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# Energy Prices, Income and Electricity Consumption in Africa: The Role of Technological Innovation

**Taiwo Owoeye[1], Dayo Benedict Olanipekun[1], Akindele John Ogunsola[2], Augustine Adebayo Kutu[3]***

[1]Department of Economics, Ekiti State University, Ado-Ekiti, Ekiti-State, Nigeria, [2]PhD Candidate, School of Accounting, Economics and Finance, University of KwaZulu-Natal, Westville Campus, Durban, South Africa, [3]School of Accounting, Economics and Finance, University of KwaZulu-Natal, Westville Campus, Durban, South Africa. *Email: dayo626@yahoo.com

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**ABSTRACT**

In this paper, we examine an extended model of the determinants of electricity consumption to include the effect of technological innovation represented by the number of patent and trademark registered. The study focused on 35 African countries from 2009 to 2018 based on availability of records on patent and trademark registration. Both the one and two-step system generalized method of moments were explored to estimate the empirical model. The models were estimated in five different categories to properly account for the behaviour of technological innovation and other determinants of electricity consumption. It was revealed that technological innovation has an insignificant effect on electricity consumption in Africa. However, other variables of interest affected electricity consumption in diverse ways; while per capita income and population growth have positive and significant effect on electricity consumption, energy price and FDI inflows exhibit a negative and significant effect on electricity consumption. The results suggest that technological innovation has not promoted energy efficiency in Africa possibly due to weak innovative capabilities of African countries. Hence government effort should be geared towards improving innovative technology in the region.

**Keywords:** Technological Innovation, Energy Price, Electricity Consumption, GDP Per Capita, System Generalized Method of Moments

**JEL Classifications**: O30, O34, P18, Q20

## 1. INTRODUCTION

The determinants of electricity consumption are well documented in the energy literature. Many studies have emphasized the importance of electricity prices, income, trade openness, population growth and FDI as major factors that influence electricity consumption (see for instance, Tang and Shahbaz, 2011; Al-Bajjali and Shamayleh, 2018; Murad et al., 2018). However, the debate on energy efficiency is ongoing. Recent evidences in the literature have shown that innovation and invention drive electricity conservation and through this promote energy efficiency and economic growth (Tang and Tan, 2013; Saudi et al., 2019). The argument is that technological improvement through innovation enables energy efficiency of electricity using appliances and products which would lead to lower energy consumption.

Electricity consumption-growth literature has evolved into four distinct hypotheses about the effect of electricity conservation on the causal relationship between electricity consumption and economic growth (Cakmak, 2015; Payne, 2010). The first hypothesis states that electricity conservation policies design to reduce electricity consumption and waste have little effect on economic growth. The second argues that electricity conservation policies stunt economic growth. The third establishes that electricity conservation policies have no effect on growth, while the fourth states that electricity conservation policies impact economic growth positively. The last approach, which is called the feedback approach is at the core of recent evidence in the literature on how innovation drives electricity conservation and through this promote energy efficiency and economic growth. The feedback approach has spurned a large body of empirical evidence about how innovation and energy efficiency, especially non-fossil fuel drives economic growth. For example, the electricity consumption-growth nexus literature has established the fact that per capita income correlates with per capita electricity consumption in most OECD countries and emerging economies in Asia (Ahmad and Islam, 2011 and Salisu et al., 2018). In contrast, studies on African countries show both low per capita electricity consumption and low per capita income (Mehara, 2007: Olomola, 2007; Fondja, 2013 and Kolawole, 2017). In some cases, African countries with large energy deposit also have low energy consumption because of low income (Yu and Chai, 1985), price distortion (Bekhet and Yusop, 2009 and Asafu-Adjaye, 2010) and low technological innovation (Tang and Tan, 2012).

The role of technological innovation or the lack of it in explaining African dismay economic growth performance has been well documented (Onyeiwu, 2011). The basic intuition behind this argument is that Africa low innovative capabilities and absorptive capacities stunt its ability to bridge the gap between the region and technologically advanced countries. Prior to the recent growing interest on how technological innovation explains poor economic growth in Africa, the literature on determinants of economic growth in Africa has concentrated on capital accumulation (Devarajan et al., 2003), unstable macroeconomic environment (Collier, 2007), aid dependency and low savings (Oshikoya, 1992), political instability and conflicts (Fosu, 2009) and trade openness (Hoffler, 2002). Yet, technological progress has been identified as the main driver of long-term economic growth (Solow, 1956: Romer, 1986). It is therefore surprising that this nexus has not been well examined in the literature until recently.

