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ICT Adoption and Stock Market Development in Africa: An Application of the Panel ARDL Bounds Testing Procedure

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Abstract: The nexus between Information Communication Technology (ICT) and stock market development has been predominantly based on studies of the developed markets and high-income economies of the world. The objective of this study was to examine the causal relationship between ICT adoption and stock market development in Africa. The study examined a panel of 11 African stock exchanges for the period 2008–2017 and employed the panel ARDL bounds testing procedure to test for cointegration and examine the causal relationship between ICT adoption and stock market development. The dependent variable employed was the stock market development index (FINDEX), while the independent variable was the ICT adoption index (ICTDEX), and the financial freedom index (FFI) was employed as a control variable. Firstly, the results of the study documented that the variables are cointegrated in the long term. Secondly, the results of the study documented a bi-directional causal relationship (complementarity) between ICT adoption and stock market development. In essence, ICT adoption and stock market development reinforce each other. Thirdly, the study established a causal relationship running from financial freedom to stock market development. This lends credence to the notion that financial market deregulation promotes stock market development. Lastly, a positive causal relationship that ran from financial freedom to stock market development was documented. This study contributes to the body of knowledge in the sense that it is the first study to examine the phenomenon of the ICT–stock market development nexus by employing a panel study. Hitherto, studies were mainly country-specific in nature. The findings of the research imply that policymakers should be more resolute when formulating ICT policies, as ICT adoption can drive stock market development and vice versa for better economic growth. Policymakers should embrace policies that support the deregulation of stock markets as this will lead to the development of the latter.

Keywords: stock market development; economic growth; financial freedom; ICT adoption; causality; cointegration; Africa

JEL Classification: G23; O16; O33; O43

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1. Introduction

Recent years have seen the remarkable growth and development of Information and Communication Technology (ICT), mostly in different countries, sectors and industries of the world, as a result of the transformational power of technology that favors efficiency and productivity. Dzidonu (2010) asserted that ICT can be termed as a collection of technologies that may consist of a microprocessor, computer, multimedia, broadcasting network telecommunication and internet technology. Further, he concluded that there has been a boost of service and operation as a result of these technologies at both individual and organization levels. Baro (2011) highlighted that the impact of ICT in the development of the global economy and life, in general, cannot be overstated. He further implied that

the increase in the implementation of ICT projects and their usage over the last few decades in Africa has been phenomenal (Baro 2011). This can be attributed to the outstanding and efficient role ICT plays in both the public and the private sectors.

The nexus between Information Communication Technology and stock market development, particularly in recent years, has been mostly determined based on studies of industrialized economies, as well as the rising markets and high-income economies of the world. The study of the relationship of Information Communication Technology with the development of stock markets, especially in the past five years, has focused mostly on the economies of developed countries and developing markets, including the economies of countries with a high interest rate (Okwu 2015). According to Petros (2012), stock markets are proficient at controlling the growth of economies by supporting investments between individuals who save, and this provides means for organizations to finance their investment. Moreover, the COVID-19 pandemic has demonstrated that individuals will generally increase their equity holdings during times of crises, which is consistent with the contrarian approach (Priem 2021). Okwu (2015) stated that stock market development is driven by Information Technology through the usage of controlled devices that provide trading information, which helps users to make investment decisions regarding their new, long-term finances. Furthermore, the use of these technology-driven devices helps with the trading of listed stocks, which are traded in real-time and at marketplace-driven prices. As a result of the criticality of innovative knowledge to steady growth at technological boundaries, an economic singularity would emerge on the grounds of some relevant alteration to the knowledge production role, shaping various spheres aside from information technology (Udell et al. 2019).

Africa's stock exchanges have experienced rapid growth over the years. However, at the same time, several reforms have been instituted in the capital and foreign exchange markets of various African countries. Arguably, the deregulation of financial markets could also have contributed to the growth of the African stock exchanges. Quintessentially, all the African stock exchanges have singled out ICT adoption as one of the major developmental factors of the reforms they have experienced throughout their existence. This highlights the importance of ICT adoption to the development of stock exchanges. Against this backdrop, the present inquiry sought to answer the following research questions: (1) What cointegrating relationships exist between ICT adoption and stock market development in Africa? (2) What is the direction of causality between ICT adoption and stock market development in Africa?

The rest of the article is organized as follows: Section 2 reviews the related literature. Section 3 presents an overview of African stock markets. Section 4 describes the research methodology employed in the study. Section 5 presents the empirical findings, and Section 6 concludes the article.

