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Effects of telecommunications investment and ICTs diffusion on economic growth in the West African Economic and Monetary Union

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Abstract

This article analyses the effects of telecommunications investment and ICTs diffusion on economic growth in the West African Economic and Monetary Union. The empirical analysis is made on the basis of an ARDL model on panel data covering the period 1996-2017. The empirical model was estimated using the Pooled Mean Group (PMG), Mean Group (MG) and Dynamic fixed effect (DFE) methods. The results show that telecommunications investment has a positive and significant impact on long-term economic growth in the WAEMU. The results also show that the combined diffusion of mobile phones and the Internet among populations in the WAEMU positively and significantly affects long-term economic growth in the Union. In view of these results, this research calls on WAEMU countries to provide greater support for telecommunications investment and the spread of ICTs use among populations in order to accelerate economic growth in the WAEMU.

Keywords: ICTs diffusion, ICTs investment, Economic growth, WAEMU.

1. Introduction

In the New York Times book review in 1987, Robert Solow said, « You can see the computer age everywhere but not in the productivity statistics». He argued that what everyone thinks is a technological revolution, a radical change in productive life, referring to the advent of information and communication technologies (ICTs), has been accompanied everywhere by a decline in the rate of growth of labor productivity. Solow (1987) indicated that ICTs do not affect the economic growth of countries. This view of the author will be the main starting point for empirical research on the effects of ICTs on countries' economic growth, the author view is not universally accepted in the literature.

Solow's (1987) point of view has emerged as a paradox in the literature. Indeed, with reference to the work of Schumpeter (1911, 1939), technological innovations are a source of economic growth and development. The advent of ICTs has also given rise to a post-industrial (Bell, 1973) or networked society (Castells, 1996) in which productivity is at the heart of the dynamics of social change and economic development of countries, and which productivity is technologically determined. Moreover, the public and private investments in telecommunications needed to accompany the continued diffusion of ICTs in every country in the world are in themselves other sources of economic growth, with reference to Romer (1986, 1990) and Barro and Sala-i-Martin (1990). Thus, from a theoretical point of view, the beneficial effects of telecommunications investment and ICTs diffusion on countries' economic growth are naturally expected, in contrast to the empirical finding of Solow (1987).

Empirically, a number of studies confirm the positive and significant effects of ICTs on economic growth (Ben Youssef and M'henni, 2004; Melka and Nayman, 2004; Erumban and Das, 2015; Chabossou, 2017). However, there is also some empirical works in this same literature that rather confirms Solow's paradox (Berndt and Morrison, 1995; Gordon, 2000; Jacobsen, 2003). On the basis of this controversial literature, the general issue of the effect of ICTs on economic growth remains topical and therefore deserves to be addressed in research work, especially in developing countries where ICTs have been seen as a means of catching up with developed countries (Bellon et al., 2003).

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On the sidelines of the controversial debate on the effects of ICTs on economic growth, it can be noted that the countries of the West African Economic and Monetary Union (WAEMU[3]) remain resolutely committed to a better diffusion of ICTs in the Union. They liberalized their ICTs sector in the 1990s (Dahmani and Ledjou, 2012) with the aim of opening it up to private investment in order to accelerate the level of ICTs diffusion in the respective economies of the Union. They quickly embarked on the development and implementation of a number of common policies in the telecommunications sector with a view to accelerating the diffusion of ICTs in the Union (UEMOA, 2003; UIT, 2005). The countries of the Union's declared willingness to increase investment in telecommunications and improve the dissemination of ICTs in the Union suggests that they have high hopes for more growth and economic development in this area.

In fact, ICTs diffusion is currently active in almost all economic and social sectors in the Union. Among the population, statistics show that the spread of ICTs use in the Union is continuously increasing. The number of mobile phones per 100 inhabitants has increased from 1 to 89 between 2000 and 2017 (ITU, 2019). The percentage of individuals using the Internet in the Union increased from 0.27% in 2000 to 17.84% in 2017. On average, the percentage of households with a computer increased from 1.88% to 7.40% between 2008 and 2017 in the WAEMU (ITU, 2019). Compared to the diffusion of mobile phones among the population, the diffusion of internet and computers has so far been slow in the Union. However, the Internet is the most important ICT technology for mobilizing information and therefore the most important in the production process. This specific state of affairs could limit the effects of the use of ICTs on the economic growth of WAEMU countries.

Each year, new investments continue to be made in the Union's telecommunication sector to improve population's access to the ICTs infrastructure. Between 2006 and 2017, the percentage of the population in the Union covered by a mobile telephone network increased from 61.01 per cent to 92.48 per cent (ITU[4], 2019). Over the period 2014-2017, the percentage of the population in the Union covered by at least one 3G mobile internet network increased from 17.36% to 46.50%. These new investments increase the level of the technological capital stock in the Union and should, in theory, have a favourable impact on economic growth in WAEMU countries.