However, there is also the need to examine how technological progress affects energy consumption in African countries simply because of how innovation improves energy efficiency. This study provides some important contribution to existing literature in a number of ways. First, studies on the effect of technological innovation on electricity consumption generally focused on developed countries and Asian economies; very little has been done on the theme in Africa. Hence, looking at the pace of technological progress in Africa, it is essential to investigate the effect of technological innovation in improving energy efficiency and reducing energy intensity Second, energy efficiency is driven by technological progress as the world attempts to shift from fossil fuel to green energy and energy savings products because of environmental concerns. In most cases, more green energy and energy saving products are usually created and used through technology innovation. In this context, the consumption of less fossil fuel can lead to better quality of the environment and therefore leads to increase in economic growth. Third, there are some inherent difficulties in measuring innovation generally and in Africa particularly where getting proxies for innovation is difficult. This difficulty arises from the poor state of innovation and invention in Africa relative to other regions in the world. It is therefore important that any study that can overcome these difficulties will make substantial contribution to the literature on growth-energy nexus in Africa.

A review of several indicators of Science and Technology shows that Africa position on innovative capabilities is weak relative to other developing countries. For example, Africa share of total global expenditure on R&D stood at 0.5% in 2001 compared to 27.97% for Asia and 15.6% for other developing countries. Africa is characterized with very low resources devoted to research and development. For example, sub-Saharan Africa expenditure on R&D as a percentage of GDP stood at 0.42 % in 2016 compared to 2.06% for East Asia and Pacific and 2.42% for North America and Western Europe (UNESCO, 2019). For a comparative analysis of numbers of US patent granted firms across different countries the figures show that Africa countries lagged behind other developing countries. For example, South Korea, China and India received thousands of patents between 2000 and 2008, while most African countries did not record any except, South Africa, Kenya and Nigeria (World Intellectual Property Organization, 2010). Predictably, Africa economies have also grown very slowly during the period of low technology innovation, while Asian economies have grown very rapidly correlating with the period of high level of innovation. This raises two important questions. First, does a combination of poor innovation and low household income explain electricity consumption in Africa? Second, how has energy prices and low technological innovation affected the ability of Africa to improve energy efficiency through reduction in fossil fuel generated electricity consumption?

This paper attempted to answer these questions by analyzing data for a sample of 35 African countries on the relationship between electricity consumption proxy by electricity power consumption measured in kilowatt per hour and technological innovation proxy by patents and trademarks registered by each country for the period under review. The paper also included other control variables and adopted a System Generalized Method of Moment to analyze the relationship among the selected variables.

The rest of the paper is structured as follows. Section two discusses the literature, while section three describes the methods and the theoretical framework. Section four presents the empirical results, while section five concludes and makes recommendation

## 2. LITERATURE REVIEW

The literature on the impact of technological innovation on economic growth can be traced to the pioneering work of growth theorists during the second half of twentieth century (Solow, 1956; Romer, 1986 and Lucas, 1988). These works reinforced the idea that technological progress explains long-run expansion in per capita output in two different ways. First, according to the Solow model, innovation and invention are driven by exogenous factors and do not occur within the growth process. This conclusion from the Solow model therefore indicates that policy makers have limited influence on how to drive technological progress. Second, the endogenous growth model extended the above argument by showing that technological progress drives long-run economic growth, and this occurs within the growth process.

This means that both approaches recognize the importance of innovation to expansion in per capita income but differs on whether technological progress is exogenous or endogenous.

The seminal work of Kraft and Kraft (1978) started this debate and since then a lot of work on the energy-growth nexus has been conducted extensively by many researchers with aim of providing policy framework on the casual relationship between energy consumption and economic growth (Akarca and Long, 1980; Soytas and Sari, 2003; Yuan et al., 2007; Narayan and Prasad, 2008; Tang and Shahbaz, 2013; Ahmed and Azam, 2016). In recent times, empirical evidence from the impressive economic growth performance of East Asian countries, Taiwan, Hong-Kong, Singapore and South Korea, has shown the massive investment in Research and Development (R and D) supported the endogenous growth approach (Rodrik, 2006).

