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Original Research Article

Technological Innovations and Financial Markets Development in Sub-Saharan Africa

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Abstract: The aim of this article is to assess the effect of technological innovations on the development of financial markets in Sub-Saharan Africa over the period 1996-2021. The study was conducted in 48 sub-Saharan African countries. The theory of financial intermediation (McKinnon, 1973 and Shaw, 1973) was used for the entire analysis process. This evaluation was carried out using the ARDL model with the Pooled Mean Group (PMG) estimator. In addition, we develop a composite index of financial development following the work of Čihák *et al.*, (2012) and Svirydzenka (2016). The results from this analysis show that in the short term, all the variables of interest internet, landline and cell phone have no significant effect on the development of direct finance; although in the long term, internet and landline have positive and significant effects. These results argue in favor of investing in technological innovations that are capable of stimulating financial markets, and whose effects can have a positive impact on the economic growth and development of sub-Saharan countries.

Keywords: Financial development, Financial markets, Technological innovations, Access, Depth, Efficiency, Stability.

I. INTRODUCTION

The dichotomous evolution of global financial markets in terms of integration and fragmentation can be partly explained by the conjunction of three events: technological innovation, deregulation and the opening up of economies (Bourguinat, 1992). Of these three factors, technological innovation appears to be the most capable of creating and balancing financial market dysfunctions. The spread of information and communication technologies is consubstantial with their adoption by both developed and underdeveloped economies. The process of ICT diffusion differs radically, mainly in terms of speed and geographical coverage, from the process of diffusion of "old" technologies (Comin and Hobijn 2011). The widespread acceleration of these new tools in terms of technological innovation has repercussions in the various sectors of economic and social activity. In the age of the information society, information and communication technologies have become an important factor in the development of financial markets in terms of productivity, growth and stability (Hanna 2003).

For developing countries, technological innovations can have a direct impact on inequalities in financial access, as they are more often than not faced with a worsening situation and a lack of adequate policies in this area. The large-scale adoption of general-purpose technologies can therefore encourage radical changes in social norms and structures, leading to the transformation of social systems and the way financial markets operate.

The development of direct finance is undeniably an important factor in economic growth (Sahay *et al.*, 2015). Although the factors influencing financial market activities are many and varied, technological innovations (especially ICT) are one of the most important in both advanced and developing economies (Yartey 2008). The financing of economies, and in particular investment, is intimately linked to their development, given their ability to grant long-term credit (Schumpeter, 1912).

However, the effects of growing ICT adoption on financial markets can also be negative, although despite recurring financial crises, capital flows have never come to a halt. In fact, they have increased tenfold (10), and the pace at which new financial markets are opening up is growing (Lechman 2015). The interest

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shown by governments, public corporations and the private sector in raising the ever-increasing amounts of funds generated by the various sovereign bond issues on the financial markets reflects their ability to mobilize local savings to finance local investments. As Levine (1997) points out, financial markets are called upon to fulfil five (05) essential functions: mobilizing savings; acquiring information on companies and allocating resources; controlling companies; providing liquidity and diversifying risk. Questioning the contribution of technological innovations to the development of financial markets is therefore crucial, insofar as they enable us to understand how they influence the financial market in terms of facilitating access to financing and risk diversification for borrowers and creditors. To do so, we will present in turn the theoretical and empirical discussions, the methodology and the econometric results.

II. LITERATURE REVIEW

There are a number of controversies surrounding the effects of technological innovations on the development of financial markets. A number of theories clash, with some drawing on the weaknesses of others. These theories are constantly trying to gain a better understanding of the behavior of markets on the one hand, and of agents on the other. These include market efficiency (Fama, 1965), behavioral finance (Kahneman and Tversky, 1979), convention theory (Salais, 1989), agency theory (Ross, 1973) and network theory (Pigou, 1932).

The theory of financial efficiency was developed by Fama (1965). It is based on the assumption that securities possess intrinsic, objectively defined values. This so-called fundamental value is embodied in the price, which at any given moment is a good estimator of the security's intrinsic value. The efficiency of financial markets is therefore subject to a certain number of necessary conditions: the rationality of investors, the free flow of information, the absence of transaction costs and stock market taxes, and finally the atomicity of investors and liquidity.