In terms of contribution, the telecommunications sector generated in 2017 an income of 5.10 per cent of the Union's gross domestic product (GDP) (ITU, 2019; World Bank, 2020). This statistic shows in particular that the ICTs sector supports wealth creation in the WAEMU. However, this statistic is not sufficient to affirm that the ICTs diffusion in WAEMU countries has a significant effect on the economic growth of the Union. Indeed, according to Schumpeter (1942), technological innovation could be the source of a process of "destruction-creation" in which certain old activities are destined to disappear and new ones will be born. Consequently, it cannot be ruled out that, over certain periods of time, the net effects of ICTs diffusion on economic growth in a country may be negative, zero or positive.

In view of the current state of ICTs diffusion in the Union and the controversial literature on the issue of the effects of ICTs on economic growth, this research also aims at giving answers to the question what are the effects of ICT on economic growth in WAEMU countries? Other authors such as Johnson (2016), Chabossou (2017) and Karabou and Adeve (2018) have already asked questions similar to those of this research in the WAEMU.

However, Chabossou's (2017) research focuses only on Benin and obscures the effects of mobile phone diffusion on economic growth. Nowadays, however, the mobile phone is an almost indispensable technological tool in the process of production and exchange of goods and services between producers and consumers in the economy. Moreover, in terms of ICTs diffusion, the relationship between the Internet, the mobile phone and the technological infrastructure is one of complementarity. As a result, all these technological variables need to be taken into account when analyzing the effects of ICTs on economic growth. Compared to Chabossou (2017), this research extends its scope beyond Benin and integrates the mobile phones diffusion in the analysis of the effects of ICTs on economic growth.

Karabou and Adeve (2018) obscure the role of the technological capital stock in their analysis of the effects of ICTs on economic growth in the WAEMU. Johnson's (2016) research focuses mainly on the effects of Internet diffusion on economic growth in the WAEMU. Thus, this author uses only a few observations (46 in total) to estimate the relationship between ICTs and economic growth in the Union. Therefore, this work can be

[3] The WAEMU includes eight West African countries, which are: Benin, Burkina Faso, Cote d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal and Togo.

[4] International telecommunication Union.

strengthened by taking into account other technological variables and by further extending the temporal dimension of the data in order to have a larger number of observations for empirical analysis.

The objective of this paper is to determine the effects of ICTs on economic growth in WAEMU countries by using a much more robust and appropriate methodology on the one hand, and by taking into account the complementarity effect between the Internet diffusion, the technological capital stock and the mobile phone diffusion on the other hand in the analysis of the relationship between ICTs and economic growth. On the basis of the Schumpeterian theory of technological innovation, this research starts from the assumption that ICTs positively affect economic growth in the countries of the Union.

The second section of the research presents a review of the literature. The third section presents the research methodology. The fourth section is devoted to the presentation and discussion of the results. The last section presents the conclusion and the economic policy implications of the research results.

2. Literature review

This section presents, on the one hand, the theoretical underpinnings of the relationship between ICT and economic growth in the literature. On the other hand, it draws on the findings of some empirical work in the literature on this subject.

2.1. Theoretical review

The theoretical relationship between ICTs and economic growth can be established in the literature based on the theories of Schumpeter (1939), Romer (1986, 1990) and Barro and Sala-i-Martin (1990). According to Schumpeter (1939), each emergence of a new "cluster5 of technological innovations" leads to improved productivity gains and the production of new products in economies where these technologies are diffused. Following this logic, ICTs are a source of economic growth for countries. Since the liberalization of the telecommunication sector in the 1990s, investment in ICTs has been largely private and to a lesser extent public. These private and public investments improve the overall level of the technological capital stock in WAEMU countries and thus constitute a source of economic growth according to Romer (1986) and Barro and Sala-i-Martin (1990).

Moreover, since their advent, ICTs have evolved by "generations" where the new ones are more efficient than the previous ones. The Internet is currently in its fifth generation. The simple mobile phones of the 1980s have given way to mobile smartphones or smartphones since the decade 2000. The capacity of computers continues to increase as predicted by Moore's Law (1965). As a result, more and more new knowledge is being incorporated into new ICT goods. The use of these new ICT goods in production activity is a source of economic growth according to Romer (1990).