2. Review of Related Literature

Studies on stock market developments and the linkage to economic growth provide insights into the relationship between economic development and stock market development. From a review of literature perspectives, the discussion on the determinants of economic growth and stock market development in this section has been structured into three categories: developing countries, developed countries, and emerging economies. Furthermore, this section describes the expectations in terms of the relationships between the stock market and economic development. In each of the empirical pieces of evidence analyzed, we determine if the relationship is shown to be positive, negative or neutral, as the case might be. At the end of this section, the predominant relationship is highlighted.

Kedibonye (2018) examined the relationship between financial development, economic growth, capital accumulation, and productivity growth in Botswana for the period 1980–2014 and established that financial development had a significant impact on economic growth.

Ngare et al. (2014) examined stock market development and economic growth in Africa and found a positive bi-directional relationship between economic growth and stock market development. Similarly, Nazir et al. (2010) explored the relationship between economic growth and stock market development in Pakistan and documented a bi-directional positive relationship between economic growth and stock market development.

Several studies were conducted to investigate the factors of stock market development in Nigeria. Among others, Osinubi (2002) investigated the impact of the stock market on economic growth in Nigeria and documented a positive relationship. This linkage also showed that stock market development leads to positive economic growth; therefore, it can be concluded that when growing an economy, having a strong stock market will give a positive boost to the process. In contrast, Ohiomu and Godfrey (2011) set out to interrogate the effect of the stock market on economic growth in Nigeria and also reported a positive relationship between economic growth and stock market development. Their study affirmed positive links between the stock market and economic growth and suggested that the pursuit of policies geared towards the rapid development of the stock market can also lead to positive economic growth. Oke and Adeusi (2012) also examined the impact of capital market reforms on economic growth in Nigeria and found that capital reforms positively impacted on economic growth.

In the realm of studies focused on Tanzania, among others, Katuma (2012) examined the role of the stock exchange market in economic growth in Tanzania and found that the stock exchange market contributed a small amount to the growth of the economy. Further, Msangi (2015) examined the determinants of capital market development in Tanzania and found no relationship between capital market development and stock market liquidity, which evidenced a neutral relationship between stock market development and economic growth.

Another strand within the African context has focused on Ghana. For instance, Quaidoo (2011) examined the relationship between stock market capitalization and economic growth in Ghana. The study found that economic growth had a positive impact on the development of the Ghana Stock Exchange. The results of the Granger causality test indicated that economic growth leads to stock market capitalization (stock market development) without any feedback supporting the "demand following" hypothesis. Acquah-Sam (2016) examined the macroeconomic factors that influence capital market development in Ghana and established a positive relationship between stock market development and economic growth.

Abdulrazzaq et al. (2019) investigated how stock market development is impacted by other events which are associated with significant levels of market uncertainty. They examined the effect of the Iraq invasion, the global financial crisis, and the Arab Spring revolution with the aim of identifying if there are connections between oil prices and the performance of the Kuwait stock market during these events. The results of their study established short-term dynamics: namely, a unidirectional causality was found between Brent and the Kuwait stock market, a result was not confirmed during the Arab Spring event, and a unidirectional relationship was found from oil to the stock market only during the Iraq invasion.

Recent studies on financing and stock markets now focus on sustainable finance and transitioning to low-carbon economies. Arguably, stock exchanges will be instrumental in raising green finance. Within this strand of literature, Ionescu (2021b) carried out a study to evaluate and analyze the relationship between green financial behavior, climate change mitigation, and environmental energy sustainability. Ionescu (2021b) documented that the climate sentiments of investors can be instrumental in preventing an incoherent transition to environmentally safe practices and that carbon risk regulation and ecologically sound public guarantees reduce emissions but intensify unpredictability. Other studies in this realm include another work by Ionescu (2021a) that established that when leveraged for low-carbon energy, sustainable economic development, and climate change mitigation during the COVID-19 pandemic, green finance has had a positive impact on environment

optimization, while having dissimilar effects on environmental quality for heterogeneous levels of economic development. Other related studies that have examined the finance–growth nexus are presented in Table 1.

Table 1. Synthesis of studies on the finance–growth nexus.

Author(s)	Study and Unit of Analysis	Main Findings
Garcia and Liu (1999)	Macroeconomic determinants of stock market development. Utilized a sample of 15 developed and developing countries for the period 1980–1995.	Stock market development and financial intermediaries are complements.
Petros (2012)	Relationship between economic growth and stock market development in Zimbabwe for the period 1991–2007.	Positive relationship between stock market and economic growth.
Quartey and Gaddah (2007)	How macroeconomic factors affect stock market development in Ghana for the period 1991 to 2004.	Positive relationship established between real income, savings and credit, and the stock market development variable.
Yartey (2008)	The relationship between financial development and ICT diffusion. Used a panel of 76 emerging and developed countries for the period 1990–2003.	Credit and stock market development fosters ICT adoption.
Sibindi and Bimha (2014)	The relationship between banking sector development and economic growth. Time series analysis using Zimbabwe as unit of analysis for the period 1980 to 2012.	Positive relationship between banking sector development and economic growth.
Sibindi (2014a)	The nexus between life insurance sector development, financial development, and economic growth in South Africa for the period 1990 to 2012.	Causal relationship running from the economy to the life insurance sector. Bi-directional causal relationship running between the economy and financial sector development and vice versa.
Sibindi (2014b)	The relationship between remittances, financial development, and economic growth in Lesotho for the period 1970 to 2010	Cointegrating relationship amongst the variables. A causal relationship that runs from remittances to the economy without feedback was established.

