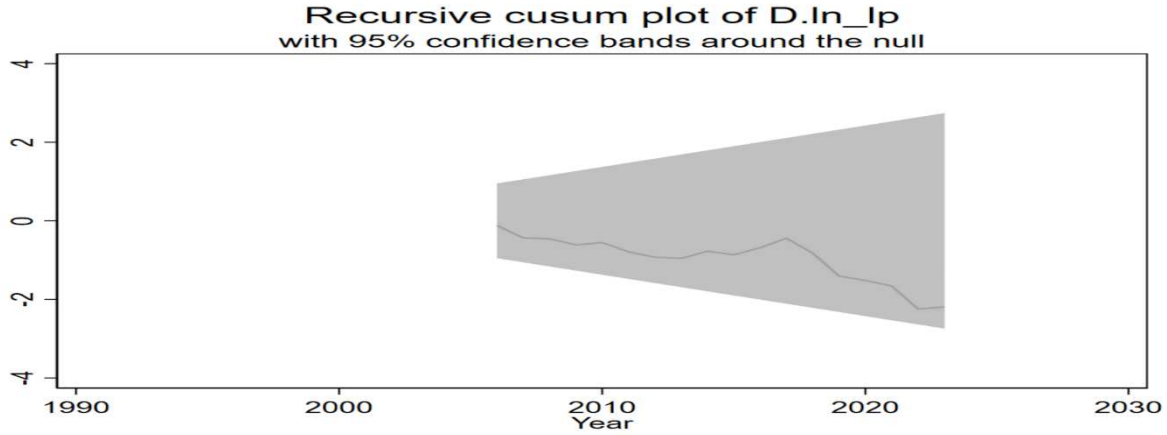
Table 7: Short-Run Dynamics and Diagnostic Suite

Component	Metric / Variable	Coefficient	Std. Error	t-Statistic	p-value
Short-Run Dynamics	$\Delta \ln GFCF_t$	0.388***	0.066	5.860	0.000
	$\Delta \ln_TO_{t-1}$	0.221***	0.067	3.270	0.004
	ΔIHS_FDI_{t-1}	-0.008*	0.004	-1.910	0.073
	ECT_{t-1} (BIC Model)	-0.242*	0.126	-1.920	0.070

Diagnostic Test	Test Applied	Statistic	df	p-value	Conclusion
Serial Correlation	Breusch-Godfrey LM (Lag 1)	$\chi^2 = 1.246$	1	0.264	No autocorrelation at lag 1
	Breusch-Godfrey LM (Lag 2)	$\chi^2 = 19.372$	2	0.000	Autocorrelation at lag 2
Heteroskedasticity	Cook-Weisberg	$\chi^2 = 0.000$	1	0.973	Homoskedastic residuals
Specification	Ramsey RESET	F = 2.980	(3, 15)	0.065	No functional misspecification
Stability	Recursive CUSUM	—	—	Within 5%	Structurally stable parameters

Short-run estimates reveal an immediate positive growth impact from capital formation (β = 0.388, p = 0.000) and a positive one-period lagged impact from trade openness (β = 0.221, p = 0.004). Diagnostic evaluations confirm residual homoskedasticity (p = 0.973) and parameter stability. The Breusch–Godfrey test shows that while the model is clean of first-order autocorrelation (p = 0.264), higher-order correlation at lag 2 (p = 0.000) justifies the deployment of DOLS with lead-lag corrections and FMOLS with Newey-West bandwidths.

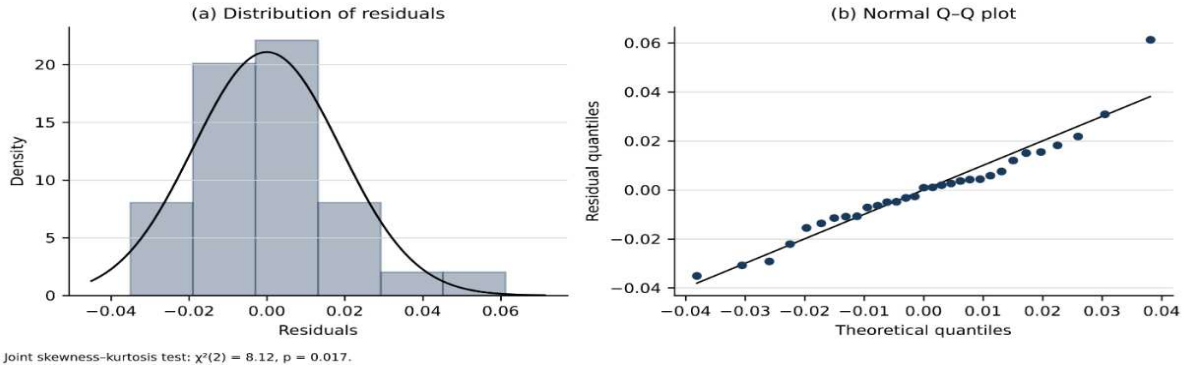
The recursive CUSUM in Figure 3 stays within the 95% confidence bands throughout the sample, so there is no significant evidence of parameter instability. The path drifts downward after 2017 but never crosses the lower bound, so stability should be read as supported rather than guaranteed.



