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Impact of Information and Communication Technologies Penetration on Human Development: Evidence from Economic Community of West African States

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Human development is a significant component of economic growth and development. Therefore, determinants of human development are crucial to designing and implementing the optimal policies to boost economic growth and development. This study investigates the impact of ICT penetration on human development in the Economic Community of West African States for the period of 2000–2018 through bootstrap cointegration and causality tests. The causality analysis disclosed a unilateral causality from internet usage to human development in Benin, Cote d'Ivoire, Nigeria, Senegal, and Sierra Leone and a one-way causality from mobile cellular subscriptions to human development in Côte d'Ivoire, Liberia, Niger, and Togo, but there existed a significant causality from human development to mobile cellular subscriptions in Benin, Cabo Verde, Gambia, and Ghana. On the other side, the cointegration analysis revealed a positive effect of internet usage and mobile cellular subscriptions on human development in the long run.

Keywords: *Human Development; ICT; ICT Penetration; Bootstrap Cointegration Test; Bootstrap Causality Test.*

Introduction

The concept of human development and its components have long been discussed among scholars and policymakers. According to the United Nations Development Programme (UNDP), human development is the process of enlarging people's choices, expanding their freedom, and leading them to pursue their personal development based on a set of diverse values (UNDP, 2020). Similarly, Sen (1999) defines human development as the process of enhancing and improving the living standards of the human through widening education opportunities and health care systems as well as expanding other conditions that would contribute to human life. However, the human development concept is not a static phenomenon that can only be limited to physical factors. In addition, freedom and human rights have also been considered significant factors of human development (Yakunina & Bychkov, 2015).

The human development concept is generating considerable interest in terms of tracking improvements in basic elements of human development. This enables us to evaluate whether developments in technology, education, and health lead to a better life and offer greater opportunities for people. This may well be measured by the Human Development Index (hereafter, HDI), which is an index aiming to assess the quality of life and measure the progress of human development based on some criteria. In this sense, the HDI points out three basic composite factors of human development, namely health, education, and the standard of living. These factors are generally proxied by life expectancy, literacy or school enrolment, and GDP per capita in some studies (see Bankole, Shirazi, & Brown, 2011; Ejemeyovwi, Osabuohien, & Osabohien 2018; Gupta, Jain, & Nagpal, 2019; Orji, Ogbuabor, Orji, Okoro, & Osondu, 2020), respectively.

Considering the effect of human development on both economic growth and development, the capability of human beings has come to the spotlight among economists. The capability approach of Sen considers opportunities created for people in addition to physical factors such as health, education, and income, and ascertains to what extent they determine the level of welfare (Ranis, 2004) (see Sen (1984) for a comprehensive discussion). Yet it is well suited to the approach of Yakunina & Bychkov (2015) as they use human capital as a proxy for human development since accumulated investment in knowledge is expected to increase the quality of life. This is the point where investment in human capital increases capability and causes economic growth and development. As increased capability represents a qualified labor force, it eventually increases economic growth, which in turn leads the resources to be reused for a sustained environment for human development (Ranis *et al.*, 2000). This two-way connection between human development and economic growth can be analyzed in a way in which they feed each other.

However, human development does not appear to follow the same path in every country. Institutional, economic, and social factors are expected to take human development to different levels, which in turn causes different levels of economic development. In general, therefore, it seems that there has been an asymmetric relationship between human development and economic growth across countries. Another key factor explaining the differences among nations may be the use of technology. The rapid development of Information and Communication Technologies (hereafter, ICT) has increased economic productivity and contributed to human development in various ways. That is to say, the extensive use of technologies in health, security, and education has substantially increased the quality of human life and led to further developments. However, the extent to which ICT would contribute to economic growth and human development will be determined by the intensity of ICT use by countries.

ICT is composed of technological tools and resources that would help disseminate information, enable people to educate themselves, offer equal opportunities, and raise the quality of life at the end. These are computers, mobile phones, broadcasting services, and the internet (Tinio, 2003). Therefore, ICTs are roughly proxied by internet penetration, technological readiness, and telephone penetration rate.

ICT, among others, may well explain the progress of human development due to its high level of penetration and major role in the knowledge economy (Asongu & Le Roux, 2017). Investment in ICTs might well be the key to equalizing opportunities for education (Gholami, Higon, Hanafizadeh, & Emrouznejad, 2010). The use of ICT, therefore, would give opportunities to underserved regions to develop their human and social capital through providing necessary resources (Assar, El Amrani, & Watson, 2010). Against this backdrop, it is possible to say that higher ICT penetration does affect human development via higher access to technological tools that would enable people to sustain their development based on their choices and values.

Despite the complex relationship between the use of ICT and human development, advancements in ICT are expected to positively affect human capital. Romer (1990) states that investments in human capital led to technological development, which is in line with new growth models. In this way, it is possible to construct a two-way relationship between human capital and technological development. However, as discussed above, the effects of ICTs on human development are heterogeneous among countries due to differences in the level of development (Bankole *et al.*, 2011; Azuh, Ejemeyovwi, Adiat, & Ayanda, 2020).