3. An Overview of the African Stock Markets

The African stock markets have witnessed sustained growth over the years. This section presents the key metrics of 11 African stock exchanges which form the unit of analysis of this study, namely Botswana Stock Exchange (BSE), Bourse de Tunis (BVMT), The Bourse Regionale des Valeurs Mobilieres (BRVM), Casablanca Stock Exchange (Casa SE), Egyptian Exchange (EGX), Ghana Stock Exchange (GSE), Johannesburg Stock Exchange

(JSE), Nairobi Securities Exchange (NSE), Namibia Stock Exchange (NSX), Nigerian Stock Exchange (NSE), and Stock Exchange of Mauritius (SEM).

The key metrics are presented in Table 2. We must highlight that, on the one hand, JSE is the most developed, while, on the other hand, the BRVM is the least developed as evidenced by their market capitalization.

Table 2. Selected African stock exchanges as of 31 December 2019.

Country	Name	Number of Listed Companies	Market Capitalization
Botswana	Botswana Stock Exchange (BSE)	33	$37,505,515,000
Côte d'Ivoire	BRVM Stock Exchange (BRVM)	45	$6,960,322,592
Egypt	Egypt Exchange (EGX)	223	$45,628,544,290
Ghana	Ghana Stock Exchange (GSE)	42	$9,951,00,000
Kenya	Nairobi Securities Exchange (NSE)	63	$22,007,506,496
Mauritius	Stock Exchange of Mauritius (SEM)	97	$8,980,000,000
Morocco	Casablanca Stock Exchange (Casa SE)	75	$60,576,297,847
Namibia	Namibia Stock Exchange (NSX)	40	$141,128,581,560
Nigeria	Nigeria Stock Exchange (NSE)	147	$35,925,467,734
South Africa	Johannesburg Stock Exchange (JSE)	353	$898,990,000,000
Tunisia	Bourse de Tunis (BVMT)	88	$8,922,590,000

Source: Authors' construction based on data obtained from World Bank Global Financial Development database.

The Stock Exchange of Mauritius Limited (SEM) was initially incorporated as a limited liability company in 1989, and it became a public company in 2008 when its shares were listed. SEM has also gone through several reforms and developments over time. In 1991, it adopted the open cry trading system, which is a single price auction system. In 1997, SEM launched its first website. This development helped the stock exchange to share trading information such as the online tracking of shares, trading prices, volume traded, and listing rules. In 2001, SEM moved away from the open cry trading system to a fully automated online trading system (Mauritius Stock Exchange 2019).

The Casablanca Stock Exchange (Casa SE) was founded in 1929. Like most African Stock Exchanges, Casa SE has also gone through different stages of reforms. In 1967, the stock exchange was reorganized to a well-organized legal and technical framework. Over the years, the stock exchange has continued to undertake reforms to strengthen and modernize the exchange. In 1997, Casa SE launched an electronic trading system to allow for online trading, and in 2001, a further improvement was made to allow stockbrokers to trade from their office. This was a significant development because trading was made possible through the use of ICT infrastructure, further supporting the objective of the research (The Casablanca Stock Exchange 2019).

Botswana Stock Exchange (BSE), like all other African stock exchanges, has undergone several developmental stages. However, the most pertinent was the initial idea to establish a stock exchange in Botswana, which was contemplated and actualized in 1989. BSE

has actively pursued the use of ICT improvements to meet stakeholders' requirements, integrity, capacity, and cost efficiency as well as to meet international standards. (Botswana Stock Exchange 2019). BSE is also the third largest stock exchange in SADC, and one of the best performing stock exchanges in the last decade (Botswana Stock Exchange 2019).

In February 1969, the Tunis Stock Exchange, which is also known as Bourse de Tunis (BVMT), was established as a public institution and also, as is the case with other African Stock Exchanges, BVMT underwent several reforms which culminated in BVMT becoming a limited liability company in 1995. In 1996, the stock exchange set up the electronic trading system (NSC) which, as in the case of the other stock exchanges, enabled the trading and settlement of trading activities electronically. This development shows that stock exchanges can enhance their operations through the use of Information and Communication Technology (Bourse de Tunis 2019).

