

Article

Infrastructure Development and Economic Growth in Nigeria: Evidence from an Autoregressive Distributed Lag Model

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Abstract

Infrastructure is widely seen as a driver of growth, yet much of the evidence for Nigeria rests on series that mix nominal and real magnitudes. This study examines how public infrastructure spending on transport, education and health is associated with real economic growth in Nigeria over 1990-2022, controlling for the labour force, gross capital formation and the 2001 liberalisation of the telecommunications sector. All monetary series are expressed in constant 2010 Naira. The analysis combines unit-root tests (Augmented Dickey-Fuller, Phillips-Perron, Zivot-Andrews), the Autoregressive Distributed Lag bounds test with critical values simulated for the available sample size, Johansen cointegration tests on the integrated variables, and Toda-Yamamoto causality tests. After deflation, the evidence for a long-run relationship is weak: the bounds F-statistic falls in the inconclusive region and the coefficient on lagged real GDP is not negative, so long-run elasticities are not interpreted. In a first-difference growth model, none of the infrastructure variables is significantly associated with real GDP growth at the 5 percent level, and Toda-Yamamoto tests indicate that real GDP precedes spending on education and health rather than the reverse. The results caution against reading associations obtained from current-price data as evidence of an infrastructure-growth link, and suggest that spending volumes alone are a poor guide to growth outcomes. Policy implications are drawn from the literature, not from the estimates.

Keywords

Infrastructure development, Economic growth, Autoregressive distributed lag bounds test, Toda-Yamamoto causality, Nigeria

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1. Introduction

Sustainable and inclusive economic growth remains one of the most challenging development problems facing Nigeria, and the state of the country's infrastructure is the core of the problem. There is extensive evidence that good infrastructure improves the productivity of human capital, reduces production and transaction costs, and increases the productive capacity of an economy [1,2]. The same is found in continental assessments, which estimate that filling the infrastructure gap in Africa will boost annual economic growth by a few percentage points and enable productive transformation [3,4].

Among the different components of infrastructure, transport occupies a particular status because it is an enabler of almost all production and distribution decisions: farms and factories are linked through roads, railways, ports and airports; reduced transport costs increase market access for producers and consumers [5]. The telecommunications infrastructure has, however, become a similarly vital enabler in the modern economy. E-commerce, digital finance, mobile services, remote services and business connectivity all depend on reliable broadband networks and data systems, and countries with robust digital networks tend to integrate faster into global value chains [6].

The direction of public investment in infrastructure is clearly justified by growth theory. The neoclassical models focus on capital accumulation which increases the stock of productive factors and improves output per worker [2], whereas endogenous growth models center on innovation and technological advancement and human capital as sources of long-run economic growth [7,8]. The cross-country empirical studies also show that capital formation and human capital are strong predictors of growth [9,10]. Infrastructure plays a strategic role in these frameworks, since it contributes to the productivity of both physical and human capital.

Nigeria has been implementing a succession of reforms to increase its infrastructure supply. The government is intent on achieving this ambition through the National Digital Economy Policy and Strategy (2020-2030), the National Broadband Plan, as well as a nationwide project to roll out an extra 90,000 km of fibre-optic cable [6]. Responses in the telecoms sector have been positive: in the second quarter of 2024, the Information and Communications Technology (ICT) sector contributed approximately 19.8 percent of real GDP, and broadband penetration was approximately 48 percent by 2024 [6,11]. However, recent macroeconomic assessments highlight that infrastructure challenges persist, hindering market integration and growth potential.

This has been a step forward; however, the expansion of infrastructure has been uneven. Competitive network coverage is found in urban centres, whereas many rural and underserved areas still struggle to get decent coverage and face high user costs [12]. Transport infrastructure is also limited: roads are poorly maintained, some are affected by erosion, and funds allocated to capital works are not always used efficiently. These challenges are further exacerbated by high deployment costs, regulatory delays, right-of-way fees, vandalism and poor project governance [13,14].

The main question of this study is “How is infrastructure development (disaggregated into transport, education and health infrastructure) associated with real economic growth in Nigeria?” To answer it, an Autoregressive Distributed Lag (ARDL) model is estimated with annual data from 1990 to 2022, with real GDP as the dependent variable, and with the labour force, gross capital formation and a dummy for the 2001 liberalisation of the telecommunications sector as additional regressors. Transport receives particular attention because it is widely regarded as a primary enabler of economic activity: good transport and communication systems support the production and distribution of goods and services and thus the growth payoff of other sectors.

The remainder of the paper is organised as follows. The theoretical, conceptual and empirical literature is reviewed in Section 2. The data, the model specification and the estimation techniques are described in Section 3. The empirical findings are presented and discussed in Section 4 and the policy recommendations are provided in Section 5.

2. Literature Review

2.1 Conceptual Review

Infrastructure comprises the physical structures, systems and services that enable an economy to operate and support the strengths of other industries. It covers a wide range of infrastructure, including large-scale public utilities (electricity grids, roads, railways, water networks, communication systems) as well as specific assets (such as data cables). Infrastructure is often financed, regulated or provided directly by the state, and frequently has features of a public good or natural monopoly, and it is therefore often provided under public-private partnership contracts [1,3]. Economic infrastructure refers to the capital spending on transport, education, telecommunications and health, and labour force and capital formation refer to the conventional factors of the production function.

Infrastructure development refers to the work of the construction, development and upgrading of these facilities to promote economic growth and improve living standards. It is widely regarded as a viable path to growth: reducing transport and communication costs, increasing access to inputs and markets, facilitating trade and specialization, and increasing the marginal productivity of private capital [5,15]. The evidence from recent continental studies suggests that investment in a broadened transport, energy, and digital network can boost Africa's average GDP growth by

approximately 4.5 percentage points annually [3], and the meta-analysis work shows a positive average effect of physical infrastructure on output, with a significant cross-country and cross-sector variation [15].

2.2 Theoretical Framework

The neoclassical (Solow-Swan) growth model and the endogenous growth theory (in the form of an augmented production function) serve as the basis of this study. In the neoclassical model, growth is a result of the accumulation of factors of production (labour and capital) which, beyond a certain threshold, brings diminishing returns; infrastructure investment increases the quantity and efficiency of the capital stock [2]. This is supported by Aschauer's groundbreaking discovery that public capital enters into private production in an important way [1].

