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Causal Nexus between Technological Innovation, Financial Innovation and Economic Growth: The case of Sub-Saharan Africa Countries

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***Abstract* - The relationships among technological innovation, financial innovation, and economic growth have received much attention in recent literature. However, there are potential gaps like the innovation-growth nexus that existing empirical studies have not rigorously examined. This study explores co integration relationships and Granger causality nexus in a trivariate framework among the three variables. Using three measures of financial innovation and employing a panel vector autoregressive model, we study 45 Sub-Saharan Africa countries over the period of 1990–2018. The results show a long-run equilibrium relationship among all three variables, no matter which indicator of financial innovation is used. We also discover a wide range of remarkable causal links among the variables. Our key result is that unlike in the long-run, there is no causality running from both technological innovation and financial innovation to economic growth in the short run. The argument that technological innovation and financial innovation spur economic growth is supported in our study, at least in the long run. The latter result may not be surprising, given that the countries considered in this study are relatively less developed countries (LDCs) from Sub-Saharan Africa. Hence, further innovation improvement may play a statistically significant role in spurring further economic growth. We suspect that results may be different for emerging and developed countries with a well-developed and advanced innovation system. This remains an open area for future research.**

Keywords: Technological innovation, financial innovation, Economic growth, Granger causality, Panel-VAR, Sub-Saharan Africa countries.

I. INTRODUCTION

It is well established in the literature that economic growth is determined by several factors (variables). However, the purpose of this study is not to examine all the possible determinants of economic growth. Instead, the purpose of this paper is to focus on the relationship between economic growth and two innovation indicators that have received much attention in recent years: Technological innovation and financial innovation.

For decades, economists and economic historians have sought to improve their understanding of the role of technological invention in economic growth [1] [2] [3] [4]. As in many fields of inventive endeavor, their efforts required time to develop and mature. In the past few years, these efforts have reached a point where they are generating robust, substantive, and intellectually exciting findings, to the benefit of those interested in promoting growth-enhancing invention across the globe, especially in developed countries.

Innovative ability was not a subject of severe and in-depth studies in the theory of economy, which follow early work by Joseph Schumpeter [1]. The studies by Paul Romer, published in 1986, indicated that technical progress is the main driver for economic growth [2]. This growth could be measured via several indicators, e.g., GDP, labor productivity, the export of products for a given economy. Technical progress improves the transformation of resources and expenditures into products. The renaissance of interest of scholars into this subject has been revived after OECD published a report concerning Technology Economy Programme[5].

The impact of financial innovation on economic growth in developing countries has not been pursued extensively, despite it being an integral part of financial development. Research studies on financial innovation in developing countries have so far focused mainly on welfare issues, particularly on its impact on financial inclusion [6]. Financial innovation has transformed and restructured banking services globally, and its impact on economies is becoming increasingly noteworthy.

The available literature confirms that financial innovation drives economic growth [7] [8]. From a historical perspective,

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Laeven, Levine, and Michalopoulos (2015) point out that financial innovation has been a driving force behind financial deepening and economic development over the past centuries. In turn, Štreimikienơ (2014) contends more specifically that "leapfrog" (financial) innovation is a driving force for broad economic growth. Despite mixed evidence on causality, there is also a broad consensus that well-functioning banking systems promote economic growth [9].

High growth rates in African countries, in recent years, have been sustained by natural resources and agriculture on the backdrop of improved macroeconomic management [10]. There has been no mention of growth being driven by or linked to finance. Financial innovation has become an integral part of financial sector development and is an essential determinant in generating new economic activity. For example, the high penetration rate of mobile financial services, which is a critical component of financial innovation compared to traditional banking in Sub-Saharan Africa, enabled by the integration of financial service with mobile communication technology, has dramatically increased financial inclusion [3].

It is evident from the background of this study that an apparent gap exists in the literature. In such a state of affairs, this paper aims to explore the possible short-run and long-run causal relationships between the three critical variables in our analysis: economic growth, technological innovation, and financial innovation. Unlike other studies, which consider possible links between two of these variables at a time, we investigate the possible nexus between all three using a trivariate framework. Furthermore, and contrary to earlier works, this paper reports on the causal relationships among the three variables by using panel co integration and causality tests. Our novel panel-data estimation technique allows for more robust estimates by utilizing variation between countries as well as variation over time. We find fantastic and essential causal links among the variables deriving uniquely from our innovations using a sample of 45 Sub-Saharan African countries over 1990–2018. To our knowledge, using this approach, neither this group of countries nor this period has been the subject of an investigation by other researchers in this field.

Following the introduction section, the rest of the paper is organized as follows: Section 2 provides a literature review on three branches of the literature, which we combined in our investigation. This section also motivates our study by summarizing the remarkable features of the present study. Section 3 introduces our three indicators of financial innovation and the data source used in the analysis. Section 4 presents the empirical methodology. Section 5 presents the results, and finally, section 6 concludes the paper.