In this study, therefore, we specifically investigated the impact of ICT penetration on human development in selected Economic Community of West African States (ECOWAS) using bootstrap cointegration and causality tests for the period of 2000–2018. The rationale behind the selection of ECOWAS is twofold: First, West African states have been considered most disadvantageous in respect to their investment in research and development (hereafter, R&D) and the HDI ranking. We, therefore, aim at understanding how and in what way ECOWAS nations can improve their technology penetration and human development to catch the world average. Secondly, most African states have not reached yet their saturation levels in the penetration of ICT, revealing the historical misfortune of being underdeveloped for those countries and showing that there is still a potential to increase their absorptive capacity and overall composite factors corresponding to the human development index.

Specifically, according to the World Bank database, the world average rate of individuals using the internet (% of the population) is 6.7 in 2000 while it is 49.9 in 2018. However, the average of ECOWAS is 0.36 and 27.3 (% of the population) for the period between 2000 and 2018, respectively. Similarly, the world average on mobile cellular subscriptions (per 100 people) is 12 in 2000 and 106.48 in 2018, while the average of ECOWAS is 1 and 90.7 (per 100 people), respectively (World Bank, 2021). Although ECOWAS nations have made huge progress in ICT penetration, the member countries of the community are still below the world average.

This study extends the methodological aspect of the problem and aims to analyze the impact of ICT penetration on ECOWAS nations' human development by additionally considering the gap between ECOWAS members in the use of ICT. The contributions of this study are twofold: Firstly, this study has been crystallizing the factors causing selected ECOWAS members to benefit differently from ICT penetration and offering solutions to handle the problem of the digital divide in the region. Second, this paper uses bootstrap cointegration and causality tests, enabling us to understand the impact of ICT on the human development of ECOWAS nations, consisting of 14 member countries with similar historical, economic, and social characteristics but different levels of ICT use without an additional test for heterogeneity and cross-section dependency.

The rest of the study is organized as follows: Section 2 reviews both empirical and theoretical literature, Section 3 defines the data set and econometric methodology, Section 4 focuses on empirical analyses and results and Section 5 concludes.

Literature Review

Though the concept of human development was first defined 30 years ago, it is subject to changes as the concept is dynamic and human-related. For instance, economic growth has been considered the most important element of human development. Yet, health and education started to be the main components of human development in addition to economic factors as the spread of information and technological progress have changed economic, social, and cultural interrelationships (Iqbal, Hassan, & Peng, 2019).

A glance at the extant literature displays the fact that the evolving structure of human development is the key to understanding the role of tools developed under ICT, which are reused to further improve the living conditions of human being. A two-way relationship between ICT and human development has long been discussed among academics and received remarkable attention in the literature, especially concerning the development of human conditions ranging from health and education to the adaptation and use of technological devices.

To explain the nature of a two-way relationship, some studies in the literature investigating the problem from different angles can be exemplified. For instance, Ferrer (2009) substantiates advancements in ICT would be expected to have a positive impact on human development due to higher quality of public services, higher education standards, higher potential through creating further technological developments, and providing a better and sound environment for health care reforms. These would eventually promote innovation by increasing information and lead to economic growth, which is supposed to be the main ingredient of human development. On the other hand, economic growth and development may also promote ICT implementation by generating additional sources for the development of ICT, enabling firms to benefit from more productive technological equipment (Pilat, 2003).

The academic literature on the role of ICT penetration has revealed the emergence of several contrasting themes. For instance, some studies (Tinio, 2003; Bankole et al., 2011) analyze a one-way relationship, whereas some others (Asongu & Le Roux, 2017; Ejemeyovwi *et al.,* 2018; Gupta, Jain, & Nagpal, 2019) investigate a two-way relationship between ICTs and human development. Despite different methods and approaches that have been taken, the empirical literature has shown that ICTs and their repercussions have a positive and geometric effect on human development. Significant analysis and discussion on the subject were presented by Asongu and Le Roux (2017). The authors have comprehensively investigated the effect of ICT for creating inclusive human development in 49 Sub-Saharan African countries using panel data analysis for the period 2000–2012. They use the telephone, the mobile phone, and the internet penetration rates (per 100 people) as a proxy for ICT. In addition, the Inequality-adjusted human development index has been taken as the main indicator of the HDI. The authors have pointed to the importance of investments and improvements in ICT, which are expected to make human development more inclusive.

However, Avgerou (2003) discusses the existence of an inverse relationship between ICT implementation and its contribution to development through supposedly higher economic growth. The author's seminal approach critically investigates the "tool-and-effect" mechanism, which is mainly thought to be working as technological advancements lead to human development. In contrast, the author well substantiates that this does not necessarily have to be functioning in this way. In effect, the author proposes that technological advancements and ICT penetration might well be the result of economic development at the same time. Parallel to this, to examine the existence of a causal relationship in both short- and long-term for Korea in a quarterly period between 1999 and 2016, Sawng, Kim, and Park (2021) used the vector error correction model (VECM) and found that the scale of investment in ICT enlarges as the economy grows, which, in turn, leads to higher investment in the ICT sector in the long-run. This mechanism through which ICT and economic growth bi-laterally affect each other works in a self-referential way and is called the "virtuous circle", as discussed by Avgerou (2003).

