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Nexus of Economic Growth, Technological Development and In-Country Utilization of Natural Gas: Evidence from Nigeria

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Abstract

The study deployed two multivariate linear models in estimating the nexus of economic growth, technological development and in-country utilization of natural gas, using annual time series data on five variables - real gross domestic product per capita (*RGDPC*), natural gas consumption (*NGC*), technological development (*TECH*), trade openness (*TOP*), and industrialization (*IND*) - from 1986 to 2019. Using the method of error correction modeling (ECM), it is observed that technological development, gas consumption, trade openness, and industrialization have growth-stimulating effects on economic activities in Nigeria. The study further revealed that technological development, trade openness, and level of industrialization positively influenced natural gas consumption in Nigeria during the period. Based on our findings, we sustain the argument that (i) gas utilization and technological development are strong predictors of economic growth, and (ii) technological development greatly determines the level of natural gas consumption in the economy. We therefore recommend design and implementation of policies that promote research and development so as to ramp up technological innovation and development initiatives towards achievement of planned economic growth. In addition, improvements in technological development and convergence of global economies due to liberalization policies demands commensurate infrastructural expansion of natural gas production to reduce or eliminate possible mismatch between production and consumption of natural gas profiles.

Keywords: *Technology development; Natural gas consumption; Industrialization; Gross domestic product per capita; Economic growth.*

1. Introduction

The energy consumption and growth dynamics is examined extensively by scholars due to its potential policy implications for national development and growth [1]. However, there are contradicting conclusions about the influence of energy consumption and energy efficiency on economic growth and development. The contradictions revolve around whether energy consumption results from, or leads to economic growth [2-4]. Destek [5-6] recommends evaluating the causal relationships between different energy sources and economic growth, especially with the current drive towards mitigating climate change due to anthropogenic activities. Currently, growing interest has emerged on the issues of natural gas utilization and its relevance to economic growth. In order to meet the Kyoto 1997 targets which commit industrial nations to limiting greenhouse gas (GHG) emission, countries around the world are exploring the policy options to encourage the use of gas as an alternative source of energy since natural gas produces less carbon dioxide (CO_2) emissions than other fossil fuels [6-9]. On average, the world natural gas consumption as a percentage of total energy is about 21% and 23 % in 1990 and 2007 respectively [10].

Likewise, between 2007 and 2035, the total natural gas consumption is expected to grow at the rate of 1.8%, on average [10]. Similarly, higher demand for electricity increases the need for natural gas due to the fact that natural gas is an important source of electricity generation. Natural gas has become an attractive option since it is more fuel efficient, provides better operational flexibility and has lower emissions. Natural gas also offers the cheapest and relatively cleaner alternative source of energy for the economy [11]. Developing countries that are not likely to attract enough investment, including foreign direct investments for other fuel mix strategies, especially nuclear energy, resolve to use natural gas as an alternative [12]. The growing need for natural gas utilization, as well as its implication for growth, compels the need to interrogate it as a positive alternate energy source for the economy

Positioning the study on Nigeria is germane for two reasons. First, there are few studies [13-15] that have examined the long-run relationship as well as the causal link between natural gas consumption and economic growth to provide sound policy lessons for Nigeria [16]. Second, natural gas is increasingly dominating the fuel source for Nigeria's industries, accounting for almost 10 percent of primary energy demand since 2017 [17-18]. The relationship between natural gas consumption and economic growth has been investigated, but there is still need for continuous research and development for increased value-addition. Related studies [19-23] examined whether economic growth leads to more natural gas consumption or vice-versa.

We identified two shortcomings within the natural gas consumption and economic growth literature. Firstly, while some argue that it is essential to consider the impact of technological progress on energy consumption and economic growth [24-25], most of the studies excluded technological advancement in their models. Examples of such studies include Akinlo [26], and Galadima and Aminu [27]. Several studies [20-27] considered labour and employment as growth variables, but failed to consider technological advancement. Considering that trade openness promotes knowledge spillover and technology diffusion, leading to technological advancement, several studies [26-27] indirectly considered technology advancement as a variable in the natural gas consumption and economic growth relationship. Although Solarin and Shahbaz [28] also considered trade openness, they stated that this represents "real exports of goods and services plus real imports of goods and services". To the best of our knowledge, no previous study has directly considered technology advancement as a primary variable in the natural gas consumption and economic growth nexus. In line with the argument of the new classical economists on the importance of technology in economic growth, this study includes technology variable as an argument in the gas consumption-growth model.