II. LITERATURE REVIEW AND KEY CONTRIBUTIONS OF THE STUDY

2.1 Technological Innovation and Economic Growth

Technological innovation is a fundamental driver of economic growth and human progress. Unfortunately, that insight is often lost or underappreciated in technology policy discussions today, which frequently focuses on the disruptive effects associated with technological change.

The literature on innovation and technological innovation is very voluminous and diverse [11] [1] [12] [13]. The core of innovation is inventing the use of production resources in a new, earlier unencountered way and simultaneous withdrawal of those resources from current application and use. The invention is an exhausting and tedious activity with a high rate of failure. According to Stevens and Burley (1997),the failure of inventions is colossal on its way to commercialization. Approximately 3000 fresh ideas are needed to produce 150 patent applications and one commercial success. Despite this, a continuous inventive activity is an element of success for traditional as well as high-tech firms [14]. During that time, the firm "s resources are placed at financial risk. Several environmental factors influence the innovation process, namely degree of competition, availability of financial resources, manufacturing intensity and the size of the market [13], legislation, social norms, the willingness of society to build the infrastructure [15] as firms do not exist in isolation.

2.2 Financial innovation and economic growth

The interaction of innovations in both the financial sector and the real sector provides a wave of economic growth [16]. Innovation, therefore, in the economy treated as the drive of improving productivity accelerates the process of economic growth [17]. Innovation can happen in the economy. Focusing on various aspects of the economy, innovation surrounding the financial system boosts the financial development process, and this is known as financial innovation. Innovation in the financial sector not only accelerates financial development processes but also assists in capital accumulation [18] and expedited technological innovation, which eventually leads to sustainable economic growth in the long run [19] [20].

Financial innovation is an integral part of economic activity with various aspects. Over the past decade, financial innovation has brought structural changes to the financial system through improvement in financial institutions, service, and modified payment systems [21] [22] [8] [23] [24]. Furthermore, financial innovation also assists in changing governmental regulations and shifting social attitudes towards financial development [25] [26], which allow the financial sector to produce more effective and efficient ways to

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maximize economic resources in productive ways. The economic theory emphasizes that the maximization of the scarcity of economic resources from productive investment can achieve the sustainable economic development of the economy. Finance researchers including, Epstein (1992) [27]; Glaeser et al. (2004) [28]; Ozturk and Acaravci (2010) [29], and Ansong et al. (2011) [18] explain that efficiency in the financial sector influence by financial innovation, especially institutional innovation, expands the area of financial services in the economy by allowing a greater number of people into the mainstream economy and transforming economic resources into productive investments following maximization.

The effect of financial innovation in the financial system is versatile and diversified, including better financial services [30] [31], smooth financial intermediation [32] [33] [34], and better payment mechanisms [35] [36]. The role of financial development in financial innovation also addresses empirical studies. Levine (1997), Jedidia et al. (2014) [37], and Simiyu et al. (2014) explore the contribution of financial innovation to stock market developments through capital liquidation offerings. Furthermore, in their respective studies, Johnson and Kwak (2012) [38], Odularu and Okunrinboye (2008) urge financial innovation in a domestic and international role with the easing of financial transactions. They imply that financial innovation transforms a static economy into a dynamic one through capital formation, encouraging private investment, financial intermediation, and a higher level of saving propensity. In turn, a higher level of economic growth can be achieved.

The efficient financial system is the prerequisite for a modern economy because a sound and the refined financial system encourage the efficiency of investment and economic growth in a market economy [39]. The efficient financial system is the collection of financial markets, institutions, instruments, and regulations that organize economic activity through productive investment [40] and expedite economic growth by creating financial opportunities [41] [42]. Financial innovation in the financial system brings diversified financial products for investment purposes, and such diversity reduces the level of risk substantially, which produces more satisfaction among customers [43] [23].

The prime focus of financial innovation is to make financial intermediation processes effective and efficient. Efficient financial intermediation enhances economic activity by providing better financial support in trade and commerce. In a study, Shittu (2012) [44] pointed out that efficient financial intermediation has a positive impact on the economy. Efficient intermediation channels economic resources in the economy with efficiency [45]. A robust and efficient financial system promotes growth by reallocating economic resources in the economy effectively and efficiently. The efficient financial system is the outcome of continuous financial innovation, which allows for the emergence of various financial institutions, especially banks that can offer improved and better financial services with more credit facilities and financial instruments in the economy, which leads to economic growth.

2.3 Key contributions to the study

Unlike the earlier studies, this paper explores the causal link between all three variables contemporaneously, which has not been done before. We first use Pedroni's panel cointegration test to reveal whether the variables are cointegrated; that is, whether there is a long-run equilibrium relationship among them. We after that, we use a panel Granger causality test to present new evidence on the nature of the short-run and long-run causal relationship between the variables. There are two main contributions of this paper, as there are two novel features of this particular study. First, we use a large sample of Sub-Saharan African countries over a long period, 1990–2018. Second, we utilize sophisticated econometrics, and undoubtedly empirical approaches that have been neglected in this literature, to answer questions concerning the nature of the causal relationship between the variables, both in the short run and long run.