Solow's (1956) microeconomic theory of the production function provides an ideal conceptual framework for understanding the transmission channel of the effects of telecommunications investment and ICTs use on countries' economic growth. Based on this production function, ICTs can affect economic growth in two ways. Considered as embodied technical progress, they can affect economic growth by acting on the productivity of at least one of the classical factors of production. Considered as autonomous technical progress, ICTs can affect economic growth by acting on the autonomous factor of production (technical progress) or by acting as a third factor of production (technological capital) alongside the two traditional factors of production (labor and capital). In the latter case, technological capital is seen as complementary to the two classical factors of production. In this research, the stock of technological capital is integrated as a third factor of production alongside non-ICT labor and physical capital. Mobile phones and the Internet are used as determinants of the level of endogenous technical progress in the economy.

2.2. Some empirical evidences

Following Solow's (1987) point of view, which was not unanimously accepted in the literature, a number of empirical studies have focused on analyzing the link between ICTs diffusion and the economic growth of countries. This section reviews the conclusions of some of this literature. In its Growth Report, the OECD6 (2001) analyzed the causes of trend differences in growth performance across its member countries. It concluded that ICTs accelerate growth in countries where conditions of macroeconomic stability were in place, while finding

[5] Schumpeter (1939) uses this term to refer to a grouped appearance, during a given period of time, of a set of technological innovations.

6 Organization for Economic Cooperation and Development (OECD).

a disparity in the contribution of ICTs to growth across countries. In 2002, another OECD report examined the contribution of ICTs to economic growth.

Using growth accounting methodology on a sample of nine countries7, the report found that ICTs contributed 0.2 to 0.5 percentage points to economic growth per year, depending on the country, in the first half of the 1990s. In the second half of the 1990s, this contribution increased to 0.3 to 0.9 percentage points per year.

Ben Youssef and M'henni (2004) examined the effects of ICTs on economic growth in developing countries in general and on the Tunisian economy in particular. They used a standard Cobb-Douglas production function on data covering the period 1975 to 2001. They conclude that despite Tunisia's low level of investment in ICT (2.5% of GDP in constant prices), ICTs contributed 3% to national output and accounted for 9% of economic growth over the last decade of the study period. Melka and Nayman (2004) used growth accounting over the 1995-2001 period to make an international comparison of factors explaining hourly labor productivity in the United States, the United Kingdom, Germany and France. They conclude that ICTs use is a source of productivity growth in these countries.

In France, Cette et al. (2005) found that ICTs diffusion has a positive effect on potential growth. Draca et al. (2006) conducted a broad review of both the microeconomic and macroeconomic literature on the effects of ICTs on productivity and concluded that the Solow paradox does not hold. Over the period 1990-2001, Sridhar and Sridhar (2007) analyzed the effects of mobile and fixed-line telephones on economic growth in 61 developing countries including WAEMU countries. These authors found that mobile and fixed-line telephones positively and significantly affect the economic growth of these countries. Vu (2011) sought to verify empirically whether ICTs are a source of economic growth in the information age. The author starts from a sample of 102 countries from both developed and developing countries over the period 1996-2005. He concludes that ICTs have been an important source of economic growth over the study period.

Erumban and Das (2015) assessed the relationship between ICTs and economic growth in India over the period 1985-2011. Their results suggested an important role of ICTs investment in India's overall economic growth. Furthermore, taking the analysis down to the level of economic sectors has clarified that the contribution of ICTs to overall economic growth in India is mainly due to their effects on the services sector. Hofman et al (2016) found a 6% contribution of ICT capital to GDP growth in Latin America, while the contribution was around 29% in the United States. They explain the labor productivity gap between Latin America and the United States by the ICT capital gap between the two countries. ICT capital explains less than one-sixth of the total contribution of capital in Latin America.

Johnson (2016) questioned the importance of the Internet for economic growth in developing countries, particularly those of the WAEMU. Over the period 2009-2014, he shows that the development of the Internet is an important pillar of economic growth in WAEMU countries excluding Guinea-Bissau. In Benin, Chabossou (2017) found that capital in the digital economy sector positively affects economic growth over the period 1985-2015.

The aforementioned empirical work shows, at the macroeconomic level, positive effects of ICTs on productivity and economic growth. However, not all the empirical works share the same conclusion about the effects of ICTs on economic growth. Indeed, Jacobsen (2003) over the period 1990-1999 with a sample of 84 countries finds no effect of ICT adoption on economic growth. On a meso-economic scale, the analysis by Berndt and Morrison (1995) found a negative correlation between ICTs investment and total factor productivity in U.S. manufacturing industries over the period 1968-1986. Gordon (2000), looking at the evolution of multifactor productivity in the United States over the period 1870-1999, found that it slowed down at the same time as ICTs investment only increased. Thus, Gordon's (2000) analysis also underlied that of Solow (1987). The findings of this earlier work show that Solow's paradox may not be a myth and that there is a need to continue to address this issue, especially empirically, of the effects of ICTs on economic activity in general.