In general, therefore, it seems that there is a positive correlation between ICT penetration and economic growth. However, the extent to which ICT investment is associated with human development through higher economic growth, better healthcare systems, and higher education level depends mainly on the countries' stage of development. Spiezia (2013) takes a critical look at the phenomena from a productivity point of view and shows that there is no correlation between ICT investments and productivity due to the miscalculation of ICT. An alternative approach attempting to explain the failure of the usage of ICT in enhancing human development might be explained by idiosyncratic factors of countries. Jayaprakash and Pillai (2021) undertake social structures and cultural dimensions to explain the complex relationship between ICT usage and human development in 80 countries over the period from 2000 to 2016 through random-effects model. According to the findings, ICT use is shown as positively and significantly effective for human development for African and Arab nations, whereas it negatively affects human development for the Asia Pacific region.

Nevertheless, some points preoccupying the previous studies should also be noted. As countries' stages of development determine the extent to which ICT use is associated with human development, the existence of some factors providing easy access to the use of digital technologies may also lead to remarkable differences across countries. A comparative study by Simsek (2006) discusses the necessity of technological literacy, rather than traditional literacy, for digital access to be beneficial for all citizens in countries where a large amount of technological investment is made. He also proposes that digital access varies across countries due to differences in development levels. In a follow-up study, Alampay (2006) defines ICTs as tools, enabling people to reach information easily and providing an environment where the digital gap may be rapidly closed. The approach of Alampay (2006) suggests that ICT may be used as a tool to achieve desired ends regarding human development through the increasing capability of people, as parallel to the capability approach of Sen (1984).

Adopting the t-test and chi-square test to investigate whether there is a digital divide between developed and developing countries for the ten years from 2000 to 2010 for 135 countries, Pratama and Al-Shaikh (2012) specifically investigated the effect of internet penetration rate (internet users per 100 inhabitants) on the human development level, which is proxied by the HDI. The authors reported that a higher internet penetration rate is highly significantly correlated with human development level. In addition, their findings show that the internet penetration rate in developed countries is faster than those of developing countries, proving the existence of a digital divide across countries. Interestingly, however, in their comprehensive study pointing to Sen's capability approach and considering the separate use of ICT by governments, individuals, and businesses, De la Hoz-Rosales, Ballesta, Tamayo-Torres, and Buelvas-Ferreira (2019) demonstrate the presence of a direct relationship between ICT use and human development regardless of countries' stage of development, suggesting that ICT improves the lives of people through increasing their capabilities and possibilities.

With these observations, the relationship between human development and ICT has been investigated for different regions. For instance, Gupta, Jain, and Nagpal (2019) has conducted empirical research on the relationship between human development and ICT for five South Asian countries using a panel fixed effects model for the period 2000-2016. Technological readiness, mobile phone subscriptions, and the internet penetration rate are the main proxies for ICT while the HDI is used for the measurement of human development. They conclude that ICT penetration positively and significantly affects the HDI and its components (school enrolment, life expectancy, and a decent standard of living). Conversely, Ejemeyovwi et al. (2018) have conducted research using the generalized method of moments (GMM) for ECOWAS between 2004 and 2014 and found ICT investments to be statistically insignificant for human development due to the lack of a stable political and economic environment.

Like Ejemeyovwi et al. (2018), Azuh et al. (2020) have conducted similar research but taken a different approach. In their study, the relationship between innovation and human development has been well analyzed for 15 West African countries for the period 2004–2014. The authors deploy fixed and random effect estimation techniques, in addition to the Hausman specification test, and use the same set of data such as primary school enrolment, credit provided by financial institutions, economic growth, and technology adoption which is proxied by the number of internet users. They come to different conclusions on the positive effect of innovation on human development for the related African countries. The findings of Azuh et al. (2020) may show that West African countries have still the potential to improve their abilities by investing more in R&D.

Considering the role of investment in ICT, Alimi and Adediran (2020) well discuss the extent to which investments in ICT are associated with financial development and contribute to economic growth in the short and long run by using both pooled mean group (PMG) and dynamic fixed-effect model (DFE) for 13 ECOWAS nations over the period from 2005 to 2016. The findings show a negative significant effect of ICT on economic growth in the long run, whereas there is no effect in the short run, which seems contrary to conventional theory. The authors, however, propose further that ICT association with financial development would lead to economic growth. Similarly, Veiga, Vaz, Monteiro, and Almeida (2018) highlight the significance of investments in internet penetration as they contribute to ICT development and promote integration among ECOWAS nations.

A broader perspective on the role of ICT in human development has been adopted by Bankole et al. (2011). The authors performed panel data analyses using a three-stage least squares method for 51 countries, which are divided into three groups according to their level of development, for the period 1994–2003. They concluded that the impact of ICT varies across countries and is rather mixed on health in middle-income countries compared to low-income countries (see also, Lee, Hong, & Hwang, 2017). An overlapping study by Karaman Aksentijevic, Jezic, and Zaninovic (2021) analyzes whether the effects of ICT use on human development vary for 130 countries, which are divided by four income groups according to the World Bank classification of 2020, over the period from 2007 to 2019. In the study using the generalized method of moments (GMM) of dynamic panel data regression, findings show that ICT use positively significantly affects low-income countries, while it affects insignificantly high-income countries.