III. VARIABLES AND PANEL OF COUNTRIES

There is no agreed measure of financial innovation; hence, researchers tend to proxy it with different variables. Laeven et al. (2015) explain that financial innovation is not limited to new financial instruments, products, or institutions, but also includes more mundane financial improvements, such as the new financial reporting procedures, improvements in data processing and credit scoring, as such, the choice of variables that capture financial innovation needs to be all-inclusive beyond those that depict product innovation only.

Hence, this study utilizes three commonly used measures of financial innovation: Domestic credit to Private Sector (DPS), Domestic Credit from Financial Sector (DCF), and the ratio of broad money to narrow money, M2/M1 (RBN). These variables are summarized in Table 1. Other variables used in our analysis also appear in Table 1. They are technological innovation, proxied by the number of mobile phone subscribers denoted by TEC, and economic growth, measured by the growth rate of gross domestic product per capita and denoted by GDPPC. We adopt the World Bank definition of all the variables and use the data published by the World Bank's World Development Indicators. Fig. 1 shows the conceptual framework of the possible causal patterns between these variables. As is evident, financial innovation could be

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represented by one of these three indicators DPS, DCF, and RBN, as defined above.

Table 1: Description of variables

Variables	Description
GDPPC	Per capita economic growth: Percentage change in real per capita gross domestic product, used as our indicator of economic growth
TEC	Number of mobile phone subscribers
DPS	Refers to financial resources provided to the private sector, such as through loans, purchases of no equity securities, trade credits, and other accounts receivable that establish a claim for payment.
DCF	For gross credit from the financial system to the private sector, it isolates credit issues to the private sector, as opposed to credit issued to the government, government agencies, and public enterprises.
RBN	The ratio between Broad money to narrow money supply in the financial system

The variables used are transformed to their natural logarithm forms for our estimations. Table 2 provides the summary statistics for the variables, while Table 3 shows the correlation matrix. The correlation coefficients in Table 3 suggest that the financial innovation variables, DPS, DCF, and LBN, are not highly correlated, except for DPS and DCF. It means we can simultaneously consider LBN and DPS as well as LBN and DCF along with technological innovation and economic growth. Hence, we proceed by examining the nexus between technological innovation, economic growth, and each of the financial innovation indicators separately, as well as with two of the indicators jointly.

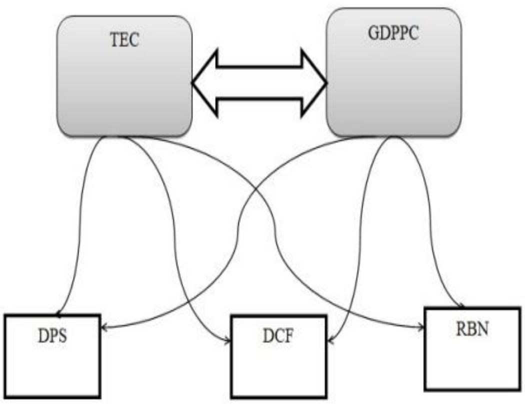

Figure 1: Conceptual framework of the research model

Our empirical analysis is based on an unbalanced panel of 45 Sub-Saharan African countries over 1990–2018.[1]

[1]That is, for some countries data covers the entire 1990–2018 period, while for others, data covers less than the entire period.

The countries considered are selected based on data availability. The countries are Angola, Benin, Burkina Faso, Botswana, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo Demographic Republic, Congo, Cote d "Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, South Africa, Sao Tome, Senegal, Seychelles, Sierra Leone, Sudan, Swaziland, Tanzania, The Gambia, Togo, Uganda, and Zambia.

The study intends to test the following hypotheses:

H_1. Technological Innovation (TEC) Granger causes economic growth (GDPPC). This is termed the TEC-led GDPPC hypothesis.

H_2. Economic growth Granger causes Financial Innovation (FIN). This is termed the GDPPC-led FIN hypothesis.

H_3. Technological Innovation (TEC) Granger causes Financial Innovation (FIN). This is termed the TEC-led FIN hypothesis.

As stated above, FIN has three separate indicators: DPS, DCF, and RBN. Figure 2 depicts our hypotheses in both broad and more specific terms.

Table 2: Descriptive statistics of the variables

Variables	Mean	Maximum	Minimum	Std. Dev.
GDPPC	2.34	81.32	-96.47	6.74
TEC	394.52	637.36	152.18	94.73
DPS	49.43	567	15	82.34
DCF	547.18	2652	27	142.17
RBN	57.32	76.8	39.7	7.84

Note: TEC denotes technological innovation; GDPPC denotes per capita economic growth rate; DPS denotes Domestic credit to Private Sector; DCF denotes Domestic Credit from Financial Sector; RBN denotes the ratio of broad money to narrow money.