3. Research methodology

3.1 Theoretical model

The effects of ICTs on economic growth are analyzed in this research using the production function of Cobb and Douglas (1928). The theoretical form of this function is as follows:

$$Y_{it} = Af(K_{it}, L_{it}) = AK_{it}^{\alpha} L_{it}^{\beta} \quad (1)$$

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[7] Australia, Canada, Finland, Germany, Italy, United Kingdom and United States.

With: $\alpha + \beta = 1Y$ represents the level of production of the country; A, represents autonomous technical progress; $K$and Lrepresent respectively physical capital and labor. i and t represent respectively the individual and temporal dimensions of the model.

3.2. Empirical specification of the model

In the theoretical production function of Cobb and Douglas (1928), technical progress can be considered exogenous (Solow, 1956, 1957) or endogenous (Romer, 1990). The present research is in line with the logic of technical progress. For Romer (1990), the evolution of the level of technical progress in a country depends on the quantity of labor assigned to the research sector. In the present research it depends on the level of ICTs diffusion in the economy. This ICTs diffusion affects the level of total factor productivity in an economy (Cette et al., 2005; Johnson, 2016). Thus, endogenous technical progress is formalized as follows:

$$A_{it} = A_0 e^{\varphi_1 \ln(mobile_{it}) + \varphi_2 \ln(internet_{it}) + \mu_{it}} \quad (2)$$

With: A_0, the exogenous level of technical progress; μ represents the effect of other factors that may determine the level of technical progress in the economy; mobile, represents the diffusion of the mobile phone in the economy and internet, represents the diffusion of the internet in the economy. e represents the exponential function.

Productive capital consists of technological and non-technological capital. Replacing equation (2) in (1), and including technology capital alongside non-technology capital, equation (2) becomes:

$$Y_{it} = A_0 (e^{\varphi_1 \ln(mobile_{it}) + \varphi_2 \ln(internet_{it}) + \mu_{it}}) KHTIC_{it}^{\alpha} KTIC_{it}^{\beta} HC_{it}^{\gamma} \quad (3)$$

The linearized form of equation (3) gives:

$$lnY_{it} = lnA_0 + \alpha \ln KHTIC_{it} + \beta lnKTIC_{it} + \gamma \ln HC_{it} + \varphi_1 \ln(mobile_{it}) + \varphi_2 \ln(internet_{it}) + \varphi X_{it} + \mu_{it} \quad (4)$$

Let's put: $y_{it} = lnY_{it}$, $a_0 = lnA_0$, $CapHTIC_{it} = \ln KHTIC_{it}$, $CapTIC_{it} = lnKTIC_{it}$, $HumC_{it} = lnHC_{it}$, $InternetUser_{it} = lnInternet_{it}$, $MobileUser_{it} = lnmobile_{it}$

Equation (4) becomes:

$$y_{it} = a_0 + \alpha CapHTIC_{it} + \beta CapTIC_{it} + \gamma HumC_{it} + \varphi_1 mobileUser_{it} + \varphi_2 internetUser_{it} + \varphi X_{it} + \mu_{it} (5)$$

In equation (5), y_{it} is the economic growth rate of country i at date t, $CapHTIC_{it}$, $CapTIC_{it} HumC_{it}$ and represent respectively non-technology capital, technology capital and human capital of country i at date t. X_{it} is a vector of explanatory variables that may affect economic growth outside the variables already mentioned.

3.3. Estimation method

In this article, the estimation method chosen is the result of a stepwise approach. The first step consists in performing a series dependency test in order to discriminate between first- and second-generation unit root tests. Once the order of integration of the series is known, the next step will consist in examining the possible presence of cointegration relationships that may exist in the long term between the variables. This analysis will follow the cointegration test procedure of Pesaran et al. (2001), which is more efficient than Johansen's (1988) strategy when the sample size is small and the number of variables high.

Given that the individual dimension of the data is smaller than the time dimension, the staggered delay autoregressive (ARDL) approach of Pesaran et al. (1999) seems the most appropriate econometric approach to use in this research. The estimation of the ARDL with a lag is appropriate because it corrects the serial correlation and the endogeneity problem at the same time. Thus, considering that all variables are integrated of order 1 then the error term is an integrated process at level I (0) for all i and is independently distributed over t. A maximum unit-order delay is also assumed for each variable. Under these conditions, the equation can be rewritten as an ARDL (p, q) distribution as follows:

$$\Delta y_{it} = \phi_i y_{it-1} + \beta_i CapHTIC_{it-1} + \rho_i CapTIC_{it-1} + \omega_i HumC_{it} + \varphi_i mobileUser_{it} + \Psi_i internetUser_{it} + \varphi'_{ij} X_{it-1} - \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{it-1} - \sum_{j=0}^{q-1} \delta_{ij} \Delta CapHTIC_{it-j} - \sum_{j=0}^{q-1} \tau_{ij} \Delta CapTIC_{it-j} - \sum_{j=0}^{q-1} \Omega_{ij} \Delta HumC_{it-j} - \sum_{j=0}^{q-1} \vartheta_{ij} \Delta mobileUser_{it-j} - \sum_{j=0}^{q-1} \Theta_{ij} \Delta internetUser_{it-j} - \sum_{j=0}^{q-1} \gamma'_{ij} \Delta X_{it-j} + \varepsilon_{it} \quad (5)$$