Some authors have mainly been interested in questions concerning the direct relationship between ICT and human development. For instance, ICT use in education is expected to positively affect human capital through higher productivity and ability. In this light, the study of Tinio (2003) suggests that ICT use in education helps provide an environment that would increase effectiveness, provide opportunities for equity and promote sustainability. In the same vein, Assar et al. (2010) point out some constraints (budget constraints, the scarcity of available material and human resources) that underdeveloped countries may face in delivering educational services. The authors claim that ICT use in education would enable disadvantaged and underserved regions to reach educational resources. Contrary to previously published studies, however, Baliamoune-Lutz (2003) has analyzed the effect of ICT diffusion for 47 developing countries using a cross-sectional model and come to a different conclusion. The author displays that there is no statistically significant relationship between ICT penetration and education level (for more, see Schware & Jaramillo, 1998).

Most of the studies reviewed here analyze the relationship between ICT penetration and human development from different aspects. Although the engaged literature is not unanimous related to the effects of ICT on human development, many studies show that there is a positive correlation between ICT investment and development (Ngwenyama *et al.*, 2006; Di Carlo & Santarelli, 2010). However, the magnitude of the effect of ICT may vary across countries due to differences in the level of development. In addition, some other country-specific factors may even play a significant role in assessing to what extent ICT investments would yield, as stated well by Gomez and Pather (2012). In this sense, this study aims to contribute to the extant literature by analyzing the impact of ICT penetration on human development with evidence from ECOWAS. The next section defines the data and econometric methodology used in the present study.

Data and Econometric Methodology

The influence of ICT penetration on the human development in 14 ECOWAS members during the 2000–2018 period is analyzed by bootstrap cointegration and causality tests. The period is dictated by two factors: Firstly, ECOWAS nations have primarily witnessed ICT diffusion at the beginning of 2000 (Alimi & Adediran, 2020). Second, the period is over by 2018 due to the scarce availability of data for each member country.

In this study, as the dependent variable, we use human development, which is proxied by the human development index of UNDP (2020). On the other hand, mobile cellular subscriptions (per 100 people) and individuals using the internet (% of the population) are used as the explanatory variables representing ICT penetration and taken from the database of World Bank (2021a&2021b). Furthermore, the study sample consists of 14 ECOWAS countries (Benin, Burkina Faso, Cabo Verde, Cote D'ivoire, Gambia, Ghana, Guinea, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo) except Guinea Bissau, because human development index of Guinea Bissau is available as of 2005.

The rationale behind using these three variables in our attempt to investigate the impact of ICT on human development is manyfold: Firstly, the human development index (HDI) is mainly used in the literature as a proxy for human development as it comprehensively covers the main elements of human development such as health, education, and income. Rather than focusing on a specific element, HDI offers a more inclusive approach (Asongu & Le Roux, 2017) and provides a better environment for the assessment of performance development on a country basis (UNDP, 2019). Second, according to the International Telecommunication Union (Bogdan-Martin, 2020, p. 44), mobile cellular is the primary service of telephony around the world and has been reaching higher levels. In ECOWAS nations, however, mobile cellular subscription is approximately 70 (per 100 people), whereas it is about 100 (per 100 people) in developing and 130 (per 100 people) in developed countries (Bogdan-Martin, 2021), putting ECOWAS well below the world average of 100 (per 100 people) as well. So, it seems that ECOWAS nations have not reached their saturation levels yet, enabling us to analyze to what extent ICT penetration may associate with human development in the region.

Finally, internet usage (% of the population) is one of the most important telecommunications that quickly transmit information between people at a lower cost. Indeed, a higher rate of internet usage provides the grounds for a better environment where people might benefit more from education and health and can generate more income through higher capabilities. On the other side, internet penetration is the key to explaining the technological gap between developed and developing countries (Archibugi & Coco, 2004). Moreover, in what way low internet penetration level leads to little integration among ECOWAS countries has been well investigated by Veiga et al. (2018). So, internet usage differs significantly among countries, which distinguishes them from each other in terms of economic and social development. Considering low internet penetration rates, it seems that there is room for ECOWAS countries to improve the capacity, thus allowing us to analyze the progress.

The variables are defined in Table 1 and all series were annual, and as previously stated, the presence of the related data directed us to specify the study period as 2000-2018.