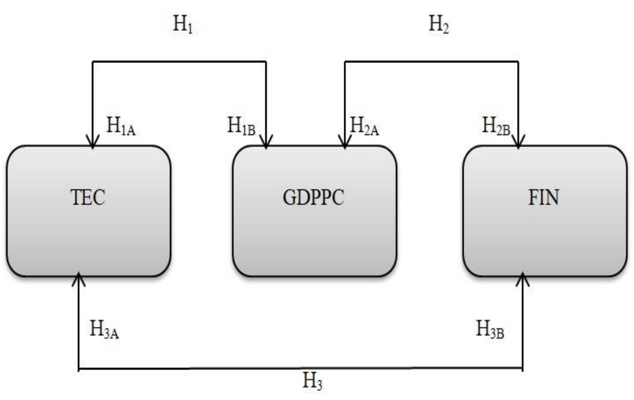

Figure 2: Proposed model and hypothesis

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Note 1: TEC denotes technological innovation; GDPPC denotes per capita economic growth rate. **Note 2:** FIN is defined as DPS, DCF, or RBN. **Note 3:** DPS denotes Domestic credit to Private Sector; DCF denotes Domestic Credit from Financial Sector; RBN denotes the ratio of broad money to narrow money. **Note 4:** Variables are defined in Table 1.

Table 3: Correlation matrix

Variables	TEC	GDPPC	DPS	DCF	RBN
First scenario: For TEC, GDPPC, DPS					
TEC	1.00	0.07	0.38		
GDPPC		1.00	0.21		
DPS			1.00		
Second scenario: For TEC, GDPPC, DCF					
TEC	1.00	0.07		0.02	
GDPPC		1.00		0.41	
DCF				1.00	
Third scenario: For TEC, GDPPC, RBN					
TEC	1.00	0.07			0.31
GDPPC		1.00			0.05
RBN					1.00
Fourth scenario: For TEC, GDPPC, DPS, DCF, RBN					
TEC	1.00	0.07	0.38	0.02	0.31
GDPPC		1.00	0.21	0.41	0.05
DPS			1.00	0.73***	0.47**
DCF				1.00	0.51**
RBN					1.00

Note: TEC denotes technological innovation; GDPPC denotes per capita economic growth rate; DPS denotes Domestic credit to Private Sector; DCF denotes Domestic Credit from Financial Sector; RBN denotes the ratio of broad money to narrow money, ***, ** denotes statistically significant at the 1% and 5% level respectively.

IV. ECONOMETRIC MODEL AND PANEL ESTIMATION PROCEDURE

We employed the panel Granger causality test proposed by Holtz-Eakin, Newey, and Rosen (1988) to examine the long-run causal relationship between technological innovation, economic growth, and financial innovation. We estimate the following dynamic panel regressions using pooled data on the 45 Sub-Saharan African countries:

$$\begin{bmatrix} \Delta lnTEC_{it} \\ \Delta lnGDPPC_{it} \\ \Delta lnFIN_{it} \end{bmatrix} = \begin{bmatrix} \eta_{1j} \\ \eta_{2j} \\ \eta_{3j} \end{bmatrix} + \sum_{k=1}^{p} \cdot \begin{bmatrix} \alpha_{1ik} & \beta_{1ik}(L) \\ \alpha_{2ik} & \beta_{2ik}(L) \\ \alpha_{3ik} & \beta_{3ik}(L) \end{bmatrix} \begin{bmatrix} \Delta lnTEC_{it-k} \\ \Delta lnGDPPC_{it-k} \\ \Delta lnFIN_{it-k} \end{bmatrix} + \begin{bmatrix} \lambda_{1ik} ECT_{1ik-1} \\ \lambda_{2ik} ECT_{2ik-1} \\ \omega_{3ik} ECT_{3ik-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \end{bmatrix} \quad (1)$$

Where

Δ is a first-difference operator $(I - L)$ applied to the variables;
P is lag lengths;
i represents country i in the panel (i = 1, 2…, N); t denotes the year in the panel (t = 1, 2, …, T);
TEC is the number of mobile phone subscribers in the economy;
GDPPC is the economic growth rate (in percentage);
FIN is financial innovation, which has three different indicators;
TEC is the number of mobile phone subscribers in the economy;
GDPPC is the economic growth rate (in percentage);
FIN is financial innovation, which has three different indicators;
ECT is an error correction term which is derived from the cointegration equation; ε_{it} is a regularly distributed random error term for all i and t with a zero mean and a finite heterogeneous variance.

We look for both short-run and long-run causal relationships among the variables. Short-run causal relationships are measured through F-statistics and the significance of the lagged changes in the independent variables. Long-run causal relationships are measured through the significance of t-tests associated with the lagged ECTs. Based on equation (1), table 4 presents the various possible hypotheses concerning the causal nexus between technological innovation, financial innovation, and economic growth.