In representation (5), ϕ_i is the coefficient of the lagged dependent variable. It is also called recall force or long-run adjustment coefficient and must be negative. ε_{it} is the random perturbation. It is assumed to be normally and independently distributed across i and t with mean 0 and variance $\sigma_i^2 > 0$. Note that one of the advantages of ARDL models is that the short term and long-run relationships are estimated jointly. In addition, these models allow for the presence of variables that can be zero, first-order or cointegrated (Pesaran, Shin and Smith 1999).

When all the conditions of ϕ are met, the long-run relationship can be written as follows:

$$y_{it} = \theta_{1i} CapHTIC_{it} + \theta_{2i} CapTIC_{it-1} + \theta_{3i} HumC_{it} + \theta_{4i} mobile_{it} + \theta_{5i} internet_{it} + \theta'_{2i} X_{it} + \eta_{it} \quad (6)$$

In equation (6), $\theta_{1i} = {}^{\beta_i}/_{\phi_i}$; $\theta_{2i} = {}^{\rho_i}/_{\phi_i}$; $\theta_{3i} = {}^{\omega_i}/_{\phi_i}$; $\theta_{4i} = {}^{\varphi_i}/_{\phi_i}$; $\theta_{5i} = {}^{\Psi_i}/_{\phi_i}$ et $\theta'_{2i} = \left({}^{\varphi'_{ij}}/_{\phi_i}\right)'$,

Represent the long-term coefficients associated respectively with the variables $CapHTIC_{it-1}$, $CapTIC_{it-1}$, $HumC_{it}$, $mobile_{it}$, $internet_{it}$ and the vector of control variables. η_{it} is the error term of the long-run relationship and must be stationary.

4. Variables and data sources

4.1. The dependent variable

In this article, the dependent variable is represented by economic growth. Its growth is synonymous with the national economy ensuring an efficient sphere of production, marketing and consumption. Economic growth is measured by GDP per capita.

4.2. Interest explanatory variables

Mobile phone: this variable is measured by the number of mobile phones available per 100 inhabitants in each country. It is supposed to have a positive impact on economic growth in the WAEMU.

Internet: this variable is measured by the percentage of individuals using the Internet in each country. It is supposed to have a positive impact on economic growth in the WAEMU.

Non-ICT physical capital: This is measured by the stock of capital available in the economy by country.

ICT physical capital: it is measured by the technological capital stock in each country. Databases do not have data on physical capital stock. However, data on gross fixed capital formation (investment) are available. Thus, the capital stock is calculated as follows:

$$K_t = (1 - \theta)K_{t-1} + I_t \quad (7)$$

In this equation, I represents the new capital investment and θ represents the rate of capital depreciation. According to Ben Youssef and M'henni (2004), the annual depreciation rate of non-technological physical capital is $\theta = 8\ \%$ and the annual depreciation rate of technological capital is $\theta = 12{,}5\ \%$. This research uses the same rates to calculate the stocks of technological and non-technological capital. The year 1996 is taken as the base year for calculating capital stocks in this research. Therefore, the investment in the year 1996 is assumed to be the capital stock in order to calculate the capital stocks in subsequent years. Non-technology capital and technology capital are positively related to the level of output in the Cobb-Douglas production function.

Human capital: Wage labor as a percentage of the total employed labor force is used as a proxy for the level of human capital in this research. This variable is assumed to have a positive effect on economic growth according to the human capital theory of Schultz (1961) and Becker (1964).

4.3. Explanatory control variables

Inflation: The effect of inflation on economic growth is controversial in the literature. Some studies claim that inflation has a positive effect on growth (Dornbusch et al. 1996), while other studies suggest that this effect is characterized by a non-linear relationship (Fischer, 1993; Kremer et al., 2009). The expected sign for this variable is ambiguous.

Foreign direct investment ratio: The foreign direct investment (FDI) ratio is calculated as the ratio of FDI to GDP. In a given country, FDI is a component of overall private investment. It is therefore a source of economic growth according to Romer (1986). While it is generally accepted in theory that foreign direct investment (FDI) has favourable effects on economic growth, empirically, its effects on economic growth are subject to debate. Borensztein et al (1998) argue that the effects of FDI on economic growth are conditional on the existence of a certain level of human capital in the host country. Carkovic and Levine (2002) found no effect of FDI on economic growth. The expected sign for this variable is ambiguous.