Behavioral finance is based on a number of theories, in particular the prospect theory and cumulative prospect theory of Kahneman and Tversky (1979). It states that decision-making in financial markets cannot be objectively rational. It is the consequence of diverse and varied behaviors, sometimes a function of experiential learning and sensory perception (loss or gain effect), and not just a function of mathematical calculation based on logic. This theory develops the idea that the evaluation of future income flows is most often made in a context of psychological and anthropological bias, which can unbalance the formation of a standard equilibrium price.

Convention theory attempts to reconcile the orthodox economic theory of the methodical individualist with political philosophy or fundamental sociology (Salais, 1989). It represents an attempt to integrate sociological considerations into the field of economic analysis, while at the same time calling into question economic fundamentals based on pure and perfect competitive markets, a neoclassical analysis whose demonstration was formalized in the 1960s through Arrow-Debreu's general equilibrium theory. It underpins a heterogeneity of agents based on a relative construction.

Agency theory is inspired by contract theory, in which Ross (1973) considers that an agency relationship exists when an individual called an agent acts on behalf of another individual called a principal or mandatary. It refers to scenarios in which, by means of a contract, "one or more persons (the principal, principal or principals) engage another person (the mandatary or agent) to perform an action on their behalf, implying the delegation to the agent of some decisionmaking power" (Jensen and Meckling, 1976). Whatever the agent's commitment, and whatever devices the principal puts in place to control the agent's actions, there will always be a divergence between the agent's action and the principal's interests. Since the principal is not omniscient, and suffers from an informational deficit with regard to the agent's profile, asymmetric information can lead to moral hazard and anti-selection. In this case, technological innovations provide the principal with the information he needs to act on the agent.

Network theory (Pigou, 1932) highlights positive and negative, direct and indirect network externalities on financial markets. Direct network externalities are observed through access and reduced transaction costs, and enable institutions to achieve economies of scale and increasing returns on demand. Indirect network externalities are characteristic of system or complementary goods. Networks are also a factor in the recognition of market opportunities (Kirzner, 1973).

The above theoretical controversies have not been mitigated by empirical work. Although most often focused on developed financial systems, the results of empirical research into the links between technological innovation and the development of financial markets are still not consensual. The relevant studies present two (02) levels of relationship. The first level is referred to as the "positive relationship", while the second is referred to as the "hypothetical relationship".

Empirically, as argued by authors such as Sassi and Goaied (2013), Lechman and Marszk (2015) and Olotu and Fasiku (2017), technological innovations, through their ability to disseminate information, constantly reshape financial markets in a positive way. Several studies have been carried out in this context, the results of which have shown a positive relationship between technological innovations and the development of financial markets. These include the work of Mehmood *et al.*, (2014), Ilyina and Samaniego (2011), Sassi and Goaied (2013), Marszk and Lechman (2018), Igwilo and Sibindi (2021; 2022). In view of the results of the abovementioned work, the adoption of technological innovations must be considered a sine qua non condition for the growth and development of financial and African markets in particular.

Other works have highlighted the existence of hypothetical links between technological innovations and the development of financial markets. In this regard, we can cite the work of Bhunia (2011), Okwu (2015), Pozzi *et al*., (2013), Khodayari and Sanoubar (2016) and Chien *et al*., (2020). Substantively, the results of these works show that technological innovations have a positive effect on financial market development indicators, but that these have become excessively volatile since the adoption of computer-assisted trading strategies, as the latter increase short-term price volatility and risk.

III. METHODOLOGY

The empirical analysis of the effects of technological innovations on the development of financial markets is carried out in all Sub-Saharan African countries (48 countries) over the period 1996-2021 in 26 years of annual data, with the exception of South Sudan, which became independent on July 9, 2011 and for which data are not available. The data comes mainly from the Global Financial Development Database (GFDD) and the World Bank's finStats, the IMF's Financial Access Survey and the Bank for International Settlements' (BIR) debt securities database. This evaluation was carried out using the ARDL model with the Pooled Mean Group (PMG) estimator. In addition, we develop a composite index of financial development following the work of Čihák *et al.*, (2012) and Svirydzenka (2016).