Author's Computation ***Note****: the shaded Area is the 95% confidence band. A path inside the band indicates stability*

The short-run estimates indicate that capital formation has an immediate positive effect on productivity growth ($\Delta lnGFCF_t$: $\beta = 0.388$, $p = 0.000$). First-differenced lagged trade openness shows positive re-acceleration (Δln_to_{t-1}: $\beta = 0.221$, $p = 0.004$). Lagged FDI differences display a small negative coefficient ($\beta = -0.008$, $p = 0.073$), capturing short-run adjustment and installation costs. The diagnostic tests provide mixed results. The Cook–Weisberg test indicates no evidence of heteroskedasticity ($p = 0.973$), while the Breusch–Godfrey test indicates no first-order serial correlation ($p = 0.264$) but detects second-order serial correlation ($p = 0.000$). The Ramsey RESET test does not reject the null hypothesis at the 5% significance level ($p = 0.065$). Therefore, some diagnostic concerns remain and should be considered when interpreting the results.

Figure 4 shows the histogram and Q-Q plot of the ARDL residuals, which follow the normal line closely except for one large positive outlier. This matches the rejected joint normality test ($p = 0.017$) and supports the use of FMOLS and DOLS, which do not rely on normally distributed errors.



Author's computation ***Note:*** *joint skewness-kurtosis test:* $x^2(2)=8.12, p=0.017$

4.6 Vector Autoregression (VAR) Granger Causality Analysis

Table 8 presents bivariate VAR(2) Granger causality Wald tests.

Table 8: Bivariate VAR Granger Causality Wald Tests

Dependent Variable	Excluded Variable	χ^2 Statistic	df	p-value	Direction of Causality
lnLP	lnTO	**30.315**	2	**0.000*** **	**lnTO → lnLP** (Unidirectional)
lnTO	lnLP	3.039	2	0.219	
lnLP	IHSFDI	2.866	2	0.239	**lnLP → IHSFDI** (Unidirectional)
IHSFDI	lnLP	**6.652**	2	**0.036** **	
lnLP	lnGFCF	1.109	2	0.574	

lnGFCF	lnLP	1.203	2	0.548	**No Causality** (Neutral)
lnLP	lnMob	**19.668**	2	**0.000*** **	**lnMOB → lnLP** (Unidirectional)
lnMob	lnLP	2.090	2	0.352	

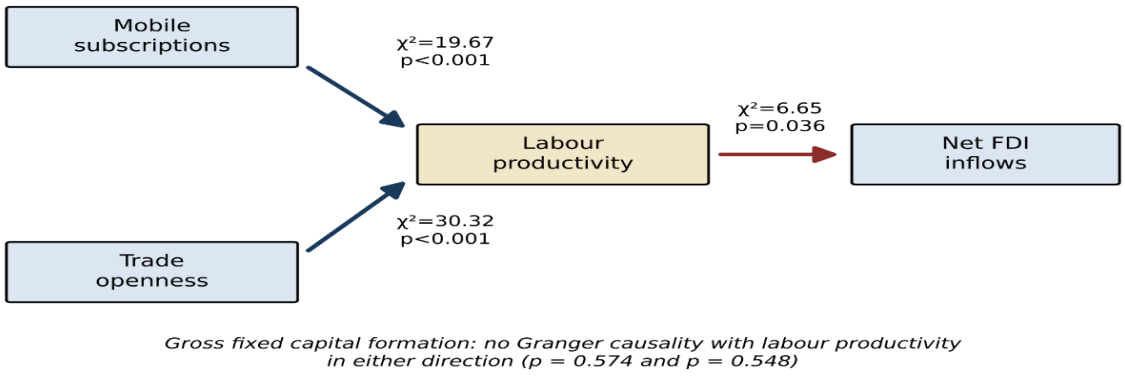
*Notes: Estimations derived from bivariate VAR(2) systems. *** and ** denote statistical significance at the 1% and 5% levels, respectively.*

The causality tests reveal clear directional links: mobile subscriptions ($\chi^2 = 19.668$, $p = 0.000$) and trade openness ($\chi^2 = 30.315$, $p = 0.000$) Granger-cause labor productivity. In contrast, causality runs from labor productivity to FDI ($\chi^2 = 6.652$, $p = 0.036$), indicating that foreign investment is attracted to productive domestic sectors.