The endogenous growth theory focuses on the ability of the economy to self-reliantly create long-lasting growth via technological innovation, knowledge creation and transfer, and the accumulation of human capital [7,8]. In this context, infrastructure is not simply a complementary factor: telecommunication networks, education and health care systems influence innovation processes and the development and maintenance of human capital. The capital formation and human capital are powerful drivers of cross-country income differences as shown by augmented growth regressions [9,10]. So the model of Section 3 is based on real GDP as being a function of disaggregated infrastructure development, labour and capital formation.

2.3 Empirical Review

Overall, there is support for positive links between infrastructure and growth from the international evidence. Calderón and Servén show that quantity and quality of infrastructure are positively related to long-run growth in Sub-Saharan Africa [16], while Kodongo and Ojah do the same [17]. Esfahani and Ramírez find that the strength of the relationship varies by country's development and institutional quality [18], and Sánchez-Robles finds positive returns to infrastructure in a cross-section of countries [19]. There is also countervailing evidence: poorly selected, debt-financed infrastructure megaprojects are known to risk economic fragility [20] and the latest multi-country estimates indicate that the overall growth benefits of transport investment are positive but also relatively small, and dependent on the efficient use of the investment [3,15]. Assessments of productivity also emphasise that it is the quality of infrastructure services, rather than spending levels that are linked to the competitiveness of these services [21].

There is a mixed picture of evidence specific to Nigeria, and it is not yet fully settled. Investment in transport and communication is found to be significantly and positively associated with growth, whereas road construction spending shows an insignificant, and at times negative, association [14]. However, Abdur-Rahman et al. report that the long-run effects of telecom infrastructure on growth are marginally positive but less than expected due to its limited penetration in rural areas and vandalism of telecom infrastructure [13]. The rapid growth of the telecommunications sector and its increasing share of GDP are recorded in policy-oriented analyses, although substantial and persistent infrastructure problems still hold back the growth of the sector, including the high operating costs and numerous taxation and right-of-way issues [6,11], and infrastructure deficits continue to be a constraint on Nigeria's growth acceleration, according to the World Bank [12].

This review identifies three gaps. First, there is a paucity of recent Nigerian studies that examine infrastructure development in the sectors of transport, education, telecommunications, and health using a joint ARDL model and a more recent sample period. Second, most of the previous Nigerian research was conducted before the telecom boom revealed by the official statistics [6,11]. Third, the short-run dynamics and the speed of adjustment to long-run equilibrium are rarely analysed together with causal linkages between the infrastructure elements. This study uses constant-price data up to 2022, tests for integration orders before applying the bounds procedure, and uses causality methods suited to the integration and cointegration properties of the data.

3. Materials and Methods

3.1 Data and Variable Measurement

The study uses annual time-series data for 1990-2022 (33 observations). The data are reported in Appendices A and B (Tables S1 and S2), and variable definitions, sources, price bases and transformations are documented in Appendix C (Table S3). Real gross domestic product (RGDP, ₦ billions at constant 2010 prices) is the dependent variable, proxying economic growth. It is built from the nominal GDP series reported by the Central Bank of Nigeria and the National Bureau of Statistics [22,23] (₦54,612 billion in 2010, the base year) and a real-output index taken from the World Bank constant-price GDP series [24] for 1990-2020, rescaled so that real and nominal GDP coincide in 2010 and extended to 2021 and 2022 using the NBS real growth rates of 3.40 and 3.10 percent. The implied GDP deflator (2010 = 100) is the ratio of nominal to real GDP. The resulting 2022 level of ₦75.5 trillion is within about 1.1 percent of the ₦74.6 trillion published by the NBS at 2010 constant prices [23]. Infrastructure development is disaggregated into transport (TPID), educational (EDID) and health (HTID) infrastructure, each measured by government capital expenditure in the respective sector as reported in the CBN Statistical Bulletin [22]. Gross capital formation (KF) is taken from the same sources. TPID, EDID, HTID and KF are converted to constant 2010 Naira with the implied GDP deflator. The labour

force (LF, millions of persons) is taken from the World Development Indicators [24]. Telecommunications enters through a dummy variable (D01) equal to one from 2001, the year of the GSM spectrum auction and the start of the mobile-telephony expansion. The NBS information-and-communication output series used in earlier versions of this paper (TCID) has been removed because it measures sectoral output that is already part of GDP and therefore creates a mechanical part-whole relationship with the dependent variable. Mobile cellular subscriptions per 100 people (TEL, World Bank), the only physical telecommunications indicator available for the full sample, is used in descriptive statistics and in a sensitivity check only, because its order of integration could not be established (Section 4.2). All monetary series and the labour force enter the models in natural logarithms.

3.2 Model Specification

Following the augmented production-function tradition [2,10], the study specifies the relationship between economic growth and infrastructure development as:

$$RGDP_t = f(TPID_t, EDID_t, HTID_t, KF_t, LF_t, D01_t) \quad (1)$$

Which, in estimable stochastic linear form, becomes:

$$\ln RGDP_t = \beta_0 + \beta_1 \ln TPID_t + \beta_2 \ln EDID_t + \beta_3 \ln HTID_t + \beta_4 \ln KF_t + \beta_5 \ln LF_t + \beta_6 D01_t + \mu_t \quad (2)$$

where β_0 is the intercept, β_1 to β_5 are elasticities, β_6 is the shift in the level of real GDP associated with the post-2001 telecommunications regime, and μ_t is the stochastic error term. The a priori expectation is that the infrastructure, capital and labour variables are positively associated with growth ($\beta_i > 0$ for $i = 1, \dots, 5$), consistent with growth theory and the empirical consensus [1,16].

3.3 Estimation Techniques

3.3.1 Unit Root Testing

Because regression among non-stationary series can produce spurious results, the stationarity properties of the variables were examined with the Augmented Dickey-Fuller (ADF) test [25], using a constant and a constant with trend in levels, a constant in first and second differences, and lag lengths chosen by the Akaike Information Criterion (maximum of three lags in levels and two in differences). The Phillips-Perron (PP) test [26] is used as a robustness check, and the Zivot-Andrews (ZA) test [27], which allows one endogenous break in intercept and trend, is used to examine the possibility that apparent non-stationarity reflects structural change. The ARDL bounds procedure requires that no variable be integrated of order two; this condition is verified explicitly from the first- and second-difference results in Section 4.2.