Secondly, a review of the existing literature reveals that significant proportions of the studies [27-29] were based on cross-sectional analysis using panel data method involving countries that are not homogenous. As a result, the study outcomes cannot be generalized across countries. The present study acknowledges these gaps and therefore, engages a time series study on a developing economy, like Nigeria, such that the findings can be generalized to economies with similar characteristics. To situate this study, attempt is made to address three salient questions: (i) to what extent does technological development, gas consumption, trade openness, and industrialization influence the contribution gas consumption to? (ii) how do technological development, trade openness, and industrialization impact on gas consumption? We consider the outcome of these interrogations novel contributions to the gas consumption-growth literature. The rest of the paper is structured as follows: Section 2 reviews the extant literature on gas consumption on economic growth nexus; Section 3 outlines the model and data; Section 4 presents and discusses the results; and Section 5 concludes with policy implications.

2. Brief literature review

Although the literature is awash with support for a strong correlation between natural gas use and economic growth [30], especially since the beginning of this century, there is no consensus regarding the exact nature of the relationship [31]. Yang [32] investigated the causal relationship between aggregate and disaggregated energy consumption (AaDEC), including natural gas consumption (NGC), and GDP in Taiwan, using Hsiao Granger causality approach and data spanning 1954 to 1997. Based on the results of the study, it is observed that causality runs from NGC to economic growth (EG). Using the same causality approach and data from 1955 to 1996, Aqeel and Butt [33] examined causal relationships between AaDEC and GDP in Pakistan, and reported no causal relationship between NGC and EG. Using data spanning 1960 to 1999 and several econometric tools, Fatai *et al.* [34] examined causal relationships between AaDEC and GDP for New Zealand and Australia, reporting no cointegration between NGC and real GDP nor causality between these variables for both countries [35]. Lee and Chang [36] investigated the stability, cointegration and causality between AaDEC and GDP in Taiwan, using data from 1954 to 2003 and weak exogeneity test on cointegrating variables that considers structural breaks. They reported unidirectional causality running from NGC and GDP.

Zamani [37] evaluated the causal relationships between disaggregated energy consumption, economic growth (EG) and other industrial variables in Iran, using data spanning 1967 to 2003, and several econometric tools, including the Vector Error Correction Model (VECM). All variables considered were cointegrated, with bidirectional causality relationship between NGC and EG in the long-run and short-run. Asghar [38] investigated causal relationship between AaDEC and GDP for five South Asian Countries (Bangladesh, India, Nepal, Pakistan and Sri Lanka), using data from 1971 to 2003 and two econometric tools: Error Correction Model (ECM) and Toda and Yamamoto approach. They reported varying causal relationships between the selected variables, with only Bangladesh having unidirectional causality running from NGC to GDP.

Using the Autoregressive Distributed Lag (ARDL) and VECM and a time horizon of 1977 to 2008, Işik [39] investigated the NGC-EG nexus, reporting no cointegration between the variables and unidirectional causality running from NGC to EG in the short- and long-runs. Lim and Yoo [40] used quarterly data from 1991 to 2008 and the VECM to evaluate the NGC-EG nexus and natural gas price, and reported cointegration among the variables, as well as unidirectional causality from NGC to EG in the short-run and bidirectional causality in the long-run. Using time horizon of 1972 to 2010, the ARDL estimator and five variables (NGC, EG, capital, labour and exports), Shahbaz *et al.* [41] reported both short-run and long-run unidirectional causality from NGC to EG for Pakistan. Shahbaz *et al.* [42] reported both short-run and long-run bidirectional causality from NGC to EG for France, using ARDL, VECM and data from 1970 to 2010. Using the same econometric tools and data spanning 1975 to 2011, Yazdi and Mastorakis [43] investigated the NGC-EG nexus, incorporating other variables like employment, financial development, fixed capital formation and exports. They reported cointegration among the variables, short-run unidirectional causality from NGC to EG and long-run bidirectional causality between NGC and EG.