The causality tests reveal three primary causal pathways:

- ***Mobile Subscriptions → Labor Productivity ($\chi^2 = 19.668$, $p = 0.000$):*** Strong unidirectional causality from telecommunications infrastructure to worker efficiency.
- ***Trade Openness → Labor Productivity ($\chi^2 = 30.315$, $p = 0.000$):*** Unidirectional causality confirming that trade movements precede productivity adjustments.
- ***Labor Productivity → FDI ($\chi^2 = 6.652$, $p = 0.036$):*** Significant unidirectional causality running from domestic labor productivity to foreign direct investment inflows.
- ***Capital Formation and Productivity ($\chi^2 = 1.109$, $p = 0.574$):*** Bilateral neutrality in temporal causality, reflecting extended gestation periods in fixed capital accumulation.

Figure 5 summarizes the Granger causality results, with causality running from mobile subscriptions and trade openness to labor productivity, and from labor productivity to FDI. Capital formation shows no causality in either direction, so the diagram highlights where the productivity effects originate and where they do not.



Source: Author's computation. Note: Arrows show Granger causality from VAR(2) Wald tests.

5. Discussion

5.1 The Digital Dividend: Telecommunications Leapfrogging in Somalia

The estimated long-run elasticity of mobile subscriptions (β ≈ 0.116–0.118, $p < 0.001$) and the confirmation of unidirectional causality (lnMOB → lnLP, $p = 0.000$) provide empirical evidence of digital leapfrogging.

This result contrasts with findings from other developing settings. In Indonesia, (Ridzuan et al., 2026) report a negative long-run ICT impact ($\beta = -0.070$), which they attribute to digital expansion outpacing domestic skills and human capital. In Serbia, (Madžar, 2023) finds no long-run cointegrating relationship between mobile phone users and labor productivity. In Somalia, however, mobile telecommunications served as an essential institutional substitute. In the absence of formal state banking and postal infrastructure, private mobile networks introduced mobile-money ecosystems that transformed domestic commerce. Mobile money lowered cash handling risks, eliminated counterfeit currency transaction costs, and enabled instant transfers of diaspora remittances across urban and rural markets (World Bank, 2020). The positive relationship between mobile subscriptions and labor productivity suggests that digital connectivity may support productivity improvements. One possible explanation is that mobile connectivity reduces information and communication costs. However, this study does not directly measure these mechanisms; therefore, they should be interpreted as possible explanations rather than directly tested effects.

The micro-foundations of this digital dividend are rooted in Somalia's informal currency arrangements. Following the collapse of the Central Bank of Somalia in 1991, the domestic market was flooded with counterfeit Somali Shillings, causing hyperinflation and currency rejections in local markets. The introduction of US dollar-denominated mobile money solved this medium-of-exchange failure. By enabling workers, micro-retailers, and transport operators to store value, settle accounts instantly, and execute small payments without transactional frictions, mobile money served as an informal financial architecture. This financial deepening reduced deadweight losses, stabilized purchasing power, and raised worker output across informal urban markets.

The diffusion of mobile connectivity has generated measurable structural efficiencies across rural agricultural and nomadic livestock value chains. Prior to mobile network penetration, livestock herders and smallholders in agricultural basins along the Juba and Shabelle rivers relied on visual inspection and local middlemen, suffering substantial price discounts and transport losses during recurring droughts. Mobile connectivity allowed real-time tracking of export prices at major coastal ports, enabling pastoralists to time their herd movements and optimize slaughterhouse sales. By facilitating localized price discovery and market integration, mobile infrastructure reduced spatial price dispersions, directly raising the value-added generated per agricultural worker.