The above econometric specification, as presented in equation (1), is meaningful if the time-series variables are integrated of order one, denoted by I(1), and cointegrated. If the variables are I(1) and not cointegrated, then the ECT component will be removed in the estimation process. Thus, the pre-condition and critical step, to the estimation process is to check the order of integration and cointegration among the variables. We employ the Levin–Lin– Chu (LLC) panel unit root test by Levin, Lin, & Chu (2002) and Pedroni panel cointegration test [46] to check for I(1) and cointegration between each financial innovation indicator, technological innovation, and economic growth. A brief discussion of these two techniques is presented below.

Table 4: Hypotheses tested in this study

Causal Movement	**Constraints**
TEC ⟹ GDPPC	$\beta 1ik \neq 0; \lambda 1i \neq 0$
GDPPC ⟹ TEC	$\delta 1ik \neq 0; \lambda 1i \neq 0$
GDPPC⟹ FIN	$B_2 1ik \neq 0; \lambda_2 1i \neq 0$
FIN⟹ GDPPC	$\delta 1ik \neq 0; \lambda 1i \neq 0$
TEC⟹FIN	$B_3 1ik \neq 0; \lambda_3 1i \neq 0$
FIN⟹TEC	$\delta^3 1ik \neq 0; \lambda_3 1i \neq 0$

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Note 1: TEC denotes technological innovation; GDPPC denotes per capita economic growth rate; DPS denotes Domestic credit to Private Sector; DCF denotes Domestic Credit from Financial Sector; RBN denotes the ratio of broad money to narrow money.

4.1 Test for the order of integration

We made use of the LLC test to establish the order of integration, where a time series variable attains stationarity. The test uses the principles of the conventional augmented Dickey-Fuller (ADF) test and allows for heterogeneity of the intercepts across members of the panel. The test involves the estimation of the following equation:

$$\Delta Y_t = \mu_i + \gamma_i Y_{it-1} + \sum_{j=1}^{p_i} \beta_{i1} \Delta y_{it-j} + \lambda_i t + \varepsilon_i \quad (2)$$

Where

i - 1, 2…, N represents the country in the panel;
t - 1, 2…, T represents the year in the panel;
Y it is the series for country i in year t;
μi represents country-specific effects;
p_i is the number of lags selected for the ADF regression;
$\Delta$is the first difference filter;
ε_{it} is an independently and normally distributed random error with a zero mean and a finite heterogeneous variance (σ_i^2).

The model allows for fixed effects, unit-specific time trends, and typical time effects. The coefficient β_j of the lagged dependent variable is restricted to be homogenous across all of the units of the panel.

4.2 Panel-data cointegration tests

A cointegration test is used to check for the presence of a long-run equilibrium relationship among the variables. In other words, if two or more series are cointegrated, it is possible to interpret the variables in these series as being in a long-run equilibrium relationship. Lack of cointegration, on the other hand, suggests that the variables have no long-run relationship, meaning that in principle, they can move arbitrarily far away from one another.

If integration of "order one" is implied for the variables, the next step is to employ cointegration analysis in order to establish whether there exists a long-run relationship among the set of such possibly "integrated" variables. By checking, an estimated cointegration equation of the following form is used:

$$Yit = \beta i0 + \beta i1Xi1t + \beta i2Xi2t + \ldots + \beta ikXikt + \varepsilon it \quad (3)$$

This equation may be re-written as:

$$\varepsilon it = Yit - (\beta i0 + \beta i1Xi1t + \beta i2Xi2t + \ldots + \beta ikXikt) \quad (4)$$

With the cointegration vector defined as:

$$[1 - \beta i0 - \beta i1 - \beta i2 \ldots - \beta ik] \quad (5)$$

We note that, as set up by Johansen (1988), the above test cannot deal with a panel setting. Thus, we use an enhancement, the Pedroni (1999, 2000, 2004) [47] [48] [46] panel cointegration test, in order to test for the existence of cointegration among the variables. The Pedroni panel cointegration test is applied to the following time series panel regression set-up:

$$Y_{i,t} = \alpha_i + \sum_{j=1}^{p_i} \beta_{ji} X_{jit} + \varepsilon_{it} \quad (6)$$

$$\varepsilon_{it} = \rho_i \varepsilon_{i(t-1)} + w_{it} \quad (7)$$

Where

Y_{it} and X_{jit} are the observable variables, ε_{it} represents the disturbance term from the panel regression; α_i allows for the possibility of country-specific fixed effects, and the coefficients β*ji* allow for variation across individual countries. The null hypothesis of no cointegration of the pooled, within-dimension, estimation is:

$$H_0 : \rho_i = 1 \text{ for all } i \text{ against } H_1 : \rho_i = \rho < 1: \quad (8)$$