Caraiani *et al.* [44] investigated both short-run and long-run relationships between energy consumption via different sources (coal, natural gas, oil and renewable energy) and economic growth (EG) for five European countries: Bulgaria, Romania, Hungary, Poland and Turkey. They observed varying Granger causalities between NGC and EG in the short-run and long-run. Considering structural breaks and using data from 1991 to 2013 and deploying econometric models that include the Sequential Panel Selection Method, Destek and Okumus [45] investigated the NGC-EG nexus in 26 Organization for Economic Cooperation and Development (OECD) countries. They observed cointegration among the variables, but causal relationships varied from country to country. Considering the panel of countries, there are short-run and long-run unidirectional causalities running from NGC to EG. Destek and Okumus [45] evaluated the nexus of disaggregated energy consumption (including oil, natural gas and coal) and economic growth (EG) in G7 countries using Panel Bootstrap Causality Approach and data spanning 1970 to 2013. They reported unidirectional causality from natural gas consumption (NGC) to economic growth (EG) in United States, United Kingdom, Japan and Italy, while EG Granger causes NGC in Germany. Zhu-Guo *et al.* [46] evaluated the NGC-EG nexus for three Northeast Asian countries (China, Japan and South Korea), using data from 1991 to 2015, and two econometric tools: the Engle-Granger two-step method and the ECM. They reported no long-run causal relationship for all selected countries but short-run unidirectional causality running from NGC to EG in China.

Using the Panel Quantile Regression Method and data from 30 provinces in China, spanning 2000 to 2014, Li *et al.* [31] evaluated, in addition to the NGC-EG nexus, how level of economic development of each province affects the NGC-EG causal relationship. Considering the panel data, unidirectional causality was observed to run from NGC to EG. Also, the result showed that the higher the economic level of the province, the higher the impact of NGC on EG. Etokakpan *et al.* [14] also considered gross capital formation, globalization index and CO_2 emissions in evaluating the NGC-EG nexus. Using data from 1980 to 2014, they reported unidirectional causality running from NGC to EG in the short-run and long-run. Considering asymmetry and structural breaks, Sohail *et al.* [47] investigated the causal relationships among NGC, EG and Financial Development in Pakistan using data from 1965 to 2019. Deploying Non-linear Autoregressive Distributed Lag (NARDL) and Hacker-Hatemi-J causality analysis, they reported asymmetric causality between NGC and EG, with short-run and long-run unidirectional causality running from NGC to EG.

2.1. Nigeria and Africa overview

The NGC-EG nexus has also been investigated for African countries, especially the top oil-producing nations. Besides NGC and EG, other variables considered in prior studies include electricity consumption (ELC), crude oil consumption (COC), crude oil production (COP), money supply (MSP), health expenditure proxy for government activities (HEpGA), labour (LBR), capital (CPL), inflation rate (INF) and exchange rate (EXR). Using time-series data of 1970 to 2005, the Johansen cointegration test and several variables (natural gas utilization, EG, ELC, COC, HEpGA and MSP), Ighodaro [48] observed unidirectional causal relationship between gas utilization (NGC) and economic growth in Nigeria. Adamu and Darma [49] observed a long-run causality relationship between NGC and EG in Nigeria, using time-series data of 1981 to 2013, using three variables (NGC, EG and COP) as well as the ARDL and UECM cointegration approaches. Although statistically insignificant, they reported short-run causality from NGC to EG.

Nasiru and Kabara [50] however reported unidirectional causality running from EG to NGC for Nigeria, using a bivariate model with data spanning 1980 to 2014 data. The authors used several econometric tools: Phillips-Perron test, augmented Dickey-Fuller test, Johansen's Maximum Likelihood cointegration technique and standard Granger causality tests. Using a multivariate framework involving four variables (NGC, EG, LBR and CPL), 1981 to 2015 time-series data on Nigeria, and two econometric tools (Momentum Threshold Autoregressive, M-TAR; Momentum Threshold Error Correction Model, M-TECM), Galadima *et al.* [51] reported bidirectional causality from NGC to EG in the long-run, but statistically insignificant causality in the short-run. Using data from eight African oil and gas-producing countries and time horizon of 1980 to 2011, Zaidi *et al*. [52] investigated the causal relationship between GDP per capita, NGC and oil consumption. The results for country-specific causal relationships varied from country to country, while GDP Granger causes NGC for the panel of countries.

Galadima and Aminu [53] evaluated the relationship between NGC and EG using the Smooth Transition Regression model and a time horizon of 1981 to 2015. They reported an asymmetric relationship between NGC and EG, emphasizing that the threshold value for NGC in Nigeria is 9085.36 standard cubic meters which is above consumption levels in 2018. Based on their results, NGC substantially impacts EG. Galadima and Aminu [53] also investigated the impacts of shocks to macroeconomic variables on NGC in Nigeria using Structural Vector Autoregressive (SVAR) model within the same time horizon. The macroeconomic variables studied are real GDP (proxy for EG), MSP, INF and EXR. They reported short-run and long-run NGC-EG inferences somewhat similar to the inferences from Galadima and Aminu [54].