A number of indicators are taken into account, from which composite sub-indices have been calculated to reflect the different variables of access, depth, efficiency and stability of financial systems. An overall index of financial market development is then calculated, which is the result of aggregating the two composite sub-indices mentioned above.

Table 1: Synthetic matrix of direct finance development

Variables	Indicators/Financial markets
Access	Value of all shares traded outside the top 10 listed companies as a proportion of total value traded
	Market capitalization excluding the top 10 companies as a percentage of total market capitalization
Depth	Outstanding international public debt/GDP
	Total outstanding international debt/GDP
	Gross portfolio commitment to equities and investment funds/GDP
	Gross equity portfolio assets and share of investment funds/GDP
	Gross debt portfolio commitments/GDP
	Gross debt portfolio assets in relation to GDP
Efficiency	Financial market turnover rate
Stability	Share price volatility

Source: Author based on Čihák *et al.*, (2012) and Svirydzenka (2016).

IV. The ARDL Model estimation procedure

The estimation procedure for models based on panel data is determined by the nature of the data. The most important criteria are the stationarity of the series and the presence (or absence) of cointegration for the ARDL model.

a. Description of test procedure

We formulate the Pesaran *et al.*, (2001) cointegration test based on an ARDL model in the form of the error-correction model as follows:

$$\Delta Y_t = \alpha_1 Y_{t-1} + \alpha_2 X_{t-1} + \sum_{j=1}^{p} a_j \Delta Y_{t-j} + \sum_{j=0}^{q-1} b_j \Delta X_{t-j} + \alpha_0 + \varepsilon_t$$

Y: our dependent variable MF
X: vector of explanatory variables, here INTERNET, MOBILE, FIXED, INFLATION, GROWTH and POPULATION
Δ difference operator p, q: optimal delays
α_i coefficients of the long-term relationship
a_i, b_j coefficients for short-term dynamics.

In the long term $\Delta Y = \Delta X = 0$ the reduced form of the solution to the above equation gives the long-term equation for Y:

$$Y_t = \theta_0 + \theta_1 x_t + \epsilon_t$$

Where $\theta_0 = \frac{-\alpha_0}{\alpha_1}$, $\theta_1 = \frac{-\alpha_2}{\alpha_1}$ and ϵ_t white noise.

We have three choices of large model group:

- An ARDL model (staggered delay model); where sizes N and T are small;
- A GMM model; where high N and low T (or vice versa);
- The model group Pooled Mean Group (PMG), Mean Group (MG) and DFE (dynamic fixed

effects); where we have both high N and high T.

We opt for the last group of ARDL models with the group of PMG, MG and DFE estimators.

❖ **Pooled Mean Group (PMG) estimator**

The PMG is a model from the class of dynamic panel models developed by Pesaran *et al*., (1999). Its specific feature is the individual variability of the model constant, short-term coefficients and error variances. For the long term, on the other hand, PMG imposes a single coefficient for all individuals.

❖ **Mean Group (MG) estimator**

Developed by Pesaran and Smith in 1995, the MG estimator determines the model coefficient by calculating the unweighted average of the coefficients of individual countries or individuals. It provides efficient long-run estimators for a large sample size. It is sensitive to extreme values.

❖ **Dynamic fixed effects (DFE) estimator**

It is similar to PMG in that, in the long run, it imposes a single coefficient as well as the constant and variance of errors for all individuals. It tends to bring the speed of adjustment coefficients closer to the short-term coefficient. It has the specificity of highlighting the constants specific to each country.

The optimal ARDL model is the one that meets certain criteria. These include the normality (with zero mean) of the residuals, the homoscedasticity of the errors, the independence of the errors, and the stability of the coefficients. To test the normality of residuals, we use the JarqueBera (1980) normality test, while the Breusch-Pagan (1979) heteroscedasticity test is used for homoscedasticity. The Breusch-Godfrey test (1978) was chosen for the non-autocorrelation of errors, while the Ramsey test (1969) was chosen to justify the model's correct specification. To test model stability, we'll use the CUSUM and CUSUMQ tests.