3.3.2 ARDL Bounds Testing and Error-Correction Model

The ARDL bounds testing approach of Pesaran, Shin and Smith [28] was employed to estimate both the short-run dynamics and the long-run relationship. The unrestricted error-correction representation of the model is:

$$\Delta \ln RGDP_t = \alpha_0 + \gamma D01_t + \sum_{i=1}^{p-1} \alpha_i \Delta \ln RGDP_{t-i} + \sum_j \sum_{i=0}^{q-1} \beta_{ji} \Delta \ln X_{j,t-i} + \theta_1 \ln RGDP_{t-1} + \sum_j \theta_{j+1} \ln X_{j,t-1} + \varepsilon_t \quad (3)$$

where X_j denotes TPID, EDID, HTID, KF and LF, and p and q are lag orders. Because only 33 annual observations are available, the lag orders were chosen by the Schwarz Bayesian criterion over $p \in \{1, 2, 3\}$ and $q \in \{1, 2\}$ on a common estimation sample, which favours the most parsimonious structure ($p = 1, q = 1$, i.e. contemporaneous first differences); results for the other structures are reported as robustness checks. The bounds F-test restricts $\theta_1 = \theta_2 = \dots = \theta_6 = 0$ and is accompanied by the t-test on θ_1 [28]. Asymptotic bounds are unreliable with so few observations [29], so lower (all regressors $I(0)$) and upper (all regressors $I(1)$) critical values were simulated for this sample ($T = 33$, five regressors, unrestricted intercept, no trend, the same dummy and lag structure; 20,000 replications), and the asymptotic response-surface bounds of Kripfganz and Schneider [30] are reported for comparison. A level relationship is supported only if F exceeds the upper bound and θ_1 is negative and significant on the t-test. Conditional on cointegration, the long-run relationship implied by equation (3) is:

$$\ln RGDP_t = \varphi_0 + \varphi_1 \ln TPID_t + \varphi_2 \ln EDID_t + \varphi_3 \ln HTID_t + \varphi_4 \ln KF_t + \varphi_5 \ln LF_t + \varphi_6 D01_t + u_t \quad (4)$$

and the restricted short-run model, obtained by re-parameterising equation (3) around the long-run solution, is:

$$\Delta \ln RGDP_t = \alpha_0 + \gamma D01_t + \sum_i \alpha_i \Delta \ln RGDP_{t-i} + \sum_j \delta_{ji} \Delta \ln X_{j,t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (5)$$

where Δ is the first-difference operator, λ is the coefficient of the error-correction term $ECT_{t-1} = \ln RGDP_{t-1} - (\varphi_0 + \varphi_1 \ln TPID_{t-1} + \dots + \varphi_6 D01_{t-1})$ obtained from equation (4), and ε_t is the white-noise disturbance. If the bounds F- and t-tests do not support a level relationship, the error-correction term is dropped, equation (5) is estimated as a growth model in first differences, and the long-run coefficients are not interpreted. Cointegration is also assessed with the Johansen trace test [31] applied to the variables found to be $I(1)$, since the Johansen procedure is not valid for series that are stationary in levels. Residual diagnostics comprise the Breusch-Godfrey serial-correlation test, the Breusch-Pagan-Godfrey heteroskedasticity test, the Jarque-Bera normality test, the Ramsey RESET test, and the CUSUM and CUSUMSQ tests

of parameter stability based on recursive residuals [32]. Causality is examined with the Toda-Yamamoto procedure [33]: a VAR in levels of order $p + d_{\max}$ is estimated ($p = 1$ and $d_{\max} = 1$) and a Wald test is applied to the first p lags only, which gives a chi-square statistic that is valid whatever the integration and cointegration properties of the variables.

4. Results and Discussion

4.1 Descriptive Statistics

Table 1 summarises the series after conversion to constant 2010 prices. Real GDP more than tripled between 1990 (₦21.7 trillion) and 2022 (₦75.5 trillion), with a mean of ₦44.7 trillion; its distribution is mildly positively skewed and platykurtic, and the Jarque-Bera test does not reject normality ($p = 0.16$). The infrastructure expenditure series behave very differently. Measured in constant prices, capital expenditure on transport, education and health is strongly right-skewed (skewness of 2.5-2.6, kurtosis of 8.5-8.9, normality rejected) because very large real values in the early 1990s are followed by a lasting decline: real transport expenditure falls from ₦162 billion in 1990 to ₦19 billion in 2022, and real education and health expenditure fall by more than 95 percent over the same period (Table S2). Real gross capital formation is also right-skewed, with its highest values in the final years of the sample. The labour force rises steadily from 31.9 to 73.3 million, and mobile subscriptions rise from zero before 1993 to almost 100 per 100 people by 2022. The divergence between rising real GDP and falling real infrastructure outlays is itself informative: it implies that the two series cannot share a simple common upward trend once prices are removed.

Table 1. Descriptive statistics of the variables (constant 2010 prices, ₦ billions; LF in millions; TEL = mobile subscriptions per 100 people).

Statistic	RGDP	TPID	EDID	TEL	HTID	LF	KF
Mean	44,694.08	43.30	2,158.41	35.19	908.63	49.49	11,142.11
Median	41,126.66	32.66	1,021.00	21.68	359.00	48.85	9,781.39
Maximum	75,477.30	162.01	12,993.42	99.59	5,626.22	73.27	24,697.83
Minimum	21,680.20	19.37	500.23	0.00	200.68	31.94	8,174.68
Std. Dev.	20,218.99	32.48	2,963.64	37.20	1,316.46	11.77	4,229.16
Skewness	0.21	2.47	2.62	0.39	2.55	0.32	2.33
Kurtosis	1.41	8.55	8.86	1.49	8.46	2.11	7.39
Jarque-Bera	3.72	76.07	84.97	3.98	76.70	1.66	56.42
Probability	0.1559	0.0000	0.0000	0.1365	0.0000	0.4366	0.0000
Observations	33	33	33	33	33	33	33

Source: Author's computation using Python (statsmodels, scipy).