Under the first hypothesis, the within-dimensional estimation assumes a common value for ρ_i (= ρ). In sum, this procedure excludes any additional source of heterogeneity between individual country members of the panel. The null hypothesis of no-cointegration of the pooled, between dimensions estimation, is expressed as

$$H_0 : \rho_i = 1 \text{ for all } i \text{ against } H_0 : \rho_i = \rho < 1: \quad (9)$$

Under the alternative hypothesis, the between-dimensions estimation does not assume a common value for ρ_i. Therefore, it allows for an additional source of possible heterogeneity across individual country members of the panel. Pedroni suggests two types of tests to determine the existence of heterogeneity of the cointegration vector. First is a test that uses the within-dimension approach (i.e., a panel test). This test uses four statistics, which are panel v-statistic, panel ρ-statistic, panel PP-statistic, and panel ADF-statistic. These statistics pool the autoregressive coefficients across different panel members for the unit root tests to be performed on the estimated residuals. Second is a test which is based on the between-dimensions approach, which is a group test that includes three statistics: a group ρ-statistic, a group PP-statistic, and a group ADF-statistic. These statistics are based

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on estimators that simply average the individually estimated autoregressive coefficients for each panel member (for more details, see Pedroni, 2000).

V. EMPIRICAL RESULT

The empirical results are presented in three stages. First, we reveal the nature of the stationarity of the time series variables.

Second, we disclose the nature of cointegration among them. Finally, we provide evidence on the direction of Granger causality between the cointegrated variables.

Note 1: TEC denotes technological innovation; GDPPC denotes per capita economic growth rate; DPS denotes Domestic credit to Private Sector; DCF denotes Domestic Credit from Financial Sector;

Table 5: Panel unit root test results

Variable	Levels/ ΔLevels	LLC	ADF-Fisher	PP-Fisher	Findings	Order of integration
TEC	Levels	-3.018	25.032	37.281	Non-stationary	I (1)
	ΔLevels	-27.45***	355.40***	247.15***	Stationary	
GDPPC	Levels	-2.070	60.884	64.224	Non-stationary	I (1)
	ΔLevels	-34.22***	273.36***	594.12***	Stationary	
DPS	Levels	-4.076	35.531	42.406	Non-stationary	I (1)
	ΔLevels	-26.53***	205.22***	173.81***	Stationary	
DCF	Levels	-1.962	40.355	43.225	Non-stationary	I (1)
	ΔLevels	-19.85***	240.81***	260.95***	Stationary	
RBN	Levels	-2.021	36.273	37.077	Non-stationary	I (1)
	ΔLevels	-31.49***	225.43***	232.55***	Stationary	

RBN denotes the ratio of broad money to narrow money; the unit rot test statistics are reported at no intercept and trend; *** denotes statistically significant at the 1% level; I(1) denotes the integration of order one.

The estimation process involves examining five different cases. Model 1 (M1) describes the causal nexus between technological innovation, economic growth, and domestic credit to the private sector (DPS). Model 2 (M2) deals with the causal connection between technological innovation, economic growth, and domestic credit from the financial sector (DCF). Model 3 (M3) explores the causal relation across technological innovation, economic growth, and the ratio of broad money to narrow money (RBN). Model 4 (M4) is concerned with the causal nexus between technological innovation, economic growth, domestic credit to the private sector (DPS), and the ratio of broad money to narrow money (RBN). Finally, Model 5 (M5) deals with causality across technological innovation, economic growth, DCF, and RBN.[1] The results are shown in Tables 5 and 6. They indicate that all the variables are integrated of order one because they become stationary after first differencing, as well as being cointegrated. These results suggest the presence of a long-run equilibrium relationship between technological innovation, economic growth, and financial innovation indicators. Remarkably, this is true in all the five models, no matter which financial innovation indicator(s) we use.

Table 6: Pedroni panel cointegration test results

Test statistics	No intercept & trend	Intercept	Intercept & trend
Model 1: TEC, GDPPC, DPS			
Panel v-statistics	-2.35 [0.77]	-1.27 [0.62]	-2.72 [0.79]
Panel ρ-statistics	-2.49 [0.04]	-0.19 [0.42]	-0.75 [0.57]
Panel PP-statistics	-5.15 [0.00]	-3.28 [0.00]	-5.61 [0.00]
Panel ADF-statistics	-3.36 [0.01]	-1.17 [0.03]	-2.74 [0.02]
Group ρ-statistics	-2.54 [0.00]	-1.01 [0.01]	-3.01 [0.08]
Group PP-statistics	-7.35 [0.00]	-4.34 [0.00]	-4.15 [0.00]
Group ADF-statistics	-5.07 [0.00]	-3.05 [0.00]	-3.02 [0.00]
Model 2: TEC, GDPPC, DCF			
Panel v-statistics	-2.25 [0.68]	-3.28 [0.75]	-3.76 [0.81]
Panel ρ-statistics	-1.89 [0.06]	-1.84 [0.27]	-1.36 [0.19]
Panel PP-statistics	-4.31 [0.00]	-3.32 [0.01]	-6.95 [0.00]
Panel ADF-statistics	-2.92 [0.03]	-1.39 [0.01]	-4.62 [0.00]

[1] As is evident, we have not considered a model with a combination of DPS and DCF since this would pose a problem of multicolinearity, given that these variables are highly correlated (see the dissuasion of Section 3).