The cointegration test involves using the Fisher (or Wald) statistic, which does not follow a standard distribution, to test the following hypotheses:

H_0: $\alpha_1 = \alpha_2 = 0$: Existence of a cointegrating relationship

H_1: $\alpha_1 \neq 0$, $\alpha_2 \neq 0$: Absence of a cointegrating relationship

Indeed, Pesaran *et al*., (2001) have simulated two critical bounds (lower and upper) for the test statistic, for several cases and different thresholds (1%, 5%, 10%). The lower bound is relative to explanatory variables assumed to be stationary, and the upper bound corresponds to the case where all explanatory variables are assumed to be at most I(1). If the Fisher statistic is greater than the upper bound, then there is cointegration. If it is smaller than the lower bound, we cannot reject the null hypothesis, so the cointegration relationship does not exist. If it is between the two bounds, we cannot conclude.

The use of the Pesaran *et al*., (2001) cointegration test results in the estimation of either a s errorcorrection model or a simple ARDL model.

b. Error-correction model estimation

If the existence of a cointegrating relationship is confirmed, an error-correction model should be estimated. Banerjee *et al*., (1993) claim that a dynamic error-correction model can be obtained simply by linearizing an ARDL model. This will be used to analyze the short- and long-term interactions between technological innovations and the development of financial markets.

Engle and Granger (1987) show that for any set of cointegrated variables, we can estimate an error-correction model where all variables are stationary:

$$\Delta Y_t = \lambda \epsilon_{t-1} + \sum_{i=1}^{p} a_i \, \Delta Y_{t-i} + \sum_{i=0}^{q} b_i \Delta X_{t-i} + \eta_t$$

The coefficient λ coefficient designates the restoring force towards long-term equilibrium. This parameter must be negative and significant in order to return the rie to its equilibrium value.

c. Estimation of the simple ARDL model

If there is insufficient evidence to reject the cointegration hypothesis, we can conclude that there is no long-term equilibrium relationship between the economic variables. We will therefore use a simple ARDL model to capture short-term dynamics. This model is written:

$$\Delta Y_t = \sum_{i=1}^{p} a_i \, \Delta Y_{t-i} + \sum_{i=0}^{q} b_i \Delta X_{t-i} + \eta_t$$

d. ARDL model specification

The ARDL model is a linear model which takes as explanatory the lagged values of the dependent as well as the explanatory values and their lagged values. For purely economic reasons, we will postulate the use of a Cobb Douglas-type production function whose logarithmic transformation is specified as follows:

$$\boldsymbol{FM = a_0 + \sum_{i=1}^{p_1} a_{1i} * MF_{t-1} + \sum_{i=0}^{p_2} a_{2i} * INTERNET_{t-1} + \sum_{i=0}^{p_3} a_{3i} * MOBILE_{t-1} + \sum_{i=0}^{p_4} a_{4i} * FIXED_{t-1} + \sum_{i=0}^{p_5} a_{5i} * INFLATION_{t-1} + \sum_{i=0}^{p_6} a_{6i} * GROWTH_{t-1} + \sum_{i=0}^{p_7} a_{7i} * POPULATION_{t-1} + \varepsilon_t}$$

p: the delay nombre of the variable

V. MODEL RESULTS AND DISCUSSION

This section presents descriptive statistics, hypothesis testing and, finally, econometric results and their interpretation.

a. Descriptive statistics and correlation of variables

This section will present the descriptive statistics and correlation test of the Financial Market Development (FMD) index and the explanatory variables.

The average financial market development index is quite low, at 0.219. As in the case of financial institutions, this low composite index reflects the underdeveloped level of financial markets as a whole in sub-Saharan Africa. Ranging from 0.004 to 0.91, it reflects the vast differences in the level of development of African countries' financial markets.

Table 2: Descriptive statistics for the financial market development index and explanatory variables

Variable	Obs	Mean	Std. Dev.	Min	Max
MF	1248	.219	.059	0,004	0,91
Fixed	1242	2.642	5.47	0	36.885
Internet	1247	10.016	7.211	0.0034	51.593
Mobile	1246	41.207	10.754	1,6	85.559
Inflation	1248	1.961	0.59	-3	4.085
Growth	1248	4.231	7.173	-26.082	30.973
Population	1248	17962772	27742434	76417	2.134e+08

Source: Author Stata 14 output

The correlation test stipulates that all explanatory variables are significantly correlated with the dependent variable financial market development, as is the case for the explanatory variable inflation. However, the correlation coefficients are relatively low. Furthermore, the correlation coefficients assigned to the growth rate and population variables are negative and extremely low. In any case, this predicts econometric results where the coefficients will not be truly significant.