Studies on growth-energy nexus have proliferated both with cross-sectional and time series data. Several empirical works have been widely discussed for both developing and developed countries by various scholars on energy-growth nexus. This is to ascertain the relationship and the causal relationship between energy consumption and economic growth or verse versa. Many of this existing literature on this nexus were published based on either a bi-variate or a multivariate framework. Therefore, the major shortcoming of bi-variate works is that they are likely to suffer from the omitted variable bias problems. Also, the colossal buildup of studies investigating the energy-growth nexus without an appropriate consensus has commanded the swing from elucidating this conventional nexus to generalize the nexus's rudiments to the choice of electricity consumption (Ozturk, 2010). These conflicting reports may not help policy makers in designing an appropriate energy and growth policies.

Using panel data several studies have investigated electricity consumption and economic growth nexus. For instance, Cowan et al. (2013) examined the casual link among electricity consumption, economic growth and $CO_2$ emission in BRICS countries. The results showed that causality differs across countries suggesting differential energy policy measures. Karanfil and Li (2014) examined the long and short run relationship between electricity consumption and economic growth in 160 countries. The full sample is divided into subsample based on income levels and OECD membership. A long run relationship between electricity consumption and economic growth was found in the full sample and majority of the subsamples. Wolde-Rufael (2016) explored the bootstrap panel Granger causality analysis to examine electricity consumption and economic growth in transition economies. The results provided mixed findings and showed a limited support for electricity led growth hypothesis. Using data from OECD countries, Salahuddin et al. (2018) found that economic growth stimulates electricity consumption both in the long and short run; causality suggest electricity consumption spurred economic growth. Khobai (2017) investigated the causal relationship between electricity consumption and economic growth in BRICS economies for the period of 1990-2014. Vector Error Correction model (VECM) was employed to test the causality among the variables (carbon dioxide emissions and urbanization). The outcome of the result indicated a unidirectional causality runs from economic growth to electricity consumption in the long run in BRICS.

Based on time series data some studies have provided useful findings on electricity-growth nexus. Polemis and Dagoumas (2013) explored the relationship between electricity consumption and economic growth in Greece by utilizing a multivariate framework. In the long run, electricity is price inelastic and income elastic while in the short run both price and income are inelastic in response to electricity consumption. In the same vein, based on multivariate procedure, Tang et al. (2013) revealed a long run relationship among electricity consumption, economic growth. Additionally, the VECM established bidirectional causality between electricity consumption and economic growth in the short run and long run. Using ARDL and VECM approaches, Hamdi et al. (2014) found a long run relationship between electricity consumption and economic growth in Bahrain. The VECM Granger causality supported the feedback effect between electricity consumption and economic growth. Similarly, Iyke (2015) showed that there is a causal flow from electricity consumption to economic growth both in the short run and long run. This finding supports the electricity led growth hypothesis for Nigeria.

From the energy literature survey, studies on electricity consumption and technological innovation have presented some insightful findings. For instance, Tang and Tan (2013) investigated the effect of technological innovation, energy prices and economic growth on electricity consumption in Malaysia. Technological innovation and energy prices were proxy by the number of patents registered and consumer price index, respectively. It was found that technological innovation and energy prices negatively affected electricity consumption. Using annual data, Fei and Rasiah (2014) examined the long run and short-run relationship among electricity consumption, economic growth, energy prices and technological innovation for Canada, Ecuador, Norway and South Africa using ARDL and VECM techniques. The result revealed an insignificant effect of technological innovation on electricity consumption. However, technological innovation affected growth in the sampled countries positively. Sohag et al. (2015) showed that technological innovation increases energy efficiency and reduces energy consumption at a given level of output. Similarly, Murad (2018) examined the relationships among energy consumption, energy price, economic growth and technological innovation in Denmark. Based on the ARDL methodology, a significant negative relationship between technological innovation and energy consumption was obtained. While an increase in energy prices reduces energy consumption, economic growth promotes energy consumption. Using an ARDL technique, Saudi et al. (2019) posited that high technology exports, number of registered patents and research and development expenditure are the major source of reducing energy intensity and promoting energy efficiency in Indonesia.