Table 1

Data Definition

Variables	**Description**	**Source**
HDI	Human development index	UNDP (2021)
INTERNET	Individuals using the internet (% of the population)	World Bank (2021a)
MOBILE	Mobile cellular subscriptions (per 100 people)	World Bank (2021b)

Source: Authors' calculations

The summary statistics corresponding to those data are reported in Table 2. The mean of HDI is 0.4397 and is relatively stable among the countries. However, the average of internet usage and mobile cellular subscriptions are respectively 6.9651 % of the total population and 43.4925 per 100 people, but both ICT indicators exhibit considerable changes among the analysed economies

Table 2

Summary Statistics

Variables	**Mean**	**Std. Deviation**	**Minimum**	**Maximum**
HDI	0.4397	0.0821	0.253	0.647
INTERNET	6.9651	10.1843	0.0177	57.1621
MOBILE	43.4925	39.4110	0.0181	138.8051

Source: Authors' calculations

In this study, we use the bootstrap cointegration test developed by Westerlund and Edgerton (2007) to analyze whether cointegration between variables exists. This method is well designed for small samples and considers cross-section dependency between variables. The null hypothesis of cointegration is tested against the alternative of no cointegration in this method. To test this hypothesis, the following equation can be used:

$$LM_N^+ = \frac{1}{NT^2}\sum_{i=1}^{N}\sum_{t=1}^{T}\widehat{\vartheta_i^{-2}}_i S_{it}^2 \quad (1)$$

As Equation (1) is derived from the Lagrange multiplier of McCoskey and Kao (1998), S_{it} represents the partial sum of the estimated Z_{it}, whereas ϑ_i^{-2} shows the long-run variance of u_{it} on $\Delta_{x_{it}}$. However, z_{it} *and* x_{it} are defined in the following equations:

Letting a scalar variate to be:

$$y_{it} = \alpha_{it} + x'_{it}\emptyset_i + z_{it} \quad (2)$$

where t denotes the time and i cross sectional units. In addition, z_{it} is assumed to be represented as follows:

$$z_{it} = u_{it} + v_{it} \; while \; v_{it} = \sum_{j=1}^{t}\gamma_{it} \quad (3)$$

where γ_{it} is assumed to be independent and identically distributed process with zero mean and variance. That is, $var(\gamma_{it}) = \sigma_i^2$.

To analyze the causal relationship between ICT and the HDI, the bootstrap Granger causality test developed by Konya (2006) has been deployed. The advantages of this method are twofold: First, this method takes heterogeneity and cross-section dependency into consideration. Second, no additional test is stipulated to determine the stationarity of variables (Konya, 2006: 991). With these qualifications, this method may deliver more accurate results compared to other methods in literature. However, before implementing the causality test, cross-sectional dependence and slope homogeneity should be tested. To do this, cross-sectional dependency was tested with Breusch and Pagan's (1980) LM test, Pesaran (2004) LM CD test, and Pesaran, Ullah, and Yamagata (2008) LM adj. tests, whereas delta and adjusted delta tilde test of Pesaran and Yamagata (2008) were applied for slope homogeneity. For cross-sectional dependency:

$$\mathrm{LM} = \sum_{i=1}^{N-1}\sum_{j=i+1}^{N} T_{ij}\ \hat{p}_{ij}^2 \tag{4}$$

In equation (4), N represents cross-section dependency dimension, T shows time dimension, and $\hat{p}$ shows the coefficient of binary correlation obtained by least squares method. This method would be appropriate if T>N. However, there are two alternative methods developed by Pesaran (2004) CD_{lm} and Pesaran, Ullah and Yamagata (2008) $LM_{adj.}$ tests. The equations would be written as follows:

$$\sqrt{\left(\frac{1}{N(N-1)}\right)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T_{ij}\ \hat{p}_{ij}^2 - 1\right) \tag{5}$$

$$\sqrt{\left(\frac{2}{N(N-1)}\right)}\ \sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{p}_{ij}^2\ \frac{(T-k)\ \hat{p}_{ij}^2-\mu_{Tij}}{\sqrt{v_{Tij}^2}} \tag{6}$$

Eq (5) represents CD_{lm}test, whereas Eq (6) shows LM_{adj} test statistics. In addition to cross-sectional dependency, we should also implement slope homogeneity delta and adjusted delta tilde tests developed by Pesaran and Yamagata (2008). This would enable us to check the cross-country heterogeneity. The equation for this test would be as follows:

$$\Delta = \sqrt{N}\left(\frac{N^{-1}\hat{s}\delta}{\sqrt{2\delta}}\right) \tag{7}$$

$$\Delta_{adj} = \sqrt{N}\left(\frac{N^{-1}\ \hat{S}-E(Z_{iT})}{\sqrt{var}(Z_{iT})}\right) \tag{8}$$

where $E(Z_{iT}) = \delta, var(Z_{iT}) = \frac{2\delta(T-\delta-1)}{T+1}$.