Financial development: several indicators are used in the literature. These indicators can be grouped into two categories. First, there are indicators relating to the size and efficiency of bank activity, and second, there are indicators relating to the functioning of financial markets. Because of the low level of financial market development in developing countries in general, it is more appropriate to use the first category. Like King and Levine (1993), credit to the private sector as a percentage of (GDP) is used as an indicator of financial development in this work. The link between financial development and economic growth is debated in the literature. For Meier and Seers (1984), no pioneer in development economics listed finance as a factor in economic development. On this basis, some authors such as Lucas (1988) argued that finance is not an important factor in the general conception of development. On the contrary, many authors suggested that finance has positive effects on economic growth (Bagehot, 1873; Schumpeter, 1911; McKinnon, 1973; Shaw, 1973; Pagano, 1993; Levine, 1997). In this research, the sign between this variable and economic growth is assumed to be indeterminate.

4.4. Data sources

The data used in this article are annual and come mainly from two sources, the ITU database (2019) and the World Bank database (2020). They cover the period from 1996 to 2017. The choice of this period is mainly guided by the availability of data on the variables of interest, notably mobile phones and the Internet. Guinea-Bissau and Niger are not included in the empirical analysis due to lack of data on telecommunication investment.

5. Key findings and discussions

5.1. Descriptive statistics of the data used

Table 1: Descriptive analysis of variables of interest

Variables	BEN	BFA	CIV	MLI	SEN	TOG
GDP per capita	1018.56	532.33	1317.38	654.82	1226.90	567.79
Internet	3.56	3.49	8.02	2.67	9.06	3.14
Mobile phone	37.81	27.96	45.78	42.19	42.26	26.87
Technological capital	8.96e+10	7.83e+10	2.14e+11	8.55e+10	1.50e+11	5.69e+10
Non-technological capital	1.32e+12	1.61e+12	2.91e+12	1.52e+12	2.81e+12	7.09e+11
Human capital	9.661	8.12	22.26	17.23	25.90	12.57

Note: BEN=Benin, BFA=Burkina Faso, CIV=Cote d'Ivoire, MLI=Mali, SEN=Senegal, TOG=Togo
Source: Authors' calculations based on World Bank (2020) and ITU (2019) data.

Table 1 summarizes the descriptive analysis of the data specifically focusing on the mean of the variables of interest. Over the period 1996-2017, the average GDP per capita in Benin was US$ 1018.56. Among the 6 reference countries, Côte D'Ivoire recorded the highest average GDP level over the study period (US$ 1317.38) while Burkina Faso recorded the lowest average (US$ 532.33). The statistics show that Internet diffusion was slower than mobile phone diffusion over the period 1996-2017 in the sample countries. In Senegal, for example, there was an average of 9.06 per cent of Internet users over the period 1996-2017 compared to an average of 42 mobile phones per 100 inhabitants over the same period.

Concerning stocks of technological and non-technological capital, statistics show that Côte d'Ivoire and Senegal recorded the highest average stock levels in volume terms over the study period among the countries in the sample. These are the same countries that recorded on average the highest levels of human capital over the same study period.

5.2. Basic test results

Prior to estimating the empirical model, preliminary tests were conducted to ensure that the ARDL model was appropriate for the data used in this research. These tests are the series dependence test, the unit root test and the cointegration test. The Pesaran (2004) test was used to test the cross-sectional dependence of each variable. In order to choose between first- or second-generation stationarity tests, the Breusch-Pagan (1980) and Pesaran (2004) independence tests were applied to the data. The results are shown in Table 2:

Table 2: Result of the Pesaran (2004) dependency test

Test	Statistics	P-value
Breusch-Pagan LM	0.00	1
Pesaran CD	-0.572	0.5673

Source: Authors' calculations based on World Bank (2020) and ITU (2019) data.

The Breusch-Pagan (1980) LM test on model residues indicates the absence of interindividual autocorrelation at the 1% threshold. Pesaran's (2004) interindividual dependency test confirms the null hypothesis of no interindividual dependency at the 1% threshold. These results suggest the use of first-generation tests to test the stationarity of the series. These are mainly the Levin, Lin and Chu [LLC] (2002) and Im Pesaran and Shin [IPS] (2003) tests. It should be noted that the LLC test is based on the assumption of a normal asymptotic or semi-asymptotic distribution of residues. Thus, possible correlations between individuals constitute nuisance parameters. To overcome this problem, it is preferable to use the IPS test, which corrects the limitations of the LLC test by exploiting the co-movements to define new test statistics. The null hypothesis of the IPS test assumes that all series are non-stationary against the alternative hypothesis that all series are level stationary. Table 3 presents the results of the IPS test.