An important gap in the literature is that there is no study that has investigated the energy-growth nexus for Africa with innovation as one of the determinants of electricity consumption despite the fact that technological innovation has been identified as an important driver of energy efficiency and economic growth. Although, there has been no study with African data in this regard, there have been studies which included innovation as control variable using Asian data (Chen et al., 2009: Lee and Less, 2013 and Tang and Tan, 2013). This paper will therefore provide substantial contribution to the extant literature on energy using African data.

## 3. METHODOLOGY

### 3.1. Empirical Model

Theoretically energy demand function is a function of income and energy prices. Given that the market clearing condition holds, where energy demand equals energy supply, the following energy consumption function is expressed in the context of the standard Marshallian demand function as:

$$EC = f(EP, Y) \quad (1)$$

Where $EC$ is energy consumption, $EP$ is energy prices and $Y$ is income. In line with the argument at the introductory section of this paper, technological innovation can influence energy consumption by increasing energy efficiency. Technological innovation is essential in improving energy efficiency. Advanced technologies enable the economy to produce a given level of output using a lower level of energy. Additionally, technological innovation gives access to opportunities for the economy to change from depletable sources of energy to renewable sources of energy to meet up with energy demand. This implies that increase in technological innovation would lower energy consumption. Some studies have measured technological innovation using number of patents registered, trademarks registration and research and development expenditure (Kortum, 1993; Thomas, 2001; Tang and Tan, 2013). In our model, two measure of technological innovation are adopted. These include the number of residence patent registered and number of trademarks registered.

Another major determinant of energy demand is energy prices. An increase in energy price could lower its demand, especially when there are alternative energy uses. Electricity price data is not available in most developing countries, Africa inclusive. Many studies have used Consumer Price Index (CPI) to proxy electricity price (see for instance Chandran et al., 2010; Lean and Smyth, 2010 and Tang and Tan, 2013). Hence, this study would employ CPI to proxy energy price. Other determinants of electricity consumption are population growth and investment. The general argument in economic literature on energy is that increase in economic activities such as investment could increase energy use (Esen, 2017). Therefore, this study also considers all these important determinants of electricity consumption. Hence, the functional relationship between electricity consumption and its determinants can be modified as follows:

$$epc_{it} = f\,(patent_{it}, tradem_{it}, gdppc_{it}, ep_{it}, pg_{it}, top_{it}, gcf\_gdp_{it}, fdi\_gdp_{it}) \quad (2)$$

In Equation 2, *epc* is electricity consumption per capita, *patent* is number of patent registered, *gdppc* is GDP per capita (household income), *ep* is energy price, *pg* is population growth, *top* is trade openness, *gcf_gdp* is gross fixed capital formation as a percentage of GDP, *fdi_gdp* is foreign direct investment as a share of GDP. The empirical model of electricity consumption and its determinants can be expressed as follows:

$$lnepc_{it} = \beta_0 + \beta_1\, lnpatent_{it} + \beta_1\, lntradem_{it} + \beta_3\, lngdppc + \beta_4\, lnep_{it} + \beta_5\, pg_{it} + \beta_6\, top_{it} + \beta_7\, lngcf\_gdp + \beta_8\, fdi\_gdp_{it} + u_{it} \quad (3)$$

Where in equation 3, *ln* denotes natural logarithm. The error term *u* is assumed to be spherically distributed and white noise. The *a priori* expectations for the parameters in equation 3 are $\beta_1 < 0$, $\beta_2 < 0$, $\beta_3 < 0$, $\beta_4 < 0$, $\beta_5 < 0$, $\beta_6 < 0$, $\beta_7 < 0$, $\beta_8 < 0$.

### 3.2. Data Sources

The study utilizes data for 35 African countries from 2009 to 2018. The dependent variable, electricity consumption (epc) refers to electric power consumption measured in kilowatts per hour. Technological innovation is captured by the number of patents registered (patent) and number of trademarks registered (tradem). GDP per capita (gdppc) refers to the gross domestic product divided by mid-year population, electricity prices (ep) is measured by consumer price index, population growth (pg) is the average change in population, trade openness (top) is the sum of export and import measured as a share of GDP, domestic investment is measured by gross fixed capital formation (gcf_gdp) as a share of GDP and FDI (fdi_gdp) is computed as foreign direct investment as a share of GDP. Data on electricity consumption per capita, GDP per capita, population growth, trade openness, gross fixed capital formation as a share of GDP and FDI as a share of GDP were collected from the World Bank's World Development Indicator (WDI). Number of patents registered, and number of trademarks registered were obtained from the World Intellectual Property Organization's (WIPO) data base.