Galadima and Aminu [54] further investigated non-linear trends between NGC and EG in Nigeria, and the causal effect of disaggregated changes in NGC on EG. Other variables considered were LBR and CPL. Using non-linear ordinary least squares method and several econometric tools, they analyzed the causal relationship between EG and changes in NGC (positive (NGC^+) and negative (NGC^-) respectively), reporting bidirectional causality between NGC^+ and EG and unidirectional causality from EG to NGC^-. Investigating the impacts of NGC^+ and NGC^-

on EG using Non-linear Autoregressive Distributed Lag (NARDL) model and time-series data spanning 1981 to 2015, Galadima and Aminu [54] reported long-run impact of NGC^{+} on EG, statistically insignificant long-run impact of NGC^{-} on EG, and no short-run impact of NGC on EG. Although this appears contradictory to the findings of Galadima and Aminu [53] with the same variables (including LBR and CPL), one should note that only causality from NGC to EG was investigated in Galadima and Aminu [54].

Based on their results, Makala and Zongmin [55] reported no cointegration and no causal relationship between NGC and GDP in Tanzania, using the ARDL and time horizon of 1995 to 2018. Using data spanning 1980 to 2015 and non-linear autoregressive distributed lag (NARDL), Awodumi and Adewuyi [56] investigated the symmetric and asymmetric impacts of disaggregated energy consumption (NGC and Petroleum Consumption) on economic growth and CO_2 emissions of five African countries: Algeria; Angola; Egypt; Gabon and Nigeria. Other variables considered were trade openness, urbanization, and financial development. They stated that in the long-run and short-run, the impacts of asymmetric NGC on economic growth varied for the countries studied, with only long-run impact of NGC on EG in Nigeria.

From previous studies reviewed above, it is obvious that the debate on the NGC-EG nexus is still inconclusive, with causal relationship varying from country to country. Karanfil [57] argued on the need for consistent results for policy makers to make sense of the future policy directions for their respective countries. He further recommended that novel methods using the recent econometric tools that are appropriate to examine the energy-growth nexus be used to provide consistent results for policy makers in this area of study.

3. Data, model, and empirical approach

3.1. Data

To achieve the study's objective, annual time series data on five variables: real gross domestic product per capita (*RGDPC*), natural gas consumption (*NGC*), technological development (*TECH*), trade openness (*TOP*), and industrialization (*IND*). Data for the period 1986 to 2019 are sourced from World Bank (2020) World Development Indicators, United Nations Conference on Trade and Development (UNCTAD) data base on the internet, the International Monetary Fund (IMF), and the Central Bank of Nigeria Statistical Bulletin (various issues).

3.2. Model specification

This study adopts the ex-post facto research design which is an after-the-fact research in which the investigation starts after an event has occurred. It is a category of research design that investigates after the fact has occurred without interference or manipulation from the researcher [58].

To empirically address the questions raised, the empirical models of Okoye *et al.* [17] and Aminu and Aminu [59] were modified into two separate models implicitly expressed as:

$$RGDPC_t = \beta_0 + \beta_1 NGC_t + \beta_2 TECH_t + \beta_3 TOP_t + \beta_4 IND_t + e_{1t} \quad (1)$$

$$NGC_t = \lambda_0 + \lambda_1 TECH_t + \lambda_2 TOP_t + \lambda_3 IND_t + \mu_{1t} \quad (2)$$

where, *RGDPC* is growth of real gross domestic Product (GDP) per capita; *NGC* is natural gas consumption; *TECH* is level of technology; *TOP* is the trade openness index and *IND* is level of industrialization. β_i and λ_i are parameters to be estimated; e_i and μ_i are the white-noise idiosyncratic error terms that are independently and identically distributed (i.i.d).

Equation (1) conjectures that the rate of economic growth depends on gas consumption, level of technology, trade openness, and industrialization; while Equation (2) argues that gas consumption depends on level of technology, trade openness, and industrialization.

3.3. Empirical approach

Error Correction Model (ECM) is used to estimate the causal relationship between technological progress and natural gas consumption, and the effect of natural gas consumption on economic growth. The ECM regression analysis technique has desirable statistical properties.

It specifically estimates the short-run parameters and traces how the model adjusts to long-run equilibrium condition [17]. This is in addition the pre-estimation tests: (i) unit root test (ii) cointegration test.