Ghana Stock Exchange (GSE) was established in 1989. Even though Ghana enacted a stock exchange act in 1971, it was only in 1989 that an actual stock exchange was established. The GSE was organiszd and registered as a private company limited by guarantee. The stock exchange commenced trading in November of 1990, after the receiving recognition as an authorized stock exchange under the stock exchange act of 1971. Then, in 1994, the stock exchange became a public company by guarantee (Ghana Stock Exchange 2019).

The GSE also went through different processes of structuring and restructuring before becoming a reality. Since the formation of the stock exchange, it has adopted ICT as a backbone of its operation. This manifested in the stock exchange winning the most innovative stock exchange award in 2018, awarded by the Africa investor (Ai) awards.

The Bourse Regionale des Valeurs Mobilieres (BRVM) is a regional stock market for members of the West African Economic and Monetary Union (WAEMU), which comprises eight-member states and includes the following countries: Côte d'Ivoire, Niger, Senegal, Togo Benin, Burkina Faso, Guinea-Bissau, and Mali. It is said to be the only stock market in the world that is shared by multiple countries, and it is totally run as a digital platform, supported by Information and Communications Technology, with a perfect integration.

In 1993, the member states of WAEMU decided to establish a joint stock market, solely for the member states. After several engagements between the member states, BRVM was established and began operations in 1998. This was a result of the member states giving a mandate to West African Central Bank to establish the stock exchange a year before. BRVM went through several rapid developments from its inception; however, the most pertinent of all was the creation in 2014 of a stand-alone index by Morgan Stanley Capital International (MSCI) for the WAEMU financial market. Then, in 2014, the BRVM was integrated into the MSCI and S&P Dow Jones indices (Bourse Regionale des Valeurs Mobilieres.org 2019).

4. Research Methodology

4.1. Measures of ICT Adoption and Stock Market Development

This study examined the causal relationship between ICT adoption and stock market development in Africa. Various data sources were employed to source the panel data on stock market development, ICT adoption, and a control variable. The ICT and stock market development data were sourced from the International Telecommunications Union and the World Bank Global Financial Development databases, respectively. The data for the financial freedom score were sourced from the Heritage Foundation databases. The variables employed in this study are described in Table 3. These are the ICT adoption variables and the stock market development variables as well as the financial freedom variable. Panel data techniques were used to analyze the data.

Table 3. Variable definitions and data sources.

Variable	Variable Definition
ICT Adoption Variables	
Number of Broadband Users (NBU)	NBU = Fixed-broadband subscriptions per 100 inhabitants
Number of Fixed Telephone Users (NFTU)	NFTU = Fixed-telephone subscriptions per 100 inhabitants
Internet Users (IU)	IU = Percentage of individuals using the internet
Number of Mobile Phone Users (NMU)	NMU = Mobile-telephone subscriptions per 100 inhabitants
Stock Market Development Variables	
Stock Market Total Value Traded (SMTV)	SMTV = (Stock market total value traded)/(Gross Domestic Product) × 100%
Stock Market Capitalization (SMC)	SMC = (Stock market capitalisation)/(Gross Domestic Product) × 100%
Stock Market Turnover Ratio (SMTR)	SMTR = (Total value of shares traded)/(Market capitalisation) × 100%
Number of Listed Companies (NLC)	NLC = Number of listed companies per 10000 people
Control Variable	
Financial Freedom Index (FFI)	FFI = Financial Freedom score

4.2. Empirical Model Specification and Estimation Techniques

Cointegration is ascertained between variables if a long-term equilibrium relationship between the variables exists (Awe 2012). The study as such noted that there exists a cointegration between ICT adoption and stock market development variables. This leads to the creation of indexes to mitigate the effects of these variables on one another. The FINDEX and ICTDEX were created using Principal Component Analysis (PCA). PCA is conducted by computing the eigenvalues of the variance matrix of the variable. Adnan (2011) suggested that PCA transforms data into new variables which are not correlated, while the highest variation of the original variables is contained in the first few principal components (Jolliffe 2002). Then, the study proceeded to estimate the error correction model between the stock market index, ICT index, and financial freedom index.