### 3.3. Estimation Technique

A system Generalized Method of Moment (GMM) developed by Blundel and Bond (1998) would be explored for this study. Both the one-step and two-step system GMM are analyzed to capture robust estimation. The system GMM has the ability to correct the potential endogeniety in the model and unobserved heterogeneity of sampled countries. The use of the lagged of dependent variable enables a dynamic operation of the model. The system GMM model for this study is expressed as follows:

$$lnepc_{it} = \alpha_0 + \alpha_1\, epc_{it-1} + \alpha_2\, lnpatent_{it} + \alpha_3 lntradem_{it} + \alpha_4 lngdppc + \alpha_4\, lnep_{it} + \alpha_6\, pg_{it} + \alpha_7\, top_{it} + \alpha_8\, lngcf\_gdp + \alpha_9\, fdi\_gdp_{it} + u_{it} \quad (4)$$

In equation (4), $epc_{it-1}$ is the lagged of electricity consumption per capita. Other variables in equation 4 have been defined earlier.

## 4. DATA ANALYSIS AND DISCUSSION

Table 1 presents the descriptive statistics of the variables used in the study. Average values of the variables employed in the study range from 2.36 to 25.49. While population growth rate recorded the lowest mean value, gross fixed capital formation as a share of GDP has the highest mean value. The median, minimum and maximum values of all the variables are provided in the table. The degree of discrepancy and deviation from the mean measured by standard deviation indicate that GCF as a share of GDP (gcf_gdp) recorded the highest standard deviation. However, energy price (ep) has the lowest standard deviation in the series. Unlike patent registration, trademark registration, population growth and trade openness that are skewed to the left, electricity consumption per capita, GDP per capita, energy price, gross fixed capital formation and FDI are skewed to the right. Series such as population growth (pg), trade openness (top) and gross fixed capital formation as a share of GDP have kurtosis values close to a normal distribution while kurtosis of other series deviate from the normal distribution.

The correlation matrix of the variables employed in the study is provided in Table 2. Since our interest is on the relationship of electricity consumption with other variables, our attention will be focus on the first column. While patent registration has positive relationship with electricity consumption, trademark registration exhibits negative relationship with electricity consumption. The relationship between GDP per capita and electricity consumption is positive and significant. This shows that increase in income could lead to higher electricity consumption in Africa. However, electricity price has a negative relationship with electricity consumption. This suggests that a higher electricity price would lower electricity consumption. Similarly, an increase in population growth would lower electricity consumption; this could be as a result of overcrowding especially in urban centres. Positive and significant relationship exists among trade openness, domestic investment and electricity consumption. FDI shows a negative relationship with electricity consumption.

Table 3 shows the results of the system Generalized Method of Moments. Five different models were estimated; model 1 captures the major determinants of electricity consumption. These include technological innovation (proxy by the number of patents registered and number of trademarks registered), per capita income (gdppc) and energy prices (ep) proxy by consumer price index. We included population growth to the explanatory variables estimated in model 2. Model 3 shows the inclusion of trade openness with other determinants of electricity consumption estimated in the previous model. The difference in model 4 with the previous ones is the inclusion of domestic investment (gcf_gdp). The complete estimation that involves all the explanatory variables is presented in model 5. A major reason for estimating model 1 to 4 is to determine how an inclusion of an explanatory variable could vary the results of the parameter estimates.

The robustness of the results is checked by testing for autocorrelation of the first and second order. Since the p-values of the autocorrelation estimates are not statistically significant for all the models especially in the second order, it implies that our results do not suffer from the problem of autocorrelation of the second order. Similarly, the results of the Sargan test of overriding restriction support the validity of the instruments. The non rejection of the null hypothesis of the Sargan test indicates that the instrumental variables are not correlated with residual and