Additionally, Eq. (8) is proposed for small samples and includes the adjusted mean and variance version of Eq. (7). Now, it is appropriate to write down bootstrap causality test equations. As previously stated, this method is developed by Konya (2006) and uses Seemingly Unrelated Regression (SUR) and Wald methods in analyzing the causality between variables. In addition, this method does not stipulate unit root and cointegration. A bootstrap causality model with $three$ variables could be written as follows:

$$\begin{aligned} y_{1,t} &= \alpha_{1,1} + \sum_{l=1}^{mly_1}\beta_{1,1,l}\, y_{1,t-1} + \sum_{l=1}^{mlx_1}\theta_{1,1,l}\, x_{1,t-1} + \varepsilon_{1,1,t} \\ y_{2,t} &= \alpha_{1,2} + \sum_{l=1}^{mly_1}\beta_{1,2,l}\, y_{2,t-1} + \sum_{l=1}^{mlx_1}\theta_{1,2,l}\, x_{2,t-1} + \varepsilon_{1,2,t} \\ &\vdots \\ y_{N,t} &= \alpha_{1,N} + \sum_{l=1}^{mly_1}\beta_{1,N,l}\, y_{N,t-1} + \sum_{l=1}^{mlx_1}\theta_{1,N,l}\, x_{N,t-1} + \varepsilon_{1,N,t} \end{aligned} \tag{9}$$

$$\begin{aligned} x_{1,t} &= \alpha_{2,1} + \sum_{l=1}^{mly_2}\beta_{2,1,l}\, y_{1,t-1} + \sum_{l=1}^{mlx_2}\theta_{2,1,l}\, x_{1,t-1} + \varepsilon_{2,1,t} \\ x_{2,t} &= \alpha_{2,2} + \sum_{l=1}^{mly_2}\beta_{2,2,l}\, y_{2,t-1} + \sum_{l=1}^{mlx_2}\theta_{2,2,l}\, x_{2,t-1} + \varepsilon_{2,2,t} \\ &\vdots \\ x_{N,t} &= \alpha_{2,N} + \sum_{l=1}^{mly_2}\beta_{2,N,l}\, y_{N,t-1} + \sum_{l=1}^{mlx_2}\theta_{2,N,l}\, x_{N,t-1} + \varepsilon_{2,N,t} \end{aligned} \tag{10}$$

$$\begin{aligned} z_{1,t} &= \alpha_{3,1} + \sum_{l=1}^{mly_3}\beta_{3,1,l}\, y_{1,t-1} + \sum_{l=1}^{mlx_3}\theta_{3,1,l}\, x_{1,t-1} + \varepsilon_{3,1,t} \\ z_{2,t} &= \alpha_{3,2} + \sum_{l=1}^{mly_3}\beta_{3,2,l}\, y_{2,t-1} + \sum_{l=1}^{mlx_3}\theta_{3,2,l}\, x_{2,t-1} + \varepsilon_{3,2,t} \\ &\vdots \\ z_{N,t} &= \alpha_{3,N} + \sum_{l=1}^{mly_3}\beta_{3,N,l}\, y_{N,t-1} + \sum_{l=1}^{mlx_3}\theta_{3,N,l}\, x_{N,t-1} + \varepsilon_{3,N,t} \end{aligned} \tag{11}$$

In the three equations above, it is shown how to construct Konya's (2006) Bootstrap Granger causality with three variables. N represents the number of countries, whereas t shows the time.

Empirical Analysis

In the empirical analysis section of the research, we first test cross-sectional dependency with Breusch and Pagan's (1980) LM test, Pesaran (2004) LM CD test, and Pesaran, Ullah, and Yamagata (2008) LM adj. test and report test results in Table 3. After the cross-sectional dependency tests, we reject the null hypothesis of cross-sectional independence at 1% significance level and prove the presence of cross-sectional dependency among the series.

Table 3

Cross-Sectional Dependence Tests

Test	Test statistic	P-value
LM	504.5	0.000
LM adj.*	62.78	0.000
LM CD*	17.25	0.000

**two-sided test*

The homogeneity of cointegration slope coefficients is tested with the adjusted delta tilde test of Pesaran and Yamagata (2008) and test results are presented in Table 4. The null hypothesis of homogeneity presence is rejected at 1 % significance level, showing that the cointegration slope coefficients are heterogeneous.

Table 4

Homogeneity Tests

Tests	Test statistic	P-value
$\tilde{\Delta}$	13.474	0.000
$\tilde{\Delta}_{adj.}$	15.279	0.000

Source: Authors' calculations

In order to see the integration levels of three variables, we use Pesaran's (2007) CIPS (Cross-sectionally augmented IPS (Im- Pesaran-Shin (2003)) unit root test and report the test results in Table 5. It seems that all series are integrated of order one (I(1)).

Table 5

CIPS Panel Unit Root Test Results

Variables	Constant	Constant + Trend
HDI	-2.117	-2.208
D(HDI)	-3.709***	-4.062***
INTERNET	-1.607	-1.901
D(INTERNET)	-2.456**	-2.882**
MOBILE	-1.253	-1.748
D(MOBILE)	-2.811**	3.061***

Optimum lag length is specified as 1 following Akaike, Schwarz, and Hannan-Quinn information criteria.
**** Significant at the 1 % level. ** Significant at the 5 % level*

The long-run impact of ICT penetration indicators on human development has been explored through Westerlund and Edgerton's (2007) bootstrap cointegration test and results have been reported in Table 6. Moreover, we have obtained the asymptotic probability values via standard normal distribution, and the bootstrap probability values have been generated from 10000 simulations. The existence of cross-sectional dependency among the series dictated us to regard the bootstrap critical values for the evaluation of cointegration relationship. The null hypothesis in favor of cointegration relationship's presence has been accepted