Furthermore, mobile telecommunications expanded the effective size of domestic markets by integrating the informal services sector. Small retail traders, logistics intermediaries, water trucking vendors, and decentralized electricity providers coordinate daily operations through digital messaging and mobile-wallet settlements. This operational flexibility allowed private enterprises to bypass physical road network disruptions and institutional bottlenecks, transforming mobile communications into a functional substitute for state-provided logistical infrastructure. The

empirical finding that mobile connectivity drives labor efficiency confirms that telecommunications in Somalia operates as a General Purpose Technology that enhances multi-factor productivity across the economic system.

5.2 Capital Deepening in a Rebuilding Economy

The positive long-run elasticity of Gross Fixed Capital Formation ($\beta = 0.092–0.142$, $p < 0.001$) validates neoclassical capital deepening within the Somali economy (Msimanga & de Jongh, 2026; Ramirez, 2006, 2006; Solow, 1956) This finding contrasts sharply with (Anyachebelu et al., 2025) who found a negative capital formation coefficient in Nigeria due to Dutch disease dynamics. In Somalia, capital investments—concentrated in commercial real estate, telecommunications towers, port handling infrastructure (e.g., Mogadishu, Berbera, and Bosaso), and off-grid diesel/solar mini-grids—have directly enhanced worker productivity.

The nature of capital formation in Somalia reflects private investment in connective assets. In the absence of public capital budgets, private conglomerates invested heavily in energy generation through decentralized diesel and hybrid solar mini-grids, filling municipal power voids. Furthermore, investments in deep-sea port terminals, refrigerated container storage for agricultural produce, and inter-city transport logistics provided the capital stock necessary to support regional trade. As capital deepening took hold, workers transitioned from manual handling to mechanized logistics and digitized inventory management, raising output per worker.

However, the neutral Granger causality between ln_gfcf and ln_lp ($\chi^2 = 1.109$, $p = 0.574$) reflects extended gestation periods. Rebuilding physical capital in fragile environments requires time to overcome installation frictions, security overhead, and logistical fragmentation before manifesting in aggregate labor efficiency (Gradzewicz, 2021). Fixed assets must be complemented by managerial expertise, road connectivity, and institutional security before generating measurable output gains.

Private capital formation in Somalia has historically faced severe capital market imperfections and credit rationing. In the absence of an integrated formal banking system, the accumulation of capital assets was financed through retained earnings, informal family networks, and diaspora partnerships. This financing structure favored investments with rapid turnover, such as retail and real estate, while capital investments in capital-intensive manufacturing and large-scale agricultural machinery faced underinvestment. The positive elasticity of gross fixed capital formation demonstrates that despite these constraints, physical capital accumulation generated substantial productivity dividends, confirming that capital deepening remains indispensable for post-conflict recovery.

5.3 Openness Dynamics and Productivity-Pull FDI

The empirical findings for external variables reveal a clear structural pattern:

- ***Trade Openness:*** While trade openness is statistically insignificant in the static long-run cointegrating vector ($\beta = -0.018$ to $+0.024$), it exhibits strong unidirectional Granger causality toward labor productivity ($\chi^2 = 30.315$, $p = 0.000$) and positive lagged short-run dynamics ($\Delta ln_to_{t-1} = 0.221$, $p = 0.004$). Somalia is an open, import-dependent economy, relying on foreign imports for consumer staples, fuel, and construction materials, while exporting livestock and agricultural goods to Gulf economies. Exposure to international

trade acts as a dynamic efficiency shock, compelling domestic trading houses and port authorities to streamline operations, even if it does not permanently alter the steady-state growth rate ((Adhikary, 2011; Rakshit, 2021)

- ***FDI Inflows:*** While FDI yields a small, positive long-run elasticity ($\beta = 0.013$, $p < 0.01$), the Granger causality test reveals that causality runs strictly from Labor Productivity to FDI ($\chi^2 = 6.652$, $p = 0.036$). This indicates an efficiency-seeking capital pull: foreign investors (principally from the Somali diaspora, the Gulf States, and Turkey) do not randomly invest in Somalia; rather, they channel capital into sectors (telecommunications, logistics, port management, financial remittances) that have already demonstrated rising productivity, organizational resilience, and commercial viability.

This efficiency-seeking pull has been reinforced in the post-HIPC completion era. International investment flows into Somalia are concentrated in high-performing service enclaves, including the modernization of the Port of Mogadishu by Albayrak Group and the Port of Berbera by DP World. These foreign investors enter partnerships with established domestic firms that have already demonstrated cost efficiency and operating capacity. Rather than initiating productivity gains from scratch, inward FDI builds on established domestic efficiency, reinforcing the finding that domestic productivity gains precede foreign investment.