Having established a cointegration between the variables, we proceeded to perform error correction between the stock market index, ICT index, and financial freedom index. In order to investigate the relationships between the stock market index, ICT index, and financial freedom index, the models below were specified and estimated using the ARDL bounds testing approach, consisting of estimating an unrestricted error correction model (ECM) as follows:

$$\begin{aligned}\Delta FINDEX_{it} = {} & a_0 + a_1 FINDEX_{it-1} + a_2 ICTDEX_{it-1} + a_3 FFI_{it-1} + \\ & \sum_{i=0}^{\infty} a_{1i} \Delta FINDEX_{it-1} + \sum_{i=0}^{\infty} a_{2i} \Delta ICTDEX_{it-1} + \sum_{i=0}^{\infty} a_{3i} \Delta FFI_{it-1} + \varepsilon_{it}\end{aligned} \quad (1)$$

$$\begin{aligned}\Delta ICTDEX_{it} = {} & a_0 + a_1 ICTDEX_{it-1} + a_2 FINDEX_{it-1} + a_3 FFI_{it-1} + \\ & \sum_{i=0}^{\infty} a_{1i} \Delta ICTDEX_{it-1} + \sum_{i=0}^{\infty} a_{2i} \Delta FINDEX_{it-1} + \sum_{i=0}^{\infty} a_{3i} \Delta FFI_{it-1} + \varepsilon_{it}\end{aligned} \quad (2)$$

$$\begin{aligned}\Delta FFI_{it} = {} & a_0 + a_1 FFI_{it-1} + a_2 FINDEX_{it-1} + a_3 ICTDEX_{it-1} + \\ & \sum_{i=0}^{\infty} a_{1i} \Delta FFI_{it-1} + \sum_{i=0}^{\infty} a_{2i} \Delta FINDEX_{it-1} + \sum_{i=0}^{\infty} a_{3i} \Delta ICTDEX_{it-1} + \varepsilon_{it}\end{aligned} \quad (3)$$

where Δ represents the first difference operator and other variables are consistent as described above.

4.3. Principal Components Analysis

Principal component analysis (PCA) is a commonly applied method to reduce the attributes of a data set, where variables have a different meaning when applied in a certain way. This method was applied to help generate a single composite index of stock market development as well as ICT adoption for the selected 11 African stock exchanges. The FINDEX and ICTDEX were created using Principal Component Analysis (PCA). PCA is performed by computing the eigenvalues of the variance matrix of the variable. The advantage of applying PCA to construct the composite indices was that the index weights were based on the correlation of the individual measures of stock market development (SMTV, SMC, SMTR and NLC,), as well as ICT adoption (NBU, NFTU, IU and NMU). This study used PCA to determine appropriate composite indices for stock market development and ICT adoption in selected African countries using the following equation:

$$\beta\varrho = \varpi\varrho 1 \times 1 + \varpi\varrho 2 \times 2 + \varpi\varrho 3 \times 3 + \ldots + \varpi\varrho\gamma \times \gamma \quad (4)$$

where

$\beta\varrho$ = estimate of the jth factor;
$\varpi\varrho$ = weight of the factor score coefficient; ϱ = variable of interest; γ = number of variables.

5. Empirical Findings

This section presents the empirical findings of the study. It begins by describing the procedure that was followed to construct the indices. This is followed by the presentation of the panel cointegration results estimated within the autoregressive framework.

5.1. Pre-Estimation Procedure for Constructing the Stock Market and ICT Indices

The first step in the estimation procedure was to create a stock market index to proxy stock market development. Table 4 presents the eigenvalues of the correlation matrix of the four different indicators that constitute the stock market development index (FINDEX). The sum of the eigen-values is equal to the number of individual indicators.

Table 4. Principal Component Analysis (FINDEX): eigenvalues.

Principal Component	Eigenvalue	% of Variance	Cumulative %
1	2.38904	132	60
2	1.07253	56	87
3	0.511295	48	99
4	0.0271344	0	100

The first principal component explains the maximum variance (60%) in all the individual indicators (eigenvalue of 2.39). The second principal component explains the maximum amount of the remaining variance (27%), with an eigenvalue of 1.07. The third principal component explains 12% of the variance with an eigenvalue of 0.51, while the fourth principal component explains the remaining 1% of the variance with an eigenvalue of 0.027. Therefore, the first two principal components are more relevant measures of FINDEX as they explain over 87% of the variance.

The second step in the estimation procedure was to create a stock market development index (FINDEX) using the principal component framework in order to proxy stock market development. Table 5 presents the results of this procedure. The positive coefficients for the first principal component (PC2) imply that it represents the overall measure for stock market development. The maximum weights in PC1 and PC4 are for the stock market transaction value of the stock exchanges (SMTV), suggesting that there is a strong influence of this variable in these components. The stock market turnover ratio has the strongest influence in PC4, while stock market capitalization shows the largest positive weight in PC3.

Table 5. Principal Component Analysis (FINDEX): eigenvectors (loadings).