3.3.1. Unit root test

Maddala and Kim [60] observed that time series data are fraught with unit root which if ignored might lead to spurious estimates. The unit root test adopted in the study is the Augmented Dickey-Fuller (ADF) test. The ADF test controls for serial correlation in the model and performs well asymptotically [61]. However, several studies [62-63] established that the ADF test has low power in differentiating from unit root and alternatives close to 1. Thus, the study also incorporates the Phillips-Perron test [64] which non-parametrically corrects for heteroskedasticity and any serial correlation in the errors by adjusting the Dickey Fuller test statistics. The PP test has a semi-parametric characteristic and estimates the autocorrelation in the stationary process using a kernel that is smoother than the approach in ADF (the auto-regressive process approximation).

3.3.2. Co-integration test

Co-integration is a necessary condition for stationarity among variables that are integrated. Co-integration test is a necessary step for checking if the relationship among the variables can be expressed in a meaningful empirical model [65]. Of the several co-integration analysis techniques [66], the Johansen [67] method was chosen for this study because, this approach is effective, simple to implement, and out-performs the Engle-Granger procedure [67]. The Johansen co-integration method is only applicable when the order of integration is the same.

3.3.3. Error correction model estimation

According to Granger representation theorem [68], if two or more non-stationary variables are co-integrated, then they have a valid error correction mechanism, and their relationship can be expressed as error correction model (ECM). Therefore, the ECM of the relationship between Real Gross Domestic Product (RGDP) capita growth rate and domestic debt structure as expressed in Equation (1) was re-specified as:

$$\Delta RGDPC_t = \sum_{i=1}^{p-1}\delta_1\Delta RGDP_{t-1} + \sum_{i=1}^{q-1}\delta_2\Delta NGC_{t-1} + \sum_{i=1}^{q-1}\delta_3\Delta TECH_{t-1} + \sum_{i=1}^{q-1}\delta_4\Delta TOP_{t-1} + \sum_{i=1}^{q-1}\delta_4\Delta I_{t-1} + ECM_{t-1} + u_t \quad (3)$$

$$\Delta NGC_i = \beta_0 + \sum_{i=1}^{p-1}\beta_1\Delta NGC_{t-1} + \sum_{i=1}^{q-1}\beta_2\Delta TECH_{t-1} + \sum_{i=1}^{q-1}\beta_3\ \Delta TOP_{t-1} + \sum_{i=1}^{q-1}\delta_4\Delta I_{t-1} + ECM_{t-1} + v_t \quad (4)$$

The ECM model is estimated using the two-step Engle-Granger method [69-70].

4. Results and discussion

4.1. Data analysis and empirical results

This section presents the empirical results from the data analysis.

4.1.1. Descriptive statistics

The descriptive statistic shows the statistical properties of the variables in the model. This enables a preview of the behaviour of the variables before applying them to regression process. Secondly, descriptive statistics of the variables gives an idea about the variables that are likely to cause problem in the model. The descriptive statistics of the variables in the model are presented tabulated in Table 1.

From Table 1, there are 28 observations for each variable and the average of real gross domestic product (RGDP) during the twenty-eight (28) years is 786.5 percent. The maximum level of value is $ 2979.84 per capita, while the minimum level for the period under review is $ 153.08. The mean of natural gas consumption during the period under review is 7.30 Mte; the maximum value is 13.00 Mte and the minimum value is 2.60 Mte. The average infrastructure development indicator is 104.25. The maximum value is 155.85; while the minimum value recorded during the period is 74.13. The mean value of trade openness index for Nigeria during the period under review is 56.23. It recorded a maximum of 81, and minimum value of 23.71. The maximum and minimum values for industrialization index 9.53 and 2.41 respectively.

Table 1. Summary statistics and correlation analysis.

Variables	*RGDPC*	*NGC*	*TECH*	*TOP*	*IND*
Mean	786.435	7.300	104.260	56.231	5.227
Median	335.964	6.350	95.904	58.939	5.184
Maximum	2979.844	13.000	155.854	81.813	9.532
Minimum	153.076	2.600	74.131	23.717	2.410
Std. Dev.	838.002	3.495	24.343	13.840	2.031
Skewness	1.588	0.283	0.643	-0.429	0.323
Kurtosis	4.159	1.500	2.176	2.805	2.250
Jarque-Bera	13.333	2.998	2.720	0.901	1.143
Correlation analysis					
RGDPC	1.000				
NGC	0.679	1.000			
TECH	0.868	0.749	1.000		
TOP	-0.314	0.083	-0.317	1.000	
IND	0.229	-0.423	0.013	-0.714	1.000