Table 3: Results of the IPS unit root test (2003)

Variables	T-statistics	P-value	Differentiation level	Decision
lnpib	-5.0078	0.0000	1	Stationary
lnInternet	-5.5865	0.0000	0	Stationary
lnMobile	-6.5366	0.0002	0	Stationary
lncaptec	-2.6769	0.0037	0	Stationary
lncaphtec	-2.0164	0.0219	0	Stationary
lncaphum	-5.6129	0.0000	1	Stationary
lninfl	-3.9800	0.0000	0	Stationary
lnide	-4.0768	0.0000	0	Stationary
lndevfin	-5.1436	0.0000	0	Stationary

*The theoretical value is from -2.88 to 5% and -3.15 to 1%

Source: Authors' calculations based on World Bank (2020) and ITU (2019) data.

The results of the stationarity test in Table 3 reveal that the variables internet, mobile phone, technology capital, non-technology capital, inflation, foreign direct investment and financial development are level stationary while GDP per capita and human capital are stationary in the first difference. These results suggest the existence of a long-term relationship between the variables in the model. A cointegration test was conducted on the data to ensure the existence of such a long-run relationship between the variables.

Given the absence of inter-individual dependency, this research uses Pedroni's (2004) cointegration test whose null hypothesis is to test for the absence of cointegration based on unit root tests on estimated residuals. In this case, seven cointegration tests on panel data are performed. These tests take into account heterogeneity in the cointegration relationship, i.e. for each individual there is one or more cointegration relationships that are not necessarily identical for each individual in the panel. In the seven Pedroni tests, four are based on the Within dimension and three are based on the Between dimension. The results of the test are shown in Table 4.

Table 4: Results of Pedroni's (2004) cointegration test

	Panel v-stat[a]	Panel rho-stat[a]	Panel pp-stat[a]	Panel adf-stat[a]	Group rho-stat[b]	Group pp-stat[b]	Group adf-stat[b]
Statistics test	1.354	1.718	-1.658	4.941	2.685	-2.537	6.316

Note: [a]tests based on the dimension within; [b] tests based on the dimension between.

Source: Authors' calculations based on World Bank (2020) and ITU (2019) data.

The results of Pedroni's (2004) cointegration tests show that the panel (rho, pp and adf) and group (rho, pp and adf) statistics are below the critical value of the normal distribution for a threshold of 5%. Thus, all these tests confirm the existence of a cointegrating relationship.

5.3. Results of the econometric estimations and discussions

The results of the estimation of the empirical model are presented in Table 5. In this research, the focus is exclusively on the long-run dynamics between the explanatory variables and the variable to be explained of the empirical model.

Table 5: Long-term relationship estimation results

Variables	PMG	MG	DFE	PMG	MG	DFE
Error correction	-0.266***	-0.651***	-0.330***	-0.514***	-0.494***	-0.602***
	(0.027)	(0.250)	(0.0797)	(0.0548)	(0.135)	(0.105)
Internet	0.0102*	0.0255	0.0121			
	(0.00549)	(0.0383)	(0.0238)			
Mobile telephone	0.00221	0.0354	0.00400			
	(0.0245)	(0.0409)	(0.00743)			
Internet*mobile telephone				0.0543***	0.0483**	0.152***
				(0.0135)	(0.0197)	(0.0246)
ICT Capital	0.0694**	0.0880**	0.0140***	0.0730**	0.0886***	0.0986***
	(0.0287)	(0.00873)	(0.00412)	(0.0327)	(0.0119)	(0.0119)
Non-ICT Capital	0.236***	0.181***	0.0162***	0.203***	0.891***	0.00794*
	(0.0709)	(0.0247)	(0.00566)	(0.0509)	(0.0275)	(0.00421)
Human Capital	0.934**	0.272***	0.0557**	0.334**	-0.563*	0.500**
	(0.405)	(0.0507)	(0.0248)	(0.405)	(0.307)	(0.229)
Inflation	-0.134**	-0.0250*	-0.00333*	-0.105**	-0.00384**	-0.0714***
	(0.0681)	(0.0142)	(0.00200)	(0.0489)	(0.00169)	(0.0221)
FDI	0.0102	0.670	0.00516	0.140	0.523*	0.384
	(0.00749)	(0.887)	(0.00526)	(0.204)	(0.280)	(0.254)
Financial Development	0.200**	0.0318*	0.404***	0.048**	-0.0250*	0.0143
	(0.0781)	(0.0186)	(0.102)	(0.019)	(0.0142)	(0.0886)
Constant	-3.539**	-1.381***	-0.524***	-2.008***	-2.418***	-0.844**
	(1.508)	(0.496)	(0.0112)	(0.435)	(0.784)	(0.377)
Hausman test	61.21 (a)		0.43 (b)	78.01 (a)		1.128(b)
	(0.001)		(0.956)	(0.001)		(0.956)

Notes: *, **, *** significance at 10%, 5% and 1% and the values in brackets are standard deviations.