4.2 Unit Root Test Results

Table 2 reports the unit-root test results. Three results stand out. First, log real GDP, gross capital formation and the labour force are non-stationary in levels under both deterministic specifications (p -values between 0.29 and 0.99). The ZA test rejects a unit root for the labour force (break in 2011), which suggests that this smooth, model-based series may be trend-stationary around a break; its classification as $I(1)$ rests on the ADF and PP tests, and the bounds procedure accommodates either case. Their first differences are stationary under the ADF test for capital formation and the labour force ($p \leq 0.001$) and under the PP test for all three, although for real GDP the evidence is marginal (ADF $p = 0.048$, PP $p = 0.046$). Second-difference tests reject a unit root decisively for each of them, so none is integrated of order two. Second, the real infrastructure expenditure series are stationary in levels under the ADF test with a constant ($p = 0.028$ for transport, 0.003 for education and 0.001 for health), which is consistent with the decline-then-stabilise profile noted in Section 4.1 and Table S2; the ZA test confirms stationarity around a break in 2010 for transport but not for education or health, so these two are classed as $I(0)$ or $I(1)$. In neither case is there evidence of integration of order two, because second differences are decisively stationary and the levels are not explosive. Third, the logarithm of mobile subscriptions cannot be classified: it is non-stationary in levels, its first difference is not stationary under ADF ($p = 0.26$) or PP ($p = 0.25$), and only its second difference is, so integration of order two cannot be excluded. Its S-shaped diffusion after 2001 is the likely reason, and the ZA test finds a break in 2001. Because the bounds procedure is invalid in the presence of $I(2)$ regressors, this variable is excluded from the ARDL model and the telecommunications regime shift is captured by the 2001 dummy instead. The remaining variables are therefore a mixture of $I(0)$ and $I(1)$ series with none integrated of order two, which is the case the ARDL bounds procedure is designed to handle.

Table 2. Unit-root tests: ADF, PP and ZA (test statistic, p-value in parentheses).

Variable	ADF level (c)	ADF level (c, t)	ADF Δ (c)	PP Δ (c)	ADF Δ^2 (c)	ZA level (break year)	Conclusion
ln RGDP	-0.68 (0.853)	-1.67 (0.766)	-2.88 (0.048)	-2.89 (0.046)	-5.21 (0.000)	-4.22 (2012)	I(1)
ln TPID	-3.08 (0.028)	-3.95 (0.010)	-2.65 (0.083)	-2.19 (0.210)	-6.31 (0.000)	-5.16 (2010)	I(0)
ln EDID	-3.76 (0.003)	-3.69 (0.023)	-2.07 (0.256)	-2.75 (0.065)	-8.59 (0.000)	-3.36 (2018)	I(0) / I(1)
ln HTID	-4.04 (0.001)	-4.07 (0.007)	-2.35 (0.158)	-2.21 (0.202)	-6.64 (0.000)	-4.09 (1994)	I(0) / I(1)
ln KF	0.98 (0.994)	-0.49 (0.984)	-4.49 (0.000)	-4.54 (0.000)	-6.76 (0.000)	-4.26 (2015)	I(1)
ln LF	0.18 (0.971)	-2.58 (0.291)	-4.05 (0.001)	-2.99 (0.036)	-6.11 (0.000)	-10.85 (2011)	I(1)
ln(1+TEL)	-1.11 (0.712)	-3.18 (0.089)	-2.06 (0.261)	-2.09 (0.247)	-3.17 (0.022)	-5.44 (2001)	I(2) excluded

Note: c = constant, t = trend; lags chosen by AIC (maximum three in levels, two in differences). MacKinnon 5% critical values are approximately -2.96 (c) and -3.56 (c, t); the 5% ZA critical value (intercept and trend break) is -5.08. Source: Author's computation using Python (statsmodels, arch).

4.3 Cointegration Test Results

Table 3 reports the multivariate assessment of cointegration. The bounds F-statistic of 4.36 exceeds the asymptotic upper bound of 3.63, which taken alone would indicate a level relationship. With 33 observations and five regressors, however, the simulated 5 percent bounds are 3.46 and 5.11, and the statistic falls between them (it exceeds only the 10 percent upper bound of 4.26), so the test is inconclusive. The accompanying t-test is more informative and points the other way: the coefficient on lagged real GDP is positive (0.007, $t = 0.07$), whereas error correction requires a negative and significant coefficient below -3.26. A positive coefficient means deviations from any long-run relationship are not reversed. The Johansen trace test on the I(1) variables gives a result that depends on the lag order: with one lag in differences, the null of no cointegration is not rejected, whereas with two lags a single relationship appears. A Johansen test on all six series is not reported because three of them are stationary or near-stationary in levels, and the procedure then returns a spuriously high cointegration rank. Taken together, the evidence does not establish a stable long-run relationship between real GDP and the infrastructure variables, and the long-run coefficients of equation (4) are therefore not interpreted.

Table 3. Cointegration tests.

Test	Statistic	5% Critical value	Decision
ARDL bounds F-test ($k = 5$, $T = 33$)	$F = 4.36$	I(0) 3.46 / I(1) 5.11	Inconclusive at 5%
asymptotic bounds (Kripfganz-Schneider)		2.46 / 3.63	Above upper bound
ARDL bounds t-test on $\ln \text{RGDP}_{t-1}$	$t = 0.07$	-3.26 / -4.48	No support (coefficient positive)
Johansen trace, I(1) variables, 1 lag in differences: $r = 0$	19.58	29.80	No cointegration
$r \leq 1$	3.76	15.49	Not rejected
Johansen trace, I(1) variables, 2 lags in differences: $r = 0$	42.90	29.80	One relation
$r \leq 1$	6.29	15.49	Not rejected
Sensitivity: bounds F with $\ln(1+\text{TEL})$ in place of D01	$F = 1.75$	3.46 / 5.11	No cointegration

Note: the I(1) variables are $\ln \text{RGDP}$, $\ln \text{KF}$ and $\ln \text{LF}$. Simulated small-sample bounds ($T = 33$, 20,000 replications) are I(0)/I(1). Source: Author's computation using Python (statsmodels).

4.4 ARDL Estimates and Growth Model

The selected specification is ARDL(1, 1, 1, 1, 1, 1) in its unrestricted error-correction form (equation 3), with an unrestricted intercept and the 2001 dummy. It is estimated on 32 effective observations (1991-2022) with 13 parameters, leaving 19 residual degrees of freedom. The maximum lag considered was three for the dependent variable and two for the regressors, and the Schwarz criterion favoured the most parsimonious structure; other structures are examined in Section 4.5. Given the small number of degrees of freedom, the estimates in Table 4 should be read with caution.

Table 4. Unrestricted error-correction model, ARDL(1, 1, 1, 1, 1, 1) (dependent variable: $\Delta \ln \text{RGDP}$).