Table 6

LM Boostrap Cointegration Test Results

	Constant			Constant+Trend		
	Test statistic	Asymptotic p-value	Bootstrap p-value	Test statistic	Asymptotic p-value	Bootstrap p-value
LM_N^+	1.740	0.041	0.895	4.445	0.900	0.000

Source: Authors' calculations

After analyzing the cointegration relationship, we estimate cointegration coefficients via panel AMG (Augmented Mean Group) estimator of Eberhardt and Teal (2010) and present the results in Table 7. The panel cointegration coefficients reveal that both internet usage and mobile cellular subscriptions of ICT penetration indicators have a significant positive impact on human development. Furthermore, the cross-section coefficients disclose that internet usage positively affected human development in all countries. On the other side, mobile cellular subscriptions have a statistically significant impact on human development in all countries except Guinea and Sierra Leone.

Table 7

Cointegration Coefficients' Estimation Test Results

Countries	Coefficients	
	INTERNET	MOBILE
Benin	0.0257***	0.0184***
Burkina Faso	0.0139**	0.0115**
Cabo Verde	0.0472***	0.0288***
Côte d'Ivoire	0.0263**	0.0129**
Gambia	0.0428**	0.0315**
Ghana	0.0350**	0.0216**
Guinea	0.0142**	0.0108
Liberia	0.0305**	0.0276**
Mali	0.0168***	0.0104***
Niger	0.0034**	0.0015**
Nigeria	0.0366***	0.0241***
Senegal	0.0418**	0.0377**
Sierra Leone	0.0051**	0.0009

Countries	Coefficients	
	INTERNET	MOBILE
Togo	0.0482**	0.0296**
Panel	0.0371***	0.0274***

**** Significant at the 5 % level. ** Significant at the 10 % level.*

The findings of cointegration estimation should be interpreted carefully. Although estimated coefficients seem to be relatively small, they are statistically significant and in line with the extant literature. These results reflect those of Asongu and Le Roux (2017) who also found that policies encouraging ICT penetration and investing in its components such as mobile phone penetration rate and internet penetration rate (both per 100 people) have a significant positive impact on human development. However, the authors point out that coefficients generated through their estimation were relatively small and did not reflect the tool-and-effect nexus between ICT penetration and human development due to the lack of integration between ICT components and some macroeconomic and institutional factors in Sub-Saharan Africa.

There are similarities between the findings indicated by Asongu and Le Roux (2017) and those displayed by Azuh, et al. (2020) in terms of obtaining relatively small coefficients corresponding to estimated results. According to the authors, a 1% increase in R&D does have a significant positive but not have a proportionate effect on human development due to a few structural and institutional factors, namely, unbalanced distribution of income, little investment in R&D, lack of infrastructure in health and education, and emigration, all of which have a detrimental effect on human development in terms of having the substantial effect of ICT development in analysed countries.

As can be seen, the existence of some factors in ECOWAS countries plays a substantial role in determining to what extent ICT penetration would associate with human development. A large amount of investment in R&D may not be properly used due to unproductive labour, thus yielding the undesired impact on human development. This may simply demonstrate the presence of the dynamic causal relationship between ICT penetration and human development, which has been discussed extensively in the previous chapters. In the study of Iqbal, Hassan, and Peng (2019) for the case of five South Asian countries, for instance, the effect of internet usage on human development is negative, showing that people are unable to use technology in favour of themselves just because they do not know how to benefit from it. It is also noteworthy that the lack of technology literacy, causing innovation and technological developments to have little impact on human development, may also originate from not having access to the internet, putting ECOWAS below the world average in internet usage (Veiga *et al.*, 2018).

It may seem that these results underestimate the true prevalence of ICT penetration in human development. However, some idiosyncratic social and institutional factors of ECOWAS demonstrate that the causal relationship between ICT penetration and human development is not straight. For instance, Ejemeyovwi, Osabuohien, and Osabohien (2018) propose a framework of factors explaining the link between ICT investments and human capital development in ECOWAS. The authors could not even find a positive effect of investments in telecommunications on human capital development because there was not enough investment in human capital that would enable people to benefit more from higher technology. More importantly, the presence of corruption and misdirection of funds decrease the efficacy of any attempt aimed at improving the standards of technology and human capital.

The mutual causality between human development and ICT penetration indicators was explored through Konya's (2006) bootstrap Granger causality test and test consequences were reported in Tables 8 and 9. The results revealed a one-way causality from internet usage to human development in Benin, Côte d'Ivoire, Nigeria, Senegal, and Sierra Leone and a one-way causality from mobile cellular subscriptions to human development in Côte d'Ivoire, Liberia, Niger, and Togo. However, a significant causality from human development to mobile cellular subscriptions existed in Benin, Cabo Verde, Gambia, and Ghana.