(a) the PMG estimate is more efficient than the MG estimate; (b) the PMG estimate is more efficient than the DFE estimate.

Source: Authors' estimations based on World Bank (2020) and ITU (2019) data.

Table 5 presents the estimation results of the ARDL panel model using the three estimators Pooled Mean Group (PMG), Mean Group (MG), and Dynamic fixed effect (DFE). For all estimates, the error correction term is negative, significant and greater than -1. This result confirms the presence of a long-term relationship between economic growth and the explanatory variables selected. The results of the Hausman test (shown in Table 5) do not reject the null hypothesis of long-term homogeneity and short-term heterogeneity of the regressors.

As a result, the PMG estimator is in this case more efficient than the MG and DFE estimators. Consequently, it is more sensible to interpret only the long-term results for the whole panel from the PMG estimator.

The results in Table 5 show that telecommunications investment in the WAEMU positively and significantly affect the economic growth of the countries of the Union in the long term. They indicate that a 10% increase in telecommunications investment leads to a 7.3% increase in GDP per capita in the Union in the long term. At the theoretical level, these results are in line with Schumpeter's theory of technological innovation (1939) and the endogenous growth theories of Romer (1986, 1990) and Barro and Sala-i-Martin (1990) concerning the role of investment in general and investment in technology in particular on economic growth. Empirically, results similar to those of the present research have also been found by Ben Youssef and M'henni (2004) in Tunisia, by Erumban and Das (2015) in India, by Hofman et al (2016) in the United States and Latin America, and by Chabossou (2017) in Benin. Overall, this result confirms the findings of work that found positive and significant effects of ICTs investment and economic growth. The result found between ICTs investment and economic growth in the WAEMU in this research contrasts with the analyses of Solow (1987) and Gordon (2000) which rather question the existence of positive effects of ICTs investment on economic growth.

The results in Table 5 indicate that the Internet diffusion in the WAEMU positively affects long-term economic growth at the 10% threshold of the countries of the Union. This result was also found by Choi and Yi (2009) on a sample of 207 countries in the world and by Tripathi and Inani (2016) on sub-Saharan African countries. The results in this research do not directly highlight the existence of significant effects of mobile phone diffusion on economic growth in the WAEMU. This result contrasts with those of Andrianaivo and Kpodar (2012) on Saharan Africa and of Sassi and Goaied (2013) on countries in North Africa and the Middle East. However, the results of this research show that the combined diffusion of mobile phones and the Internet among the WAEMU population has a positive and significant effect on long-term economic growth in the Union. In particular, the results show that the combined effect of the Internet and mobile phones is more significant and more important than their individual effects on economic growth in the WAEMU.

Apart from the technological variables, the classical variables (non-ICT capital and human capital) exert positive and significant effects on economic growth in the WAEMU. The results also show that inflation and financial development have significant effects on economic growth in the Union. The level of inflation has a negative impact on long-term economic growth. This finding underpins the conduct of anti-inflationary policies in the Union with a view to accelerating economic growth. Financial development has positive effects on long-term economic growth in the Union. This result is consistent with the theoretical analyses of Bagehot (1873), Schumpeter (1911), McKinnon (1973), Shaw (1973) and Pagano (1993).

6. Conclusion and implications

The debate on the effects of information and communication technologies is controversial in the literature, while significant investments continue to be made in these technologies and their dissemination is progressing among the world's populations, including in the West African Economic and Monetary Union (WAEMU) zone. The objective of this research was to determine the effects of ICTs on the economic growth of WAEMU countries. For the empirical verification of the effects of ICTs on economic growth, the ARDL model was used. It was estimated using the Pooled Mean Group (PMG), Mean Group (MG) and Dynamic fixed effect (DFE) methods over the period 1996-2017. The Hausman test showed that the results generated by the PMG method are to be preferred to those obtained by the other two estimation methods.

The results show that telecommunications investment has a positive and significant impact on long-term economic growth in the WAEMU. The results also show that the combined diffusion of mobile phones and the Internet among populations in the WAEMU positively and significantly affects long-term economic growth in the Union. In view of these results, this research calls on WAEMU countries to provide greater support for investments in telecommunications and the spread of ICTs use among populations in order to accelerate economic growth in the WAEMU.

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