The structural composition of international trade in Somalia explains the disconnect between short-run dynamic impacts and long-run steady-state insignificance. The country's export profile remains concentrated in live animals shipped to Saudi Arabia, Oman, and the United Arab Emirates during the Hajj season, alongside modest shipments of sesame, dried limes, and frankincense. These primary agricultural goods embody low technological complexity and generate limited industrial learning-by-exporting. Meanwhile, imports consist predominantly of processed foodstuffs, petroleum products, manufactured consumer durables, and construction materials. While imported capital equipment introduces superior foreign technology—supporting the significant short-run Granger causality—the persistent trade deficit drains domestic liquidity, preventing trade openness from operating as an independent, sustained engine of long-run worker productivity.

6. Conclusion and Policy Implications

This study examined the relationships between digital infrastructure, gross fixed capital formation, foreign direct investment, trade openness, and labor productivity in Somalia over the period 1990–2024. The findings indicate positive and statistically significant associations between mobile subscriptions, gross fixed capital formation, IHS-transformed FDI, and labor productivity in the supplementary FMOLS and DOLS estimates. Trade openness is statistically insignificant in the reported long-run estimates. The Granger causality results indicate predictive relationships from mobile subscriptions and trade openness to labor productivity, and from labor productivity to FDI. However, the ARDL bounds test provides inconclusive evidence of cointegration, and second-order serial correlation remains a diagnostic concern. Therefore, the findings should be interpreted cautiously., several primary conclusions emerge. First, all macroeconomic variables exhibit first-order integration, I(1), confirming their suitability for cointegration modeling. Second, digital telecommunications infrastructure and domestic physical capital formation constitute the primary structural determinants of labor productivity, yielding robust long-run output elasticities of approximately 0.12% and 0.09%–0.14%, respectively. Third, foreign direct investment inflows

generate a modest, positive long-run productivity effect, with temporal causality flowing from domestic labor efficiency to foreign investment. Finally, international trade openness operates as an external dynamic catalyst in the short run rather than a permanent driver of the long-run steady state.

The historical trajectory of Somalia demonstrates that private entrepreneurial adaptation can sustain economic activity and generate productivity dividends even in the prolonged absence of centralized state institutions. The rapid expansion of mobile telecommunications infrastructure and digital financial platforms provided an informal institutional substitute that lowered transaction costs, mitigated currency instability, and supported domestic trade. However, informal market arrangements face structural limits. As the economy modernizes and rebuilds formal state structures, relying on uncoordinated private networks cannot substitute for comprehensive public infrastructure planning, national energy grids, and standardized legal frameworks.

Sustaining long-run labor productivity growth requires addressing structural capital allocation constraints. While private investment has driven commercial real estate, telecommunications, and urban retail, capital accumulation remains underrepresented in rural agricultural production, industrial manufacturing, and value-adding processing. Bridging this capital gap necessitates moving beyond post-conflict coping strategies toward targeted capital deepening, ensuring that domestic savings and foreign capital inflows are channeled into productivity-enhancing physical assets.

The successful attainment of the HIPC completion point in late 2023 represents a structural turning point for Somalia's economic architecture. By securing the cancellation of over $4.5 billion in external debt, the Federal Government of Somalia has restored sovereign financial legitimacy and reopened access to concessional development financing from the World Bank, International Monetary Fund, and African Development Bank. This structural shift allows the state to transition from humanitarian crisis management toward long-term public capital investment, establishing the foundational physical assets required to support private-sector efficiency.

Furthermore, international trade integration must transition from passive import dependence toward strategic export diversification. While trade openness provides important short-run competitive pressures, its long-run productivity contribution is constrained by the export of raw agricultural commodities and live animals. Transforming trade into a permanent driver of worker efficiency requires developing domestic agro-processing, meat packaging, cold-chain logistics, and maritime fisheries, enabling the Somali economy to capture a greater share of value-added across global supply chains.

To maximize the economic returns of the digital dividend, the Federal Government of Somalia (FGS) and the National Communications Authority (NCA) must institutionalize predictable regulatory frameworks for the telecommunications sector. Policy should focus on ensuring open spectrum allocation, safeguarding telecommunications infrastructure, and enforcing mobile-money interoperability across competing commercial platforms. Promoting rural mobile broadband penetration—particularly across nomadic pastoral corridors and agricultural river basins—will expand access to digital market information, deepen financial inclusion, and raise the productivity of rural workers.