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Group ρ-statistics	-1.96 [0.09]	-1.53 [0.34]	-2.21 [0.46]
Group PP-statistics	-7.60 [0.00]	-7.46 [0.00]	-7.67 [0.00]
Group ADF-statistics	-7.46 [0.00]	-5.65 [0.00]	-5.25 [0.00]
Model 3: TEC, GDPPC, RBN			
Panel v-statistics	-2.59 [0.63]	-3.38 [0.69]	-3.36 [0.59]
Panel ρ-statistics	-3.50 [0.00]	1.59 [0.07]	1.42 [0.22]
Panel PP-statistics	-5.58 [0.00]	-3.43 [0.01]	-4.52 [0.00]
Panel ADF-statistics	-3.92 [0.00]	-1.56 [0.02]	-3.63 [0.01]
Group ρ-statistics	-3.18 [0.02]	-1.54 [0.03]	2.35 [0.09]
Group PP-statistics	-8.90 [0.00]	-7.37 [0.00]	-7.83 [0.00]
Group ADF-statistics	-7.65 [0.00]	-5.76 [0.00]	-4.58 [0.00]
Model 4: TEC, GDPPC, DPS, RBN			
Panel v-statistics	-2.88 [0.67]	-3.45 [0.69]	-3.18 [0.79]
Panel ρ-statistics	-1.67 [0.09]	2.31 [0.05]	2.86 [0.08]
Panel PP-statistics	4.99 [0.00]	-3.35 [0.01]	-6.45 [0.00]
Panel ADF-statistics	-1.82 [0.08]	2.12 [0.04]	-3.12 [0.02]
Group ρ-statistics	1.52 [0.05]	2.67 [0.04]	4.35 [0.09]
Group PP-statistics	-7.87 [0.00]	-6.13 [0.00]	-5.74 [0.00]
Group ADF-statistics	-5.96 [0.00]	-3.71 [0.00]	-4.09 [0.00]
Model 5: TEC, GDPPC, DCF, RBN			
Panel v-statistics	-2.65 [0.79]	-3.62 [0.65]	-3.43 [0.74]
Panel ρ-statistics	-1.46 [0.06]	2.51 [0.02]	2.85 [0.07]
Panel PP-statistics	-4.68 [0.00]	-3.17 [0.00]	-6.39 [0.00]
Panel ADF-statistics	-2.32 [0.01]	2.59 [0.03]	-2.83 [0.04]
Group ρ-statistics	0.79 [0.11]	2.75 [0.15]	4.53 [0.19]
Group PP-statistics	-7.33 [0.00]	-5.83 [0.00]	-5.53 [0.00]
Group ADF-statistics	-5.59 [0.00]	-4.61 [0.00]	-5.73 [0.00]

Note 1: TEC denotes technological innovation; GDPPC denotes per capita economic growth rate; DPS denotes Domestic credit to Private Sector; DCF denotes Domestic Credit from Financial Sector; RBN denotes the ratio of broad money to narrow money; the unit rot test statistics are reported at no intercept and trend; values in square brackets are probability values indicating statistical significance.

The existence of I(1) and cointegration among these variables imply the possibility of Granger causality among them. Hence, we perform a causality test, using a vector error correction model (VECM) and utilizing equation (1), the results of which are shown in Table 7. This table reports the panel Granger causality test results for both the short-run, represented by the significance of the F-statistic, and the long-run, represented by the significance of the lagged error correction term (ECT).

Table 7: Panel Granger causality test results

Dependent variable	**Independent variables**			**The lagged error correction coefficient**	
Model 1: VECM with TEC, GDPPC, DPS					
	ΔTEC	ΔGDPPC	ΔDPS	ECT_{-1}	
ΔTEC	…..	6.45***	13.6**	-9.69***	
ΔGDPPC	14.76	…..	2.76	-8.08***	
ΔDPS	3.72	7.25***	…..	-12.73***	
Model 2: VECM with TEC, GDPPC, DCF					
	ΔTEC	ΔGDPPC	ΔDCF	ECT_{-1}	
ΔTEC	…..	5.47**	11.68***	-5.62***	
ΔGDPPC	17.18	…..	1.15	-11.21***	
ΔDCF	1.33	8.94***	…..	-12.14***	
Model 3: VECM with TEC, GDPPC, RBN					
	ΔTEC	ΔGDPPC	ΔRBN	ECT_{-1}	
ΔTEC	…..	6.28***	8.46**	-4.91***	
ΔGDPPC	12.4	…..	2.55	-13.06***	
ΔRBN	7.31	7.33***	…..	-9.59***	
Model 4: VECM with TEC, DPPC, DPS, RBN					
	ΔTEC	ΔGDPPC	ΔDPS	ΔRBN	ECT_{-1}
ΔTEC	…..	5.37***	14.53***	3.64	-14.45***
ΔGDPPC	14.36	…..	2.90	1.78	-10.15***
ΔDPS	4.33	5.91**	…..	7.83***	-11.36***
ΔRBN	1.83	7.72**	9.26***	…..	-5.63***
Model 5: VECM with TEC, GDPPC, DCF, RBN					
	ΔTEC	ΔGDPPC	ΔDCF	ΔRBN	ECT_{-1}
TEC	…..	7.33***	13.82***	8.13*	-12.53***
ΔGDPPC	18.42	…..	2.75	1.54	-11.43***
ΔDCF	5.72	4.57*	…..	12.72***	-12.11***
ΔRBN	1.61	4.51*	8.17***	…..	-7.93***