**Table 1: Summary statistics**

| Statistics | *lnepc* | *Lnpatent* | *Lntradem* | *lngdppc* | *Lnep* | *Pg* | *lntop* | *gcf_gdp* | *fdi_gdp* |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 5.933 | 3.582 | 8.271 | 7.307 | 4.813 | 2.363 | 4.213 | 25.493 | 3.866 |
| Median | 5.631 | 3.784 | 8.141 | 7.188 | 4.706 | 2.677 | 4.230 | 23.986 | 2.511 |
| Min | 3.741 | 0.000 | 3.526 | 5.351 | 4.470 | 0.055 | 3.031 | 1.612 | −6.057 |
| Max | 8.426 | 7.748 | 10.545 | 9.267 | 8.430 | 4.535 | 4.887 | 58.826 | 41.810 |
| SD | 1.230 | 1.986 | 1.244 | 1.032 | 0.339 | 0.900 | 0.369 | 10.490 | 5.314 |
| Skewness | 0.145 | −0.033 | −0.866 | 0.164 | 5.553 | −0.612 | −0.477 | 0.682 | 3.411 |
| Kurtosis | 1.929 | 2.136 | 5.982 | 1.948 | 51.609 | 2.691 | 2.894 | 3.283 | 19.317 |
| CV | 0.207 | 0.554 | 0.150 | 0.141 | 0.070 | 0.381 | 0.088 | 0.411 | 1.374 |

Authors' computation based on data collected from WDI and WIPO

**Table 2: Correlation matrix**

| | *Ec* | *Patent* | *Tradem* | *ict_imp* | *Gdppc* | *Cpi* | *pg* | *gcf_gdp* | *fdi_gdp* |
|---|---|---|---|---|---|---|---|---|---|
| Epc | 1.0000 | | | | | | | | |
| Lnpatent | 0.2618 | 1.0000 | | | | | | | |
| | [0.0025] | | | | | | | | |
| Lntradem | −0.4202 | 0.6942 | 1.0000 | | | | | | |
| | [0.0004] | [0.0000] | | | | | | | |
| Lngdppc | 0.6682 | 0.2355 | 0.0976 | 1.0000 | | | | | |
| | [0.0000] | [0.0000] | [0.2888] | | | | | | |
| Lnep | −0.1418 | 0.0640 | 0.3133 | −0.0357 | 1.0000 | | | | |
| | [0.0000] | [0.0000] | [0.0007] | [0.5221] | | | | | |
| Pg | −0.5330 | 0.1980 | 0.0052 | −0.5092 | −0.0793 | 1.0000 | | | |
| | [0.0000] | [0.7663] | [0.9548] | [0.0000] | [0.1546] | | | | |
| Lntop | 0.1479 | −0.3046 | −0.3599 | 0.2894 | −0.1599 | −0.1296 | 1.0000 | | |
| | [0.0000] | [0.0000] | [0.0001] | [0.0000] | [0.0049] | [0.0180] | | | |
| gcf_gdp | 0.0233 | −0.2103 | −0.1043 | 0.0753 | −0.1399 | 0.1977 | 0.3508 | 1.0000 | |
| | [0.7753] | [0.0004] | [0.2608] | [0.1721] | [0.0143] | [0.0070] | [0.0003] | | |
| fdi_gdp | −0.0243 | −0.1863 | −0.1556 | −0.1899 | −0.2028 | 0.1683 | 0.3338 | 0.4453 | 1.0000 |
| | [0.7656] | [0.0013] | [0.0938] | [0.0004] | [0.0003] | [0.0017] | [0.0000] | [0.0000] | |