Variable	Coefficient	Std. Error	t-Statistic	Probability
Constant	0.5931	0.3276	1.810	0.0861
D01 (post-2001)	0.0417	0.0291	1.432	0.1684
$\ln \text{RGDP}(-1)$	0.0067	0.0945	0.070	0.9445
$\ln \text{TPID}(-1)$	0.0366	0.0465	0.787	0.4407
$\ln \text{EDID}(-1)$	-0.2940	0.1584	-1.856	0.0790
$\ln \text{HTID}(-1)$	0.2730	0.1520	1.795	0.0885
$\ln \text{KF}(-1)$	-0.0699	0.0580	-1.205	0.2429
$\ln \text{LF}(-1)$	0.0721	0.2492	0.289	0.7754
$\Delta \ln \text{TPID}$	-0.0214	0.1018	-0.211	0.8354
$\Delta \ln \text{EDID}$	-0.0820	0.1723	-0.476	0.6398
$\Delta \ln \text{HTID}$	0.1331	0.1635	0.814	0.4255
$\Delta \ln \text{KF}$	0.0357	0.0502	0.711	0.4857
$\Delta \ln \text{LF}$	-0.2318	0.4472	-0.518	0.6102
R-squared	0.714			
Adjusted R-squared	0.534			
F-statistic (prob.)	3.958			0.0038
Durbin-Watson	2.79			
Observations / parameters	32 / 13			

Source: Author's computation using Python (statsmodels).

The estimates in Table 4 offer little sign of a stable level relationship. The coefficient on lagged real GDP, which measures the speed of adjustment towards equilibrium, is effectively zero and has the wrong sign (0.007, $p = 0.945$). None of the lagged-level coefficients on the infrastructure variables, capital formation or the labour force is significant at the 5 percent level; education ($p = 0.079$) and health ($p = 0.089$) are significant only at the 10 percent level, with opposite signs. None of the contemporaneous differences is significant either. The R-squared of 0.71 refers to a regression in growth rates and is more modest than the near-perfect fit of levels models of trending series; it should not be taken as evidence of strong explanatory power given 19 residual degrees of freedom.

Because the bounds and Johansen tests do not support cointegration, the relationship is examined in the growth model of Table 5, in which all variables enter in first differences and no long-run term is imposed. Real GDP growth shows significant persistence (coefficient 0.39, $p = 0.015$). Growth in real transport, education and health spending, in capital formation and in the labour force is not significantly associated with real GDP growth, and the 2001 dummy is also insignificant; the model as a whole is not significant at the 5 percent level (F $p = 0.083$). Transport infrastructure, the original focus of the study, has a coefficient close to zero (-0.016 , $p = 0.915$). These results are conditional associations estimated on 31 observations; they are not evidence that infrastructure is unproductive, but they show that year-to-year variation in real capital spending does not explain year-to-year variation in real output in this sample.

Table 5. Growth model in first differences (dependent variable: $\Delta \ln \text{RGDP}$; Newey-West standard errors).

Variable	Coefficient	Std. Error	t-Statistic	Probability
Constant	0.0277	0.0323	0.857	0.3914
$\Delta \ln \text{RGDP}(-1)$	0.3865	0.1594	2.424	0.0153
$\Delta \ln \text{TPID}$	-0.0158	0.1470	-0.107	0.9146
$\Delta \ln \text{EDID}$	0.1220	0.1264	0.965	0.3345
$\Delta \ln \text{HTID}$	-0.0927	0.1921	-0.483	0.6293
$\Delta \ln \text{KF}$	-0.0034	0.0302	-0.113	0.9099
$\Delta \ln \text{LF}$	-0.3665	0.3485	-1.052	0.2929
D01 (post-2001)	0.0120	0.0239	0.504	0.6141
R-squared / adjusted	0.392 / 0.206			
F-statistic (prob.)	2.115			0.0829
Observations	31			

Source: Author's computation using Python (statsmodels).

4.5 Diagnostic and Stability Tests

The diagnostics in Table 6 are mixed. The error-correction model passes the normality, heteroskedasticity and RESET tests, and the CUSUM and CUSUMSQ plots in Figure 1 stay inside their 5 percent bounds, although with only 19 recursive residuals these stability tests have limited power. However, the Breusch-Godfrey test rejects the absence of serial correlation ($p = 0.010$ at one lag), and the Durbin-Watson statistic of 2.79 and the first-order residual autocorrelation of about -0.40 in Figure 1(b) point to negative autocorrelation. This is a further sign that the levels terms in Table 4 do not describe an equilibrium relationship, and it is one reason the long-run coefficients are not interpreted. The growth model of Table 5 passes all four tests applied to it, and its standard errors are Newey-West adjusted. The ZA results in Table 2 show significant breaks in the transport (2010), labour-force (2011) and mobile-subscription (2001) series, but none in real GDP, capital formation, education or health. The sample is retained intact, and the 2001 dummy, which corresponds to the telecommunications break, is the only break term.

Table 6. Residual diagnostic and stability tests (error-correction model of Table 4).

Test	Statistic	Probability	Conclusion
Breusch-Godfrey LM (1 lag)	6.66	0.0098	Serial correlation present
Breusch-Godfrey LM (2 lags)	9.58	0.0083	Serial correlation present
Breusch-Pagan-Godfrey LM	18.27	0.1077	No heteroskedasticity
Jarque-Bera	0.30	0.8600	Residuals normal
Ramsey RESET (F, one fitted term)	0.74	0.4000	No misspecification
CUSUM			Within 5% bounds
CUSUMSQ			Within 5% bounds
Growth model (Table 5): BG(1) / BP / JB / RESET p		0.92 / 0.72 / 0.07 / 0.64	No violations at 5%

Source: Author's computation using Python (statsmodels). Recursive residuals follow Brown, Durbin and Evans [32].