Note 1: TEC denotes technological innovation; GDPPC denotes per capita economic growth rate; DPS denotes Domestic credit to Private Sector; DCF denotes Domestic Credit from Financial Sector; RBN denotes the ratio of broad money to narrow money; VECM: vector error correction model; ECT: error correction term. *** denotes significance at 1% level; ** denotes significance at 5% level.

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A summary of the short-run results for our five specifications is as follows:

In the case of model 1, there exists unidirectional causality running from economic growth to technological innovation [GDPPC⟹TEC], economic growth to domestic credit to the private sector [GDPPC⟹DPS], and a causality running from domestic credit to the private sector to technological innovation [DPS⟹TEC].

In model 2, there is a unidirectional causality running from domestic credit from the financial sector to technological innovation [DCF⟹TEC from economic growth to technological innovation [GDPPC⟹TEC] and from economic growth to domestic credit from the financial sector [GDPPC⟹DCF].

In Model 3, our results support unidirectional causality running from the ratio of broad money to narrow money to technological innovation [RBN⟹TEC], from economic growth to technological innovation [GDPPC⟹TEC], and from economic growth to the ratio of broad money to narrow money [GDPPC⟹LBR].

In model 4, we identify the existence of bidirectional causality between the ratio of broad money to narrow money and domestic credit to the private sector [RBN⟺DPS]. Additionally, we find unidirectional causality from economic growth to domestic credit from the financial sector [GDPPC⟹MMR], from economic growth to life expectancy [GDPPC⟹RBN], and from domestic credit to the private to technological innovation [DPS⟹TEC].

In the case of model 5, there exists unidirectional causality running from economic growth to technological innovation [GDPPC⟹TEC], domestic credit from the financial sector to technological innovation [DCF⟹TEC], economic growth to domestic credit from the financial sector [GDPPC⟹DCF], economic growth to the ratio of broad money to narrow money [GDPPC⟹RBN] and from the ratio of broad money to narrow money to technological innovation [RBN⟹TEC]. Moreover, there also exists bidirectional causality between the ratio of broad money to narrow money and domestic credit from the financial sector [RBN⟺DCF]. However, from all the five models specified above, we did not find any causal relationship running from technological innovation and financial innovation to economic growth in the short-run.

The results from the short-run causality presented in table 7 are worthwhile. Though, more important are the results from the long-run causality, which we now explain. In table 7, from Models 1 to 5, when ΔGDPPC serves as the dependent variable, the lagged error correction term is statistically significant at the one percent level. This implies that GDPPC tends to converge to its long-run equilibrium path in response to changes in its predictors. The significance of the error correction (ECT_{-1}) coefficient in the ΔGDPPC equation in each of the five models confirms the existence of a long-run equilibrium between GDPPC and its predictors, which are technological innovation and financial innovation. In other words, we can broadly conclude that both technological innovation and financial innovation Granger-cause economic growth in the long run.

VI. CONCLUDING REMARKS

This paper reveals the causal links between technological innovation, financial innovation, and economic growth in Sub-Saharan Africa over 1990–2018. Indeed, there is the inadequacy of advanced cointegration and causality tests in the existing literature. Furthermore, in divergence from other studies, we examine the relationship between the three variables contemporaneously. We first establish that there is a long-run equilibrium relationship among all three variables, no matter which indicator of financial innovation is used. We also discover a wide range of remarkable causal links between technological innovation, financial innovation, and economic growth. Our key result is that unlike in the long-run, there is no causality running from both technological innovation and financial innovation to economic growth in the short run.

Consequently, the argument that technological innovation and financial innovation spurs economic growth is supported in our study, at least in the long run. The latter result may not be surprising, given that the countries considered in this study are relatively less developed countries (LDCs) from Sub-Saharan Africa. Hence, further innovation capacity improvement may play a statistically significant role in spurring further economic growth. We suspect that results may be different for developed and emerging countries with a well-developed and advanced technological system. This remains an open area for future research.

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