Authors' computation based on data collected from WDI and WIPO

**Table 3: One-step system GMM**

| Variables | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 |
| L.lnepc | 0.894*** | 0.887*** | 0.919*** | 0.918*** | 0.939*** |
| | (0.0507) | (0.0572) | (0.0406) | (0.0430) | (0.0415) |
| Lnpatent | 0.0218 | 0.0219 | 0.0215 | 0.0207 | 0.0143 |
| | (0.0191) | (0.0193) | (0.0155) | (0.0161) | (0.0122) |
| Lntradem | −0.0433 | −0.0439 | −0.0201 | −0.0184 | −0.0132 |
| | (0.0461) | (0.0460) | (0.0295) | (0.0309) | (0.0231) |
| Lngdppc | 0.0633 | 0.0644 | 0.0468 | 0.0437 | 0.0642*** |
| | (0.0503) | (0.0496) | (0.0316) | (0.0305) | (0.0242) |
| Lnep | −0.212*** | −0.214*** | −0.188*** | −0.185*** | −0.261*** |
| | (0.0633) | (0.0615) | (0.0451) | (0.0415) | (0.0487) |
| Pg | | −0.00458 | 0.0170 | 0.0140 | 0.0561*** |
| | | (0.0266) | (0.0156) | (0.0203) | (0.0197) |
| Lntop | | | 0.100 | 0.0963 | 0.137*** |
| | | | (0.0638) | (0.0612) | (0.0504) |
| gcf_gdp | | | | 0.000474 | −0.000646 |
| | | | | (0.00156) | (0.00120) |
| fdi_gdp | | | | | −0.0109*** |
| | | | | | (0.00418) |
| Constant | 1.530** | 1.589** | 0.723* | 0.735* | 0.580 |
| | (0.726) | (0.798) | (0.435) | (0.441) | (0.426) |
| AR(1) | −1.97 | −1.96 | −2.51 | −2.44 | −2.40 |
| | [0.049] | [0.050] | [0.012] | [0.015] | [0.017] |
| AR(2) | −1.16 | −1.16 | −1.16 | −1.17 | −1.04 |
| | [0.248] | [0.244] | [0.245] | [0.244] | [0.299] |
| Sargan | 0.98 | 0.93 | 1.13 | 1.20 | 2.65 |
| | [0.323] | [0.334] | [0.287] | [0.274] | [0.104] |
| Hansen | 1.32 | 1.35 | 1.54 | 1.93 | 1.30 |
| | [0.251] | [0.245] | [0.214] | [0.165] | [0.254] |

Robust standard errors in parentheses *** p<0.01, **p<0.05, *p<0.1. Dependent variable = electricity consumption per capita (epc). Authors' computation based on data collected from WDI and WIPO

are satisfying the orthagonality condition. Additionally, Hasen test support the robustness of the instruments. All these tests confirmed that the results of our regression are valid and the inferences from the estimates are reliable.

In model 1 to 5, our measurement of technological innovation, namely the numbers of patent trademark registered have insignificant effect on electricity consumption. Although the coefficient of trademark registration conforms to expectation, it is not significant at the conventional levels. This result suggests that increase in technological innovation may not considerable affect electricity consumption in Africa. It shows that technological innovation has not led to energy efficiency in Africa. This is contrary to the findings from some studies conducted in Asia (see for instance, Tang and Tan, 2013; Sohag et al., 2015 and Saudi et al., 2019). A plausible reason for this could be the state of technology advancement in Africa. Available statistics have revealed that Africa countries have consistently experienced a slow pace of technological progress unlike the newly industrialized countries in Asia, such as Malaysia, Indonesia and others.

Other important determinants of electricity consumption were investigated. Although at this point, our prime interest is on model 5, the behaviours of the variables in model 1-4 are also analyzed. Per capita income has a positive and significant effect on electricity consumption. The positive effect of income on electricity consumption is in line with theory. In Africa, most electricity users that could not regularly pay their bills are disconnected from gaining access to it. Thus, an increase in income of a household would enhance his access to electricity. In terms of energy prices, the estimates of model 1 to 5 suggest that the higher the price of electricity the lower the consumption.

The coefficient of population growth generated an interesting finding. In model 5, the coefficient of population growth has a statistically significant effect on electricity consumption. Noteworthy is the obtained coefficient obtained; it suggests that a 10% increase in population growth would result to 0.5% increase in electricity consumption. This finding is in line with theory and some empirical studies on developing countries. The usual occurrence in many countries in Africa is that electricity especially in locations that are densely populated. In addition, the coefficient of trade openness shows a positive and statistically significant effect on electricity consumption (see model 5). It shows that an increase in trade openness would result to about 0.14% increase in electricity consumption. The intuition here is that increase in trade openness increases economic activities which could lead to higher electricity consumption.