Note: *RGDPC* = Real GDP growth per capita; *NGC* = natural gas consumption; *TECH* = level of technology; *TOP* = trade openness index; *IND* = level of industrialization *Source: authors' computations*

RGDP is positively skewed, that is, they tend to have positive momentum, and this shows an increasing tendency. The other variables' values of skewness are not much different from zero. Therefore, they can be assumed to have normal skewness. The kurtosis value for RGDPC is greater than 3.00, which implies that it has excess kurtosis and is therefore leptokurtic. It means that it has more peak top than the normal distribution. The kurtosis values for TECH, NGC, TOP and IND are less than 3.00, thus, they are platykurtic. This implies that they have peaks that are flatter than the normal curve. The p-values of Jaque-Bera statistics value for RGDPC is less than 0.05. Hence, its distribution is not normal. The p-values of the Jaque-Bera statistics for TECH, NGC, TOP and IND are all greater than 0.05 critical values which indicate that their distributions are normal, except for RGDP.

The correlation matrix test examines the pairwise correlation coefficients of the variables to determine whether there is a problem of multi-collinearity among the variables. The results of the test which are presented in the lower panel of Table 1 have values lower than 0.75. Hence, there is no reason to suspect any possible problem of multi-collinearity in the model.

4.1.2. Unit root test

The variables in the model are tested for stationarity using the augmented Dickey- Fuller (ADF) and Phillips-Perron (PP)) approaches and the generated results are presented in Table 2. The test of unit root results shows that none of the variables is stationary at level but all they are at first difference. They are, therefore, $I(1)$ series.

4.1.3. Co-integration test

The cointegration result shown in Table 3 investigates long-run relationship among the variables to ascertain whether the model can be used long-term for policy decisions. The Johansen [73] cointegration method was used for the purpose. The trace statistics reveals existence of four (4) cointegrating equations in the model, which indicates rejection of the null hypothesis of no cointegration at the 5% significance level. The result (model 1) suggests a stable long-run relationship between real GDP growth per capita and the explanatory variables.

Table 2. ADF and PP unit root tests.

Variables	ADF			PP		
	Level	1st Diff.	Decision	Level	1st Diff.	Decision
RGDPC	0.1528	-5.3774***	$I(1)$	-1.5079	-5.4617***	$I(1)$
NGC	-2.8258	-5.1378***	$I(1)$	-1.6267	-5.3632***	$I(1)$
TECH	-2.1228	-6.3176***	$I(1)$	-2.1228	-6.4085***	$I(1)$
TOP	0.8873	-3.8994***	$I(1)$	-2.7035	-25.7679***	$I(1)$
IND	-1.2322	-6.3994***	$I(1)$	-1.234	-6.4304***	$I(1)$

Note: *RGDPC* = Real GDP growth per capita; *NGC* = natural gas consumption; *TECH* = level of technology; *TOP* = trade openness index; *IND* = level of industrialization Source: authors' computations.
*** denote statistical significance at 1%.

Table 3. Unrestricted cointegration rank test (Trace) – Model 1.

Hypothesized No. of CE(s)	Eigenvalue	Trace statistic	0.05 Critical value	Prob.**
None *	0.9476	184.236	88.804	0.000
At most 1 *	0.8368	110.498	63.876	0.000
At most 2 *	0.7666	65.174	42.915	0.000
At most 3 *	0.5556	28.803	25.872	0.021
At most 4	0.2891	8.529	12.518	0.212

* denotes rejection of the hypothesis at the 0.05 level; **MacKinnon-Haug-Michelis [71] p-values;
Source: authors' computations

Table 4. Unrestricted cointegration rank test (Trace) – Model 2

Hypothesized No. of CE(s)	Eigenvalue	Trace statistic	0.05 Critical Value	Prob.**
None *	0.8926	112.406	63.876	0.000
At most 1 *	0.7365	56.621	42.915	0.001
At most 2	0.4999	23.278	25.872	0.102
At most 3	0.2119	5.954	12.518	0.466

* denotes rejection of the hypothesis at the 0.05 level; **MacKinnon-Haug-Michelis [71] p-values
Source: authors' computations

For model 2, the cointegration results are shown in Table 4. Both Trace and Maximum Eigen value statistics show two cointegrating equations in the model. Thus, there is a stable long-run relationship between technological development progress and natural gas consumption.