Table 3: Correlation test of the financial market development index and explanatory variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
IF	1.000						
Fixed	0.283***	1.000					
Internet	0.286***	0.389***	1.000				
Mobile	0.305***	0.309**	0.815**	1.000			
Inflation	0.000	0.015	0.042	0.054*	1.000		
Growth	-0.073**	-0.041	-0.132***	-0.103***	-0.036	1.000	
Population	-0.090***	-0.172***	0.054*	0.036	0.053*	0.034	1.000

Source: Author Stata 14 output

b. Hypothesis and stationarity testing

We are now going to test the unit root hypothesis, i.e. the non-stationarity of the series. The following table shows the results of our stationarity tests (ADF, PP and KPSS).

Table 4: Stationarity tests for the financial market development index and explanatory variables

Variables		Level		Pri	mary difference		Decision
	ADF	PP	KPSS	ADF	PP	KPSS	
MF	-7,69*** (-4,345)	-10,4*** (-4,345)	0,23 (0,347)	- -	- -	0,042*** (0,739)	I(0)
Internet	-10,5*** (-3,435)	-10,1*** (-4,435)	0,089 (0,739)	- -	- -	0,013*** (0,739)	I(0)
Mobile	-13,0*** (-3,435)	-9,61*** (-3,435)	0,06 (0,739)	- -	- -	0,005*** (0,739)	I(0)
Fixed	-4,84*** (-3,435)	-5,38 (-3,435)	0,15 (0,739)	- -	- -	0,014* (0,739)	I(0)
Inflation	-6,16*** (-3,437)	-15,4*** (-3,437)	1,634 (0,739)	- -	- -	0,010*** (0,739)	I(0)
Growth	-11,1*** (-3,435)	-25,9*** (-3,435)	0,04 (0,739)	- -	- -	0,041*** (0,739)	I(0)
Population	-5,65*** (-3,435)	-5,92** (-3,435)	0,042 (0,739)	- -	- -	0,011*** (0,739)	I(0)

Source: Author on Eviews 9

Note: ***, **, * indicate that a t-stat (or LM-stat) is significant at 1%, 5%, 10%, respectively. Values in brackets represent critical values.

As in the previous chapter, we assume that all variables are stationary, i.e. level-integrated. As our variables are of different order of integration and less than or equal to 1, they are valid for use with the Pesaran *et al*., (2001) cointegration test.

Table 5: Summary of model validity tests

TESTS	Test statistics	P-value
Overall significance	294,5652	0,00000
Breusch-Godfrey autocorrelation test	29,46375	0,12775
Breusch-Pagan heteroskedasticity test	11,94388	0,54961
Jarque-Berra normality test	782771,2	0,48645
Ramsey test	9,455199	0,05464

Source: Author based on Eviews output

This model is globally significant, the p-value associated with the Fisher statistic is 0.000000 and therefore significant at the 5% threshold. The p-value of the residual autocorrelation test is 0.12, and we accept the null hypothesis of no autocorrelation of the errors. The errors are also normal and homoscedastic, and both tests have non-significant p-values at the 5% level (0,5496 for the Breusch-Pagan test (1979) and 0.486455 for the Jarque-Berra test (1980), In addition, the Ramsey test (1969) indicates through the insignificant p-value that our model is well specified, The estimated model is globally stable, with no apparent instability factor. The CUSUM and CUSUMSQ graph tests confirm the stability of the model coefficients over the entire study period.

c. Results of the cointegration test

Following the procedure outlined above, we can apply the Pesaran *et al*., (2001) cointegration test to the estimated ARDL model, verifying the validity hypotheses. This involves comparing the value of the Fisher statistic with that of the simulated critical values at the 1%, 5% and 10% thresholds. The test results are shown in the table below.