In parallel, domestic capital formation policies must shift from consumption-driven real estate toward productive industrial and agricultural capital assets. The FGS, in collaboration with Federal Member States (FMS), should prioritize public-private partnerships (PPPs) to expand renewable energy generation, specifically solar and wind mini-grids. Lowering the cost of electricity—which remains among the highest in Sub-Saharan Africa due to reliance on fragmented diesel generators—will remove a primary operational bottleneck for small and medium-sized enterprises, directly lowering unit production costs and boosting labor productivity.

Given that labor productivity Granger-causes foreign direct investment, investment promotion strategies should focus on domestic institutional capacity and infrastructure readiness rather than tax concessions. Foreign investors and diaspora entrepreneurs are drawn to sectors with demonstrated operational efficiency. Establishing specialized commercial courts, clarifying property rights, streamlining business registration, and enforcing commercial contracts will lower sovereign risk premiums and attract productive foreign capital into agro-industrial processing, energy generation, and deep-sea fisheries.

Trade policy must focus on mitigating external imbalances by supporting export diversification and domestic value addition. The Ministry of Commerce and Industry should establish export quality-assurance agencies, phytosanitary inspection facilities, and modern slaughterhouses compliant with international food safety standards. Expanding processing facilities for livestock, hides, sesame, and marine resources will insulate the economy from external import bans, improve terms of trade, and raise worker output across trade-oriented sectors.

Inter-governmental fiscal and regulatory coordination between the Federal Government of Somalia and Federal Member States represents an institutional prerequisite for national productivity growth. Harmonizing customs administration, transit tariffs, and internal commercial codes across regional jurisdictions—including Mogadishu, Puntland, Jubaland, and Galmudug—is essential to eliminate internal trade barriers. Creating an integrated domestic common market will lower logistical costs, enhance internal labor mobility, and allow domestic enterprises to achieve critical scale economies.

The Central Bank of Somalia (CBS) should continue modernizing the national financial architecture. Building upon the National Payment System (NPS), the CBS must formalize regulatory oversight of digital mobile-money operators, establish reserve backing requirements for digital deposits, and reinforce anti-money laundering (AML) and counter-terrorist financing (CFT) compliance. Providing institutional stability to the digital payments ecosystem will protect consumer purchasing power, encourage formal banking intermediation, and lower the risk of systemic financial disruptions.

Educational policy and workforce development must be aligned with the technological requirements of the modern economy. The Ministry of Education, Culture and Higher Education should partner with private telecommunications operators and international technical institutes to establish accredited Technical and Vocational Education and Training (TVET) centers. Curricula should emphasize practical training in digital technology maintenance, fiber-optic installation, electrical grid management, mechanized agriculture, and modern commercial accounting, transforming informal workforce experience into verified human capital.

Finally, post-HIPC development finance should be channeled toward strategic transport corridors under the Ninth National Development Plan (NDP-9). Constructing durable paved highways connecting rural agricultural production zones to primary maritime export terminals will reduce inter-city freight costs and minimize transit times. Integrating improved road connectivity with automated customs clearance at seaports will enhance trade velocity and raise the overall efficiency of Somali labor.

7. Limitations and Future Research

This study is subject to several empirical limitations that provide avenues for future scholarly inquiry. First, the analysis utilizes national-level annual macroeconomic data, which may mask substantial spatial disparities across Federal Member States and conceal productivity differentials between urban service centers and nomadic pastoralists. Second, while mobile cellular subscriptions serve as a robust proxy for digital infrastructure in an economy that leapfrogged fixed wirelines, future research should incorporate granular indicators of mobile-money transaction volumes, digital financial service penetration, and internet bandwidth as historical reporting matures. Finally, as sub-national economic datasets and firm-level enterprise surveys become accessible in Somalia, future studies should employ micro-econometric panel techniques to examine the distributional impacts of digital finance and foreign investment across varying enterprise size categories and economic sectors.

Declarations

- **Ethical Approval:** Not applicable. This study does not involve research on human participants or animal subjects.
- **Consent to Participate:** Not applicable.
- **Consent to Publish:** Not applicable.
- **Competing Interests:** The authors declare that they have no competing financial or personal interests.
- **Funding:** The authors received no specific funding for this research.
- **Data Availability:** The datasets analyzed in this study are derived from the SESRIC database, supplemented by official statistical publications from the Central Bank of Somalia and the IMF, and are available from the corresponding author upon reasonable request.

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