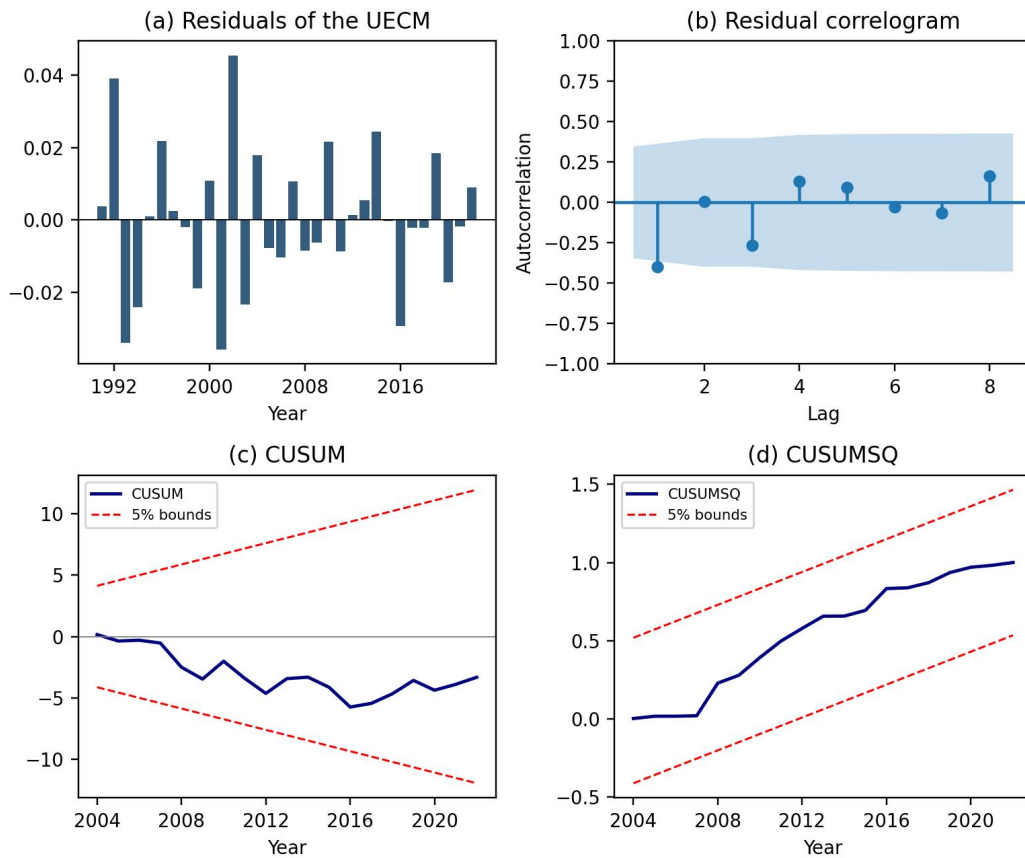


Figure 1. Residuals, residual correlogram, CUSUM and CUSUMSQ of the error-correction model in Table 4. Source: Author's computation using Python (statsmodels, matplotlib). (a) Residuals of the UECM. (b) Residual correlogram. (c) CUSUM. (d) CUSUMSQ.

Across the twelve specifications in Table 7, the coefficient on lagged real GDP is negative and statistically indistinguishable from zero in some and positive in others, and its t-statistic never approaches the -3.26 needed to reject the null at 5 percent. The F-statistic exceeds the simulated upper bound of 5.11 in only three of the twelve cases ($p = 3$, $q = 1$ with and without the dummy, and $p = 3$, $q = 2$ without it), all of which use the shortest effective sample and the fewest degrees of freedom, and none is accompanied by a negative adjustment coefficient. The conclusion that the data do not support a stable long-run relationship is therefore robust to the lag structure and to the treatment of the 2001 break.

Table 7. Robustness of the bounds test to the lag structure and the 2001 dummy.

Lag structure	D01 included	Obs.	Resid. d.f.	F-statistic	Coefficient on $\ln \text{RGDP}(-1)$	t-statistic
$p = 1, q = 1$	Yes	32	19	4.36	0.007	0.07
$p = 1, q = 1$	No	32	20	4.11	0.043	0.46
$p = 1, q = 2$	Yes	31	13	3.57	-0.168	-1.09
$p = 1, q = 2$	No	31	14	3.74	-0.123	-0.86
$p = 2, q = 1$	Yes	31	17	3.15	0.027	0.26
$p = 2, q = 1$	No	31	18	2.74	0.054	0.51
$p = 2, q = 2$	Yes	31	12	2.64	-0.115	-0.69
$p = 2, q = 2$	No	31	13	2.67	-0.083	-0.50
$p = 3, q = 1$	Yes	30	15	5.18	0.071	0.76
$p = 3, q = 1$	No	30	16	5.21	0.087	0.93
$p = 3, q = 2$	Yes	30	10	4.83	0.031	0.21
$p = 3, q = 2$	No	30	11	6.73	0.026	0.19

Note: the simulated 5% bounds for the F-statistic are 3.46 (I(0)) and 5.11 (I(1)); the 5% t-test bounds are -3.26 and -4.48 . Source: Author's computation using Python.

4.6 Toda-Yamamoto Causality Test Results

The Toda-Yamamoto results in Table 8 replace the earlier pairwise Granger tests, which are not valid for variables with different integration orders and omit the other model variables. No infrastructure variable, capital formation or the labour force helps predict real GDP at the 5 percent level, and the infrastructure variables are not jointly significant ($\chi^2(3) = 3.28$, $p = 0.350$). Health spending is borderline ($p = 0.095$). In the opposite direction, real GDP helps predict real spending on education ($p = 0.010$) and health ($p = 0.022$). This pattern is compatible with infrastructure spending following income rather than leading it, in the manner of Wagner's law, although it rests on 31 observations and a VAR with 14 parameters per equation and should be read as indicative. With 30 tests in the full system, a few rejections at 5 percent would also be expected by chance.

Table 8. Toda-Yamamoto causality tests (VAR(2) in levels, $p = 1$, $d_{\max} = 1$; χ^2 statistic, null: no causality).

Null hypothesis ($X \rightarrow Y$: X does not cause Y)	χ^2 statistic	Probability	Decision (5%)
TPID $\rightarrow$ RGDP	0.40	0.527	Do not reject
EDID $\rightarrow$ RGDP	1.21	0.272	Do not reject
HTID $\rightarrow$ RGDP	2.79	0.095	Do not reject
KF $\rightarrow$ RGDP	0.79	0.375	Do not reject
LF $\rightarrow$ RGDP	1.95	0.162	Do not reject
RGDP $\rightarrow$ TPID	1.01	0.315	Do not reject
RGDP $\rightarrow$ EDID	6.70	0.010	Reject
RGDP $\rightarrow$ HTID	5.23	0.022	Reject
RGDP $\rightarrow$ KF	2.29	0.130	Do not reject
RGDP $\rightarrow$ LF	0.02	0.878	Do not reject
TPID, EDID, HTID jointly $\rightarrow$ RGDP	3.28	0.350	Do not reject
All five regressors jointly $\rightarrow$ RGDP	7.63	0.178	Do not reject

Source: Author's computation using Python (statsmodels). The VAR contains the six log variables and D01; 31 observations and 14 parameters per equation.