Principal Component	PC 1	PC 2	PC 3	PC 4
NLC	−0.014	0.937	0.336	0.095
SMC	0.5908	0.2305	−0.4381	0.6371
SMTV	0.6341	0.0122	−0.2174	0.7419
SMTR	0.4986	0.2623	0.805	0.186

This study thus applied PCA to determine an appropriate composite index for stock market development in selected African stock exchanges using the following specific PCA equation:

$$\text{FINDEX} = (0.5908 \times \text{SMC}) - (0.014 \times \text{NLC}) + (0.6341 \times \text{SMTV}) + (0.4986 \times \text{SMTR}) \quad (5)$$

where

FINDEX = the first principal component for stock market development;
SMC = stock market capitalization as a percentage of GDP;
NLC = number of listed companies per 10,000;
SMTV = stock market total value traded as a percentage of GDP;
SMTR = stock market turnover ratio.

Similarly, Tables 6 and 7 presents the eigen values of the correlation matrix of the four different indicators that constitute the ICT adoption index (ICTDEX) as well as how the ICTDEX PCA was constructed. The same procedure as outlined above was adopted.

Table 6. Principal Component Analysis (ICTDEX): eigenvalues.

Principal Component	Eigenvalue	% of Variance	Cumulative %
1	2.17692	120	54
2	1.07253	38	79
3	0.511295	35	94
4	0.0271344	0	100

Table 7. Principal Component Analysis (ICTDEX): eigenvectors (loadings).

Principal Component	PC 1	PC 2	PC 3	PC 4
NBU	0.6118	0.0998	−0.2517	−0.7432
NFTU	0.5550	−0.3065	−0.5041	0.5864
IU	0.2938	0.8916	0.1450	0.3126
NMU	0.4809	−0.3180	0.8133	0.0778

Thus, the ICT adoption index was constructed with the following weights:

$$\text{ICTDEX} = (0.6118 \times \text{NBU}) + (0.5550 \times \text{NFTU}) + (0.2938 \times \text{IU}) + (0.4809 \times \text{NMU}) \quad (6)$$

where

ICTDEX = the first principal component for information and communication technology adoption;
NBU = number of broadband users;
NFTU = number of fixed telephone users;
IU = internet users;
NMU = number of mobile phone users.

5.2. Panel Unit Root Test

In determining whether the variables used in this study were stationary or otherwise, panel unit root tests were conducted by applying Levin Lin and Chu, ADF–Fisher Chi-

square and PP–Fisher Chi-square tests, which were conducted to check robustness. Table 8 documents the panel unit root tests for the stock market index (FINDEX), ICT index (ICTDEX) and financial freedom index (FFI) variables that were conducted by applying the Levin Lin and Chu, ADF–Fisher and PP–Fisher methods. The decision criteria were that if the *p*-value was >0.05, then the null hypothesis would be accepted that a unit root exists, implying that the data are non-stationary. Conversely, if the *p*-value was <0.05, the null hypothesis would be rejected, implying that a unit root does not exist leading, to the inference that the data would be stationary.

Table 8. Panel unit root tests.

	Levin Lin and Chu		ADF—Fisher Chi-Square		PP—Fisher Chi-Square	
	Test Statistic	**Stationarity**	**Test Statistic**	**Stationarity**	**Test Statistic**	**Stationarity**
FINDEX	−11.7403 ***	I(0)	65.7015 ***	I(0)	81.8188 ***	I(0)
ICTDEX	−4.31602 **	I(1)	41.4621 **	I(1)	58.8585 **	I(1)
FFI	−7.00584 **	I(0)	23.0201 **	I(0)	44.7795 **	I(0)

t statistics in parentheses ** $p < 0.05$, *** $p < 0.01$. I(0) indicates that the variable is stationary at levels; I(1) indicates that variable is stationary at first difference and so on.

The unit root tests revealed that the stock market index (FINDEX), financial freedom index (FFI) and gross domestic Product (GDP) were all stationary at levels, as their *p*-values were less than 0.05, while the ICT index was stationary at the first level of difference. Thus, since a unit root exists among one of the variables, which is the ICT index, then there was a need to conduct a cointegration test to ascertain the long-term relationship among the variables.

5.3. Cointegration and Error Correction Model for Stock Market Index, ICT Index and FFI Variable

Within this estimation framework, it is pertinent to decide if Pooled Mean Group (PMG), Mean Group (MG) or the Dynamic Fixed Effects (DFE) is the most suitable estimator for the panel ARDL. The Hausman test was conducted to select the most suitable estimator for the ARDL model, and the *p*-value of the Hausman test was statistically insignificant, rendering the PMG estimator most appropriate. If there is a probability that the slope exhibits homogeneity, the PMG is the most suitable estimator, and the null hypothesis of slope homogeneity over the long term cannot be dismissed. If the likelihood or probability value is in excess of 5%, PMG is the best estimator to use to analyze panel data.