Table 6: Cointegration test

F-statistic	Threshold	Lower terminal	Upper terminal
11,90630	10%	1,99	2,99
	5%	2,27	3,28
	1%	2,88	3,99

Source: Author based on Eviews output

We can confirm that there is a cointegrating relationship between the variables in our model. Indeed, the test statistic of 11.91 is higher than the upper critical bound values, whatever the significance level, so we can estimate a long-term model. This validates the use of the PMG, MG and DFE estimators.

d. Econometric model results

For this part, the DFE model estimate does not converge. There is therefore no universal or immediate solution. The model may not fit the data, or the data may not fit the model. We have decided to use only the PMG and MG estimators.

Table 7: Effects of technological innovations on the development of financial markets

Long-term parameters		
VARIABLES	**PMG**	**MG**
Internet	0.0696***	0.0543
	(0.00455)	(0.0791)
Mobile	0.000321	0.113**
	(0.000932)	(0.0538)
Fixed	0.0917***	0.837
	(0.0252)	(0.879)
Inflation	-5.48e-05	-0.166*
	(7.55e-05)	(0.0984)
Growth	0.0268***	-0.0721
Population	(0.00365)	(0.141)
	0.000712	-0.485
	(0.00983)	(64.15)
Average error correction terms		
$\emptyset\ \boldsymbol{i}$	-0.1578***	-0.610***
	(0.0004552)	(0.0747)

Short-term parameters		
D.Internet	0.0225*	7.01-06
	(0.0136)	(0.0162)
D.Mobile	0.0101	0.0194a
	(0.00883)	(0.0148)
D.Fixed	0.377	0.359
	(0.423)	(0.425)
D.Inflation	-0.00508	5.57e-05
	(0.00768)	(0.0133)
D.Growth	-0.00129	0.0290
	(0.0194)	(0.0287)
D.Population	-41.295	-110.6
	(40.826)	(98.30)
D.Constant	0.00151*	0.0144
	(0.00241)	(0.0310)
Comments 1,200 1,200 Number of imfn 48 48		
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1		
P-value (Hausman) MG/PMG =0.2998		

Source: Author based on Eviews output

The Hausman (1978) test, with a p-value of 0.2298, once again forces us to choose the PMG model for the effect of technological innovations on the development of financial markets. The error correction terms are also below 1%. The coefficients of the short-term model are not significant, with the exception of internet, which is significant at the 10% level. A one-unit increase in internet access leads to a 0.0225-point improvement in financial market development, all else being equal. The insignificant impact of certain technological variables on financial market development may mean that sub-Saharan African countries have not yet invested sufficiently in organizational infrastructure, which is complementary to ICT investment, to reap its benefits (Khodayari and Sanoubar, 2016).

On the other hand, in the long term, the effects of Internet access and fixed-line telephone access are significantly positive at the 1% threshold. Thus, among these indicators, only cell phone access does not have a significant effect. In fact, a one-unit increase in internet access improves financial market development by 0.0696 points, all else being equal. In the case of fixed-line telephone access, a one-point increase implies a 0.0917-point improvement in financial market development, all other things being equal.

Overall, in the long term, our working hypothesis is verified, as two of the three indicators have a positive impact on the development of direct finance. These findings corroborate those of Mehmood *et al*., (2014), Sassi and Goaied (2013), Corrado *et al*., (2017), Igwilo and Sibindi (2021), and Marszk and Lechman (2018), whose results highlight the positive and significant effect of technological innovations on the development of financial markets.

IV. CONCLUSION

The aim of this article was to analyze the effect of technological innovations on the development of financial markets. Descriptive analysis shows that financial markets in sub-Saharan Africa are narrow and underdeveloped. All stock markets present weak signals in terms of cumulative numbers of listed companies and market capitalization. Sub-Saharan financial markets are highly embryonic and characterized by a drying-up of liquidity.

The econometric analysis of the effect of technological innovations on the development of financial markets is based on the Auto Regressive Staggered Lag (ARDL) model. The results show that the model's short-term coefficients are not significant. In the long term, the effects of internet and fixed-line telephone access are significantly positive at the 1% level. Only cell phone access does not have a significant effect. These results argue in favor of investing in technological innovations that are capable of stimulating financial markets, and whose effects can have a positive impact on the economic growth and development of sub-Saharan countries.

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