4.7 Discussion of Findings

The main finding is a negative one: once the series are expressed in constant prices and their integration properties are respected, there is no stable long-run relationship between infrastructure spending and real GDP in this sample. The bounds test is inconclusive, the adjustment coefficient has the wrong sign, and the Johansen result is sensitive to the lag order. This contrasts with the strong apparent long-run relationship that current-price series produce, and it is a reminder that regressions on nominal series are dominated by a shared inflationary trend. The result is in line with studies that find the growth return to infrastructure to be conditional on the quality of investment, project delivery and maintenance rather than on the volume of spending [16,17,20], and with Nigerian evidence on abandoned and poorly maintained projects [14].

The sharp fall in real capital expenditure on transport, education and health between 1990 and 2022, at a time when real GDP more than tripled, is probably central to the weak association. Real outlays on these sectors in the early 1990s were much larger than in the 2010s, so the series carry little of the upward co-movement with output that a positive elasticity would require. The causality results are consistent with this: real GDP precedes spending on education and health, which is more compatible with expenditure following income, as in Wagner's law, than with an infrastructure-led growth process. The transport coefficient is statistically insignificant in both the error-correction and the growth model, which is consistent with arguments that transport investment has a growth payoff only when projects are completed and maintained [5,20]; the present data do not test that mechanism.

Telecommunications is the sector for which the expectation of a growth effect is strongest [3,15], yet it could not be modelled satisfactorily. The NBS information-and-communication series is part of GDP, and the mobile-subscription series is not demonstrably integrated of order one or lower, so telecommunications enters only as a post-2001 dummy, which is not significant in the growth model. The negative but insignificant coefficients on the labour force and on capital formation in the differenced model should likewise be read cautiously, since annual labour-force estimates are smooth, model-based series. Several limitations apply: the sample has only 33 annual observations and few residual degrees of freedom; the series are public expenditure flows and not measures of infrastructure stocks or quality; the real GDP series and deflator are reconstructed from World Bank and NBS data and may differ slightly from the official constant-price series; and the error-correction model shows residual serial correlation. These findings should therefore be treated as evidence that a robust infrastructure-growth relationship cannot be established with these data, not as evidence that none exists.

5. Conclusion and Policy Recommendations

This study examined how infrastructure development is associated with real economic growth in Nigeria from 1990 to 2022. Monetary series were converted to constant 2010 prices, integration orders were verified before applying the ARDL bounds procedure, and small-sample critical values were simulated for the available sample. The evidence does not support a stable long-run relationship: the bounds test is inconclusive and the adjustment coefficient is positive. In a growth model in first differences, transport, education and health spending, capital formation and the labour force are not significantly associated with real GDP growth, and Toda-Yamamoto tests show real GDP preceding spending on education and health, not the reverse. Real capital expenditure on all three sectors fell sharply over the period while real GDP more than tripled. The title of the study reflects its scope: transport is one of three expenditure categories examined jointly and is statistically insignificant in both models. The recommendations below are drawn from the literature reviewed in Section 2 and are not implied by the estimates; the estimates themselves do not identify a robust growth payoff to the volume of infrastructure spending.

- (1) The insignificant transport results, read alongside Nigerian evidence on abandoned projects, poor maintenance and erosion [14,20], suggest that completion, quality control and maintenance of existing roads may matter more than new project announcements. This is an implication from the literature; road quality and maintenance are not measured in this study.
- (2) Telecommunications could not be modelled with a satisfactory continuous indicator. Literature on rural coverage gaps, right-of-way costs and vandalism [12-14] suggests that sustaining investment in rural broadband, harmonising right-of-way charges and protecting fibre assets may broaden the sector's contribution. These measures are implications from the literature and are not tested by the model.
- (3) Because health spending does not lead GDP in the causality tests, the wider literature on the governance and efficiency of public investment [16,20] suggests attention to how health infrastructure spending is used, including the revival of abandoned facilities and, as some studies propose, public-private partnership arrangements for facility management. These options are drawn from the literature and are not supported directly by the model.
- (4) Educational infrastructure is not significantly associated with growth in the differenced model; the literature emphasises pairing educational infrastructure with quality improvements [21]. Any expansion should be judged on that broader evidence.
- (5) The labour force is not significantly associated with real GDP growth in the differenced model. The literature on context-dependent labour-force effects [18,19,34] suggests that job-rich, productivity-enhancing policies, such as skills

development and support for labour-absorbing sectors, are worth considering. This is a policy hypothesis rather than a tested result.

Future research could extend the analysis with official constant-price series from the NBS and CBN, quarterly data, measures of infrastructure stocks and quality (for example road condition, power and broadband coverage), and panel data for African countries, which would also relieve the small-sample constraint.

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Ethics Statement

This study uses only publicly available, aggregate macroeconomic data. It involved no human participants, personal data or animals, and ethical approval was therefore not required.

Data Availability Statement

All data used in this study are reported in Appendices A and B (Tables S1 and S2) and documented in Appendix C (Table S3). They were obtained from publicly available sources: the Central Bank of Nigeria Statistical Bulletin, the National Bureau of Statistics and the World Bank World Development Indicators.

Author Contributions

The author contributed to the conception and design of the study, data collection, analysis and interpretation, and to drafting and revising the manuscript. The author read and approved the final version.

Conflict of Interest

The author declares that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Generative AI Statement

Generative AI was used only to assist with language editing and to improve the clarity of the text. The AI tool used was Claud AI, ChatGPT. No other AI tools were used in the preparation of the manuscript. The author reviewed and edited all output and take full responsibility for the content of the manuscript.

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Appendix A. Current-price data as reported by the sources (₦ billions; LF in millions)

Table S1 reports the series before deflation (current prices). Education, transport and health are government capital expenditure; KF is gross capital formation. These are the inputs to the constant-price series in Appendix B.

Table S1. Current-price data as reported by the sources (₦ billions; LF in millions).