Therefore, as PMG is the expected estimation procedure, the discussion of the outcomes is based on the yield of the PMG estimator (Hausman test results not reported here). According to Pesaran et al. (2000), PMG has some advantages over the MG and the DFE methods. This is because the PMG estimator permits heterogeneity in the intercept, the short-term parameters, and the error variance between the groups while restricting the homogeneity of the long-term coefficients among the groups. Therefore, in order to examine the cointegration between the variables, the study utilized the panel ARDL.

The panel ARDL helps to analyze the long and short-term elements of the variables of interest. The panel ARDL is ideal as it additionally enables the examination of the heterogeneity of the factors of interest crosswise over a country in the short term. The study contrasts these outcomes and those reached by utilizing increasingly restrictive Dynamic Fixed Effects (DFE) techniques. The Mean Group (MG) approach and the output of these results for all the three panel error correction estimators—that is, PMG, MG, and DFE—are displayed. This segment presents the outcomes acquired by utilizing the PMG estimator, as the Hausman test neglected to dismiss the null hypothesis. Moreover, it is a favored estimator because of its advantages in consistency and proficiency over the other panel estimators (Loayza and Ranciere 2006). The results that were acquired from Mean Group and the dynamic fixed effects are additionally displayed for comparison purposes.

This section presents the results of the cointegration and the error correction between the stock market index, ICT index, and financial freedom index. The results presented in this study are those of the Pooled Mean Group (PMG). The PMG assumes that the long-term relationships between the stock market index, financial freedom index, and ICT index are identical across countries while allowing the short-term relationships to be country-specific. The coefficients have been verified for long-term homogeneity using the Hausman test.

Table 9 summarizes the Pooled Mean Group estimates of the cointegrating relationship between the stock market index, ICT index, and financial freedom index for the African countries selected for this study. The results in Table 9 document that there is a long-term relationship between the stock market index, ICT index, and financial freedom index. The long-term relationship between the stock market index (FINDEX) (which proxies stock market development) and ICTDEX (which proxies ICT adoption) is positive and significant at the 1% level of significance. A one percent increase in the adoption of ICT in the long term increases the stock market indices by 0.7 percent.

Table 9. Summary of PMG, MG, and DFE on the cointegrating relationship between the stock market index, ICT index, and FFI.

	PMG	MG	DFE
	D.FINDEX	**D.FINDEX**	**D.FINDEX**
Long Term			
ICTDEX	0.707 ***	−0.936	2.700 ***
	(12.6)	(−0.50)	−3.67
FFI	0.0440 ***	−4.55	−2.129
	(4.1)	(−0.97)	(−0.67)
ECT	−0.541 **	−0.722 ***	0.244 *
	(−2.86)	(−4.19)	−2.35
Short Term			
D.ICTDEX	−0.782	−0.0466	0.2
	(−1.54)	(−0.11)	−0.98
D.FFI	−0.187	0.908	−1.452 *
	(−0.27)	−1.12	(−2.11)
_cons	−0.13	−0.307	−0.281
	(−1.35)	(−0.42)	(−0.66)
N	98	98	98

t statistics in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Furthermore, the results show a significant positive long-term relationship between the stock market index and financial freedom index. This implies that improved financial efficiency will lead to the development of stock markets in Africa. However, in the short term, the study observed an insignificant negative relationship between the ICT index and stock market index. Similarly, the study also observed an insignificant negative relationship between the financial freedom index and stock market index. Hence, the insignificance of the *p*-values for all the proxies in the short term also implies that there is no short-term cointegration. The error correction term is negative and significant under the preferred PMG estimator. Further, the results document that stock markets in Africa adjust to changes in the ICT index and financial freedom index to a long-term equilibrium at a speed of adjustment of 54.1%.

5.4. Panel Causality Test

This section presents the results of the panel causality tests. The trivariate ECM within the ARDL framework was utilized to examine the causal relationships between

each of the stock market indices: the ICT index and financial freedom index. The study did not perform the Granger causality test; rather, we used the ECM approach to examine the causality between the variables of interest in this study. For this study, the causality between the variables was determined by the statistical significance of the coefficients, while the statistical significance of the respective error terms shows joint causality for the variables for the panel. The causal links that are presented in Table 10 show that the causal links are mainly in the long term, and there is joint causality for the selected variables as the ECT coefficients are statistically significant.

Table 10. (a) Summary of the Pooled Mean Group on the cointegration and causality relationship between the stock market index, ICT index and financial freedom index. (b) Summary of the Pooled Mean Group on the cointegration and causality relationship between the stock market index, ICT index, and financial freedom index (explanation).