4.1.4. Error correction (ECM) test

Following Engle-Granger representation theory, which says if two or more variables are cointegrated, then there is a valid error correction mechanism among them that can be modeled and estimated, this study proceeds to estimate the error correction. The results for model 1 are presented in Table 5.

The coefficients show the impact of a unit change in independent variables on the dependent variable. The result shows that the natural gas consumption has a positive and significant relationship with economic growth in the long-run. It shows strong positive effect of past and present levels of natural gas consumption on real GDP growth per capita. Specifically, an increase in gas consumption by 1% brought about a 6% increase in real per capita income growth after one period lag, and about 12% after two period lag. This is in line with the *a priori* expectation for this variable and in line with the findings of Fadiran *et al.* [22] which found positive and significant impact of natural gas consumption on economic growth in 12 European countries. However, the result contradicts the findings of Yazdi and Mastorakis [43] which found negative impact of natural gas consumption on economic growth in Turkey.

The result shows the nexus of infrastructure development and economic growth as positive and statistically significant. It suggests that an increase in the level of infrastructure development by 1% produces a growth of economic activities by 10% and 26% after one and two-period lags respectively. The result is also in conformity with the *a priori* expectation for this variable and the findings of Okoye *et al.* [8] and MacKinnon [71] but it contradicts the result of a later research by Okoye *et al.* [9] which presented a negative result, as well as the outcome of Lee and Chang [36] which failed to establish significant relationship between infrastructure development and economic growth in China province.

Table 5. Error correction estimate for Model 1

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DLog(RGDPC(-1))	-0.7122	0.1287	-5.5364	0.0052
DLog(NGC)	16.5642	3.7116	4.4628	0.0028
DLog(NGC(-1))	6.3109	2.6483	2.3823	0.0277
DLOG(NGC(-2))	12.4462	2.9741	5.5492	0.0048
DLog(TECH)	17.11465	2.0544	8.3309	0.0011
DLog(TECH(-1))	-10.3564	3.2100	-3.2263	0.0321
DLog(TECH(-2))	-26.8670	3.4601	-7.7649	0.0015
DLog(TECH(-3))	-13.6042	4.0506	-3.3585	0.0283
DLog(TOP)	-6.5603	2.3461	-2.7963	0.0490
DLog(TOP(-1))	23.1155	3.9166	5.9019	0.0041
DLog(TOP(-3))	9.0673	2.3682	3.8287	0.0186
DLog(IND)	8.9723	19.4997	4.1525	0.0142
DLog(IND (-1))	10.3617	27.4911	3.9053	0.0175
ECT	-0.0637	0.0070	-9.1062	0.0008
Observations	28	R-squared		0.9706
Adjusted R-squared	0.9249	*Source: authors' computations*		

The study also reveals the relationship between trade openness and economic growth as positive and statistically significant. The result is in line with our *a priori* expectation for the variable and with economic theory. Specifically, change in trade openness index by 1% brings about a change in economic growth of 23% after one period lag and 9% after two periods lag. It implies that increase in trade openness leads to increase in economic growth rate. This highlights the relevance of trade to the economy. The impact of industrialization on economic growth is also shown to be positive and statistically significant. The result also lends support to our *a priori* expectation for the variable and with economic theory. It implies that policies aimed at industrializing the economy have growth-inducing effects [72].

The error correction coefficient (ECT) is appropriately signed and significant. The value of the coefficient indicates the speed of adjustment of the model. The ECT coefficient value of -0.0637 implies that about 6% of any discrepancy between the short-run value and the long-run value is corrected for within one year. The model R^2 value of 0.9706 implies that changes in the explanatory variables (natural gas consumption, level of infrastructural development, trade openness, and industrialization) accounted for about 97% change in economic growth during the period under review. Thus, the analysis has shown that natural gas consumption has long-run growth-impact on the economy of Nigeria. It also reveals the importance of trade, infrastructure development, and industrialization to economic growth in Nigeria. The findings of the study are in line with economic theory and the *a priori* expectations of all the variables.

4.1.5. Model 2: Natural gas consumption, technology, trade openness and industrialization

The error correction result for the second empirical model is presented in Table 6. The coefficients show the impact of a unit change in the independent variables on the dependent variable. The relationship between infrastructure development and natural gas consumption is positive and statistically significant. It shows that an increase in the level of infrastructure development by 1% leads to increase in economic growth by 0.13% after one lag and 0.12%

two period lags. However, a growth-retarding effect is observed for current level infrastructure development.