The effect of domestic investment and foreign direct investment on electricity consumption was investigated. Both domestic investment and foreign direct investment have negative effect on electricity consumption. However, the effect of domestic investment on electricity consumption is not statistically significant at conventional levels. A 10 percent increase in foreign direct investment would lead to 0.1% rise in electricity consumption in

**Table 4: Two-step system GMM**

| Variables | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 |
| L.lnepc | 0.903*** | 0.891*** | 0.930*** | 0.931*** | 0.933*** |
| | (0.0743) | (0.0961) | (0.0580) | (0.0652) | (0.0417) |
| Lnpatent | 0.00745 | 0.00771 | 0.00816 | 0.00450 | 0.00883 |
| | (0.0163) | (0.0177) | (0.0127) | (0.0131) | (0.0105) |
| Lntradem | −0.0169 | −0.0225 | 0.00128 | 0.00840 | −0.00702 |
| | (0.0533) | (0.0620) | (0.0261) | (0.0260) | (0.0213) |
| Lngdppc | 0.0676 | 0.0768 | 0.0522 | 0.0412 | 0.0681** |
| | (0.0591) | (0.0547) | (0.0367) | (0.0377) | (0.0269) |
| Lnep | −0.247*** | −0.248*** | −0.215*** | −0.209*** | −0.245*** |
| | (0.0826) | (0.0737) | (0.0483) | (0.0518) | (0.0485) |
| Pg | | −0.00224 | 0.0176 | 0.00792 | 0.0474** |
| | | (0.0373) | (0.0178) | (0.0339) | (0.0223) |
| Lntop | | | 0.0958 | 0.0843 | 0.112** |
| | | | (0.0951) | (0.0943) | (0.0504) |
| gcf_gdp | | | | 0.00131 | −0.000358 |
| | | | | (0.00251) | (0.00158) |
| fdi_gdp | | | | | −0.00737** |
| | | | | | (0.00317) |
| Constant | 1.429 | 1.491 | 0.620* | 0.656* | 0.595 |
| | (0.891) | (1.096) | (0.324) | (0.362) | (0.411) |
| AR(1) | −2.11 | −2.04 | −2.53 | −2.26 | −2.42 |
| | [0.035] | [0.041] | [0.011] | [0.024] | [0.016] |
| AR(2) | −1.13 | −1.14 | −1.14 | −1.15 | −1.07 |
| | [0.257] | [0.254] | [0.254] | [0.250] | [0.283] |
| Sargan | 0.98 | 0.93 | 1.13 | 1.20 | 2.65 |
| | [0.323] | [0.334] | [0.287] | [0.274] | [0.104] |
| Hansen | 1.32 | 1.35 | 1.54 | 1.93 | 1.30 |
| Computation | [0.251] | [0.245] | [0.214] | [0.165] | [0.254] |

Standard errors in parentheses ***p<0.01, ** p<0.05, * p<0.1. Note: Dependent variable = electricity consumption per capita (epc). Source: Authors' based on data collected from WDI and WIPO

Africa. This result explains the fact that increases in investment would lead to energy efficiency. A plausible explanation for this could be as a result of the use of alternative source of power by many foreign international companies in Africa.

Table 4 presents the two-step system GMM explore for robustness and to confirm the accuracy of our parameter estimates in Table 3. A close look at Tables 3 and 4 would shows that the results are consistent and robust.

## 5. CONCLUSION AND RECOMMENDATION

The relationship among electricity consumption, electricity prices and household income are well documented in the economic literature. However, the role of technological innovation in influencing this relationship has remained scanty. This study empirically investigated the relationship between electricity consumption and its major determinants and examined the role of technological innovation in improving the efficiency of electricity use in Africa. Both the one and two-step dynamic system GMM were explored to correct the potential problem of endogeniety and ensure consistency and robustness.

This study showed that per capita income, electricity prices, population growth, trade openness and FDI influenced electricity consumption in diverse ways. While per capita income, population growth and trade openness have positive and significant effect on electricity consumption; the effects of electricity prices and FDI were negative. The result suggests that increase in household income would raise electricity consumption. Similarly, population growth and openness had resulted to greater electricity consumption in the continent. In line with theoretical expectation, increase in electricity prices would lower electricity consumption. In addition, empirical findings indicate that technological innovation plays no significant role in reducing energy consumption and improving energy efficiency in Africa.

Based on the findings of this study, some policy recommendations can be inferred. First, since increase in per capita income increases electricity consumption and electricity generation in Africa generally is insufficient, government should increase investment in electricity infrastructure to enhance access to power supply. Second, the result shows that increase in population growth rate increases electricity consumption. Hence to reduce overburden the available electricity infrastructures, government efforts should be geared towards providing alternative power supply. Third, an important finding of this study is that technological innovation does not play a significant role in reducing energy consumption and this is as a result of low level of innovation in Africa. Therefore, government should concentrate efforts towards improving technological innovation to enhance energy efficiency in Africa.

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