Dependent Variable	Source of Causation (Independent Variables)						
	Long-Term Coefficients			Short-Term Coefficients			
	FINDEX	ICTDEX	FFI	ΔFINDEX	ΔICTDEX	ΔFFI	ECT
				(a)			
ΔFINDEX		0.707 *** (12.60)	0.0440 *** (4.10)		−0.782 (−1.54)	−0.187 (−0.27)	−0.541 ** (−2.86)
ΔICTDEX	0.673 *** (9.41)		−0.340 (−1.50)	22.90 (0.71)		0.000538 (0.00)	−0.402 * (−2.44)
ΔFFI	1.397 (−1.13)	1.401 (0.44)		33.50 (1.02)	−33.33 (−0.79)		−0.733 *** (−6.89)
				(b)			
ΔFINDEX		Causality *** (12.60)	Causality *** (4.10)		No causality (−1.54)	No causality (−0.27)	Cointegration ** (−2.86)
ΔICTDEX	Causality *** (9.41)		No causality (−1.50)	No causality (0.71)		No causality (0.00)	Cointegration * (−2.44)
ΔFFI	No causality (−1.13)	No causality (0.44)		No causality (1.02)	No causality (−0.79)		Cointegration *** (−6.89)

t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The study found bidirectional causality between the stock market index and ICT index in the long term. The causal links are in both directions, where the stock market index causes ICT adoption and vice versa. The findings are in line with the view of Okwu (2015). We also established a positive causal relationship between financial freedom and the stock market index without feedback. The direction of causality ran from financial freedom to stock market development. This demonstrates that financial freedom (which is a proxy for financial regulation) has a positive influence on stock market development.

6. Conclusions

The present inquiry was predicated on the following twin research questions: (1) What cointegrating relationships exist between ICT adoption and stock market development in Africa? (2) What is the direction of causality between ICT adoption and stock market development in Africa? The study employed a panel of 11 African stock exchanges and applied the novel panel ARDL bounds testing procedure for estimation. There were four main findings of the study. Firstly, the results of this study confirmed the cointegration of the variables; namely, that there was long-term relationship between the stock market development index and the ICT index. This implies that an increase in the adoption of ICT, with consumers making use of the internet and mobile broadband and increased mobile telephone penetration, increases the stock market indices in the long-term (as demand for shares and the volume of transactions increase), which implies improvement in stock market development in Africa. Secondly, the study found a significant positive long-term relationship between the stock market index and the financial freedom variable.

This implies that the higher the financial freedom (deregulation of the capital market), the better the prospects of stock market development. Thirdly, the study established a causal bidirectional relationship between stock market development and ICT adoption. This evidences that stock market development and ICT adoption complement one another. Lastly, the study documented a causal relationship running from financial freedom to stock market development.

There are several policy implications that flow from this study. It is trite to highlight that there is a lack of adequate ICT policies that are focused on the development of African stock markets. The focus of ICT-driven initiatives has mainly been on the Fintech space; however, policymakers need to focus on ICT policies which can support stock market development, given the impact of stock market development on the economy. One of the major policy issues that this study sought to address is that, with the speed of African stock market integration, especially with the ratification of the African Continental Free Trade Area (AfCFTA) agreement by most African countries, there is a need for a major ICT policy shift to drive the integration of African stock markets and in the process foster their development. The lack of a cohesive or uniform ICT policy can be a major impediment to the adequate integration of African stock markets in this era of AfCTA. Thus, a major opportunity would be lost to further develop the African stock market if ICT-driven initiatives are not harnessed.

Therefore, if African governments promulgate ICT policies that promote investments in the improvement of internet services and broadband and telephone (mobile and fixed) infrastructure, this will spur stock market development. For example, African governments can remove restrictions on the repatriation of dividends or profits on ICT-related investments by foreign investors, and they can also give tax holidays for a specific period or can give tax credit for companies that invest in ICT-related infrastructure. Arguably, these restrictions result in multi-national firms divesting or closing shop in African countries in favor of other markets.

There are two main limitations of this study. Firstly, this study was focused more on the adoption of technology by investors and general ICT users as a proxy (supply-side); this implies that there can be improvement on this topic if more emphasis is placed on the demand side (stock market development). Future studies should look at the actual adoption of technologies by the stock exchanges, such as automated trading platforms, to determine whether it has a bearing on stock market development proxied for instance by volumes traded and turnover ratios. Secondly, this study employed a short time series of 10 years and few control variables. For robustness, future studies could extend the time series dimension and also add more country-level control variables in their analysis (for example, literacy rate, corruption, and an ease of doing business index).

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