Year	GDP (current)	Transport	Education	Health	Capital formation	Labour force
1990	490	3.66	293.53	127.10	263	31.94
1991	584	3.72	296.64	129.95	286	32.84
1992	897	3.97	305.17	137.58	397	33.75
1993	1,245	4.37	314.01	140.62	559	34.70
1994	1,751	4.96	318.49	140.26	744	35.67
1995	3,069	5.76	318.30	138.09	1,153	36.66
1996	4,045	6.62	327.52	141.10	1,495	37.68
1997	4,374	7.61	333.18	143.41	1,698	38.71
1998	4,757	9.14	338.84	147.50	1,949	39.76
1999	5,426	10.97	344.51	150.27	2,099	40.82
2000	6,991	11.84	350.17	157.23	2,405	41.89
2001	8,150	13.03	355.83	160.23	2,473	43.02
2002	11,384	15.18	383.83	163.35	3,079	44.14
2003	13,418	15.18	410.83	166.43	3,846	45.28
2004	17,938	16.08	455.40	184.49	4,724	46.43
2005	22,885	17.03	503.44	203.06	5,773	47.62
2006	30,064	18.07	557.67	224.14	7,948	48.85
2007	34,319	19.18	617.78	247.44	6,998	50.11
2008	39,542	20.36	684.31	273.16	7,535	51.41
2009	43,013	21.48	752.79	300.74	9,177	52.75
2010	54,612	22.65	826.67	330.96	9,183	54.15
2011	62,980	26.96	1,087.67	374.12	9,897	55.65
2012	71,714	33.39	1,105.90	390.30	10,282	54.75
2013	80,093	39.14	1,278.41	427.72	11,478	53.71
2014	89,044	44.69	1,391.95	472.63	13,594	55.76
2015	94,145	47.11	1,498.71	484.34	14,112	57.87
2016	101,489	46.58	1,518.93	475.69	15,104	60.06
2017	113,712	46.68	1,507.98	474.24	16,908	62.42
2018	127,737	47.60	1,507.56	472.70	24,550	64.86
2019	144,210	48.87	1,519.66	474.17	35,864	67.37
2020	152,324	46.55	1,313.39	484.74	41,254	68.63
2021	173,528	48.45	1,303.55	508.63	58,294	70.62
2022	199,336	51.15	1,321.11	529.99	65,227	73.27

Source: CBN Statistical Bulletin [22]; NBS [23]; World Bank WDI [24].

Appendix B. Constant-price series used in the estimation (2010 prices, ₦ billions; LF in millions; TEL per 100 people)

Table S2 reports the series after deflation. The implied GDP deflator (2010 = 100) is current-price GDP divided by real GDP. Real TPID, EDID, HTID and KF equal the current-price values in Appendix A divided by the deflator and multiplied by 100.

Table S2. Constant-price series used in the estimation (2010 prices, ₦ billions; LF in millions; TEL per 100 people).

Year	Deflator	Real GDP	Transport	Education	Health	Capital formation	Labour force	TEL
1990	2.3	21,680	162.01	12,993.4	5,626.2	11,632	31.94	0.00
1991	2.7	21,758	138.54	11,047.1	4,839.4	10,636	32.84	0.00
1992	3.9	22,766	100.74	7,744.1	3,491.3	10,065	33.75	0.00
1993	5.6	22,302	78.29	5,625.9	2,519.4	10,018	34.70	0.01
1994	8.0	21,898	62.02	3,982.3	1,753.8	9,304	35.67	0.01
1995	14.0	21,882	41.06	2,269.1	984.4	8,223	36.66	0.01
1996	17.7	22,800	37.31	1,845.9	795.3	8,425	37.68	0.01
1997	18.6	23,469	40.83	1,787.5	769.4	9,109	38.71	0.01
1998	19.8	24,075	46.26	1,715.0	746.5	9,863	39.76	0.02
1999	22.4	24,216	48.95	1,537.4	670.6	9,365	40.82	0.02
2000	27.5	25,430	43.07	1,273.8	572.0	8,748	41.89	0.02
2001	30.3	26,935	43.06	1,176.0	529.6	8,175	43.02	0.21
2002	36.6	31,064	41.42	1,047.4	445.8	8,402	44.14	1.18
2003	40.2	33,347	37.73	1,021.0	413.6	9,559	45.28	2.30
2004	49.2	36,431	32.66	924.9	374.7	9,593	46.43	6.48
2005	59.0	38,777	28.86	853.0	344.1	9,781	47.62	12.82
2006	73.1	41,127	24.72	762.9	306.6	10,873	48.85	21.68
2007	78.3	43,837	24.50	789.1	316.1	8,939	50.11	26.36
2008	84.5	46,803	24.10	810.0	323.3	8,919	51.41	39.97
2009	85.1	50,564	25.25	885.0	353.5	10,788	52.75	45.98
2010	100.0	54,612	22.65	826.7	331.0	9,183	54.15	52.39
2011	109.5	57,511	24.62	993.2	341.6	9,038	55.65	55.53
2012	119.6	59,944	27.91	924.4	326.2	8,594	54.75	64.01
2013	125.3	63,943	31.25	1,020.6	341.5	9,164	53.71	70.28
2014	131.0	67,978	34.12	1,062.6	360.8	10,378	55.76	74.75
2015	134.9	69,781	34.92	1,110.9	359.0	10,460	57.87	79.10
2016	147.8	68,652	31.51	1,027.5	321.8	10,217	60.06	78.97
2017	164.3	69,206	28.41	917.8	288.6	10,290	62.42	72.37
2018	181.1	70,536	26.28	832.5	261.0	13,557	64.86	84.28
2019	200.0	72,094	24.43	759.7	237.0	17,929	67.37	88.12
2020	215.1	70,801	21.64	610.5	225.3	19,175	68.63	95.44
2021	237.0	73,208	20.44	549.9	214.6	24,593	70.62	89.29
2022	264.1	75,477	19.37	500.2	200.7	24,698	73.27	99.59

Source: Author's calculations from Appendix A; World Bank WDI [24] (TEL).

Appendix C. Variable documentation

Table S3. Definitions, sources and transformations of the variables.

Variable	Definition and unit	Source and code	Price basis and transformation
RGDP	Real GDP, ₦ bn, 2010 prices	CBN/NBS nominal GDP [22,23]; World Bank constant-price GDP [24] (index, 1990-2020); NBS growth 2021-2022	Constant 2010 prices; rescaled to nominal GDP in 2010; log
TPID, EDID, HTID	Government capital expenditure on transport, education, health, ₦ bn	CBN Statistical Bulletin [22]	Deflated by implied GDP deflator (2010 = 100); log
KF	Gross capital formation, ₦ bn	CBN Statistical Bulletin [22]	Deflated by implied GDP deflator; log
LF	Labour force, millions	World Bank WDI [24]	Log
TEL	Mobile cellular subscriptions per 100 people	World Bank WDI, IT.CEL.SETS.P2 (retrieved 8 October 2026 via FRED series ITCELSETSP2NGA)	$\ln(1 + \text{TEL})$; sensitivity check only
D01	Telecommunications liberalisation dummy	Constructed: 1 for 2001-2022	Level dummy
Deflator	Implied GDP deflator, 2010 = 100	Nominal GDP / real GDP $\times$ 100	Used to deflate TPID, EDID, HTID, KF