Table 6. Error correction estimate for Model 2.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(NGC(-1))	-0.3612	0.0925	-3.9029	0.0059
D(TECH)	-0.0502	0.0122	-4.1095	0.0045
D(TECH(-1))	0.1341	0.0103	13.0223	0.0000
D(TECH(-2))	0.1268	0.0153	8.2944	0.0001
D(TECH(-3))	0.0481	0.0136	3.5558	0.0093
D(TOP)	0.0285	0.0113	2.5338	0.0390
D(TOP(-1))	0.1028	0.0116	8.8350	0.0000
D(TOP(-2))	0.1001	0.0112	8.9507	0.0000
D(IND (-1))	1.2591	0.1911	6.5870	0.0003
D(IND (-2))	1.2608	0.1552	8.1257	0.0001
D(IND (-3))	0.8327	0.1009	8.2562	0.0001
*CointEq(-1)**	-0.1866	0.0241	-7.7423	0.0001
Observations	*28*	*R-squared*		*0.9583*
Adjusted R-squared	*0.9129*	*Source: authors' computations*		

The result further reveals that technological progress, trade openness and industrialization have positive and statistically significant relationship with natural gas consumption. From the result, a 1% change in index of technological progress caused 0.13% increase in natural gas consumption during the period under review after one-period lag and about 0.12% after two period lags. In the case of trade openness, the impact is about 0.10% after one and two period lags. Industrialization has positive and significant impact on natural gas consumption in Nigeria during the period under review. Specifically, increase in industrialization index by 1% led to increase in gas consumption by about 1.2% after one period lag and about the same value after two period lags [73-74]. The positive impact of industrialization on natural gas consumption implies that increase in industrial development significantly raises the volume of natural gas consumption.

The ECT coefficient value of -0.1867 implies that the about 18% of any discrepancy between the short-run and long-run equilibrium is corrected within one year. The model adjustment coefficient ECT is appropriately signed and statistically significant. The model R^2 value of 0.9583 indicates that the explanatory variables explain about 96% change in the natural gas consumption during the period under review.

4.2. Post estimation test

This section evaluates the model and the parameter estimates to ensure that they have the optimum statistical properties and that they are reliable. The choice of the empirical method employed for this study presupposes that the model is correctly specified, and that the error terms are normally distributed, serially uncorrelated and have constant variance over time (Homoskedastic). The results of the model diagnostic test are presented in Table 7.

Table 7. Model diagnostic test.

Specifications	Model 1	Model 2	Conclusion
	Stat./*p*-values	Stat./*p*-values	
Durbin-Watson (autocorrelation)	2.193	18,397	No autocorrelation
Breusch-Godfrey (autocorrelation)	2.119/0.3465	0.107/0.7437	No higher-order autocorrelation
ARCH LM	2.327/0.3124	0.004/0.9487	No conditional heteroscedasticity
Ramsey RESET (omitted variables)	1.65/0.1339	0.95/04311	None
Jarque-Bera (normality)	1.558/0.4589	2.271/0.3213	Normality validated
Skewness and Kurtosis (normality)	-0.609/2.895	3.63/0.1625	Normality validated

The last issue we address is related to the goodness of fit of the ARDL-error correction models. For this purpose, series of diagnostic and stability tests were carried out. The results of the diagnostic tests for serial correlation, heteroscedasticity, conditional heteroscedasticity, Ramsey's RESET test and normality show no challenges of model misspecification, heteroscedasticity, higher-order autocorrelation or normality in the models, which indicates that estimates from the models are robust and reliable for making policy decisions [75-76].

5. Conclusion and recommendations

The study revealed that technological development, gas consumption, trade openness, and industrialization induce great growth-stimulating properties on the Nigerian economy. It further showed that technological development, trade openness, and level of industrialization greatly increase natural gas consumption in Nigeria. From these observations, we conclude that (i) gas utilization and technological development are strong predictors of economic growth in Nigeria, and (ii) technological development greatly determines the level of natural gas consumption in the economy. We therefore recommend that policies that promote research and development should be vigorously pursued so as to ramp up technological innovation and development initiatives towards achievement of planned economic growth. Also, following sustained advancements in technological development and convergence of global economies due to liberalization policies, infrastructures relevant to expansion of natural gas production should be developed to reduce or eliminate possible mismatch between production and consumption of natural gas.

Availability of data and material: *Data are available upon request.*

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