Table 8

Causality Analysis between Internet Usage and Human Development

Countries	H_0: INTERNET is not the Cause of HDI				H_0: HDI is not the Cause of INTERNET			
	Wald St.	Bootstrap Critic Value			Wald St.	Bootstrap Critic Value		
		1 %	5 %	10 %		1 %	5 %	10 %
Benin	**890.597*****	**356.949**	**92.988**	**50.972**	23.534	762.904	376.677	282.364
Burkina Faso	36.165	345.835	101.890	59.893	14.106	453.103	266.089	189.186
Cabo Verde	0.450	867.449	306.296	173.456	38.029	529.736	238.137	144.666
Côte d'Ivoire	**163.454***	**644.859**	**309.352**	**162.047**	5.040	1239.483	642.270	448.691
Gambia	240.527	2089.181	735.309	394.043	0.026	749.352	258.768	152.857
Ghana	219.792	1226.758	535.058	327.035	6.401	190.643	88.095	62.488
Guinea	11.240	607.594	318.381	195.132	7.232	400.086	177.013	120.296
Liberia	58.957	1113.169	385.503	218.038	5.581	551.837	241.124	168.216
Mali	9.724	255.835	97.647	71.075	0.216	147.905	72.740	46.906
Niger	0.226	338.270	72.771	43.293	18.343	347.233	168.897	125.433
Nigeria	**65.586***	**163.280**	**92.279**	**59.507**	18.291	164.273	47.246	28.113
Senegal	**99.770****	**190.442**	**69.541**	**41.278**	10.039	247.288	138.380	96.959

Countries	H_0: INTERNET is not the Cause of HDI				H_0: HDI is not the Cause of INTERNET			
	Wald St.	Bootstrap Critic Value			Wald St.	Bootstrap Critic Value		
		1 %	5 %	10 %		1 %	5 %	10 %
Sierra Leone	**7.026***	**29.739**	**14.667**	**7.003**	8.666	80.708	41.720	31.667
Togo	4.874	293.116	119.773	83.153	15.909	238.560	94.498	63.351

Source: Authors' calculations

Table 9

Causality Analysis between Mobile Cellular Subscriptions and Human Development

Countries	H_0: MOBILE is not the Cause of HDI				H_0: HDI is not the Cause of MOBILE			
	Wald St.	Bootstrap Critic Value			Wald St.	Bootstrap Critic Value		
		1 %	5 %	10 %		1 %	5 %	10 %
Benin	24.342	168.488	90.530	57.658	**36.890***	**115.407**	**55.005**	**32.815**
Burkina Faso	52.358	807.751	304.910	208.082	0.733	180.537	83.112	59.454
Cabo Verde	0.071	2554.611	990.744	504.536	**579.336***	**2264.125**	**838.824**	**575.038**
Côte d'Ivoire	**7.822***	**23.394**	**9.853**	**7.292**	0.233	85.969	34.666	20.741
Gambia	1.683	274.036	119.495	81.835	**432.524*****	**292.530**	**152.560**	**106.716**
Ghana	151.377	578.517	276.644	187.666	**61.372****	**81.058**	**27.387**	**19.520**
Guinea	40.351	786.407	305.492	209.421	21.804	881.159	260.473	174.607
Liberia	**105.456*****	**83.307**	**44.932**	**29.452**	5.629	152.358	75.473	48.486
Mali	68.052	902.794	447.570	323.675	31.547	2103.615	671.119	395.996
Niger	**78.662****	**154.474**	**63.265**	**43.424**	5.044	110.913	50.264	35.487
Nigeria	8.851	89.565	51.659	35.002	4.003	191.201	77.675	35.572
Senegal	23.919	179.635	75.425	48.347	0.508	245.867	68.526	38.370
Sierra Leone	25.874	807.963	286.348	184.678	46.086	464.683	198.881	124.576
Togo	**30.010****	**41.643**	**27.832**	**20.935**	0.088	38.611	13.546	9.345

Source: Authors' calculations

The table also shows how causality depends on countries' capacity in adapting themselves to ICT penetration. The capacity, to a great extent, is determined by the level of human development, which is a composite factor proxied by main elements determining the living standard of people like income, health, and education. A healthy and educated society with high income earnings is expected to have a greater absorptive capacity through the higher potential of using and understanding new developments in telecommunications. This well explains the one-way causality from human development to mobile cellular subscriptions. This finding broadly supports the work of previous studies in this area linking ICT penetration and human development. For instance, Elmawazini, Atallah, Nwankwo, and Dissou (2013) indicated that a minimum threshold level of human development is crucial for countries in absorbing technology diffusion that would increase their labor productivity. More specifically, Zhang (2019) examined the dynamic relationship between ICT, human development and economic growth for 29 Asian developing countries over the period from 1990 to 2016 and found human development essential for mobile phone usage while finding no evidence for internet usage. Those that have the one-way causality from human development to mobile cellular subscription may need more investment in the three key dimensions of human development: namely income, health, and education.

There is a likely cause explaining the differences in the direction of causality among analysed countries. Although ECOWAS nations almost have a similar level of human development, some countries in the region might be able to better adapt to technological developments compared to others. This might be justified by the fact that there is a deep rift among ECOWAS countries in terms of reaping the benefits of technology diffusion due to having an unequal infrastructure. For instance, in the study of Ejemeyovwi, Osabuohien, Johnson, and Bowale (2019), Nigeria has been reported as having 42.48 internet users (per 100 people), which is the highest level of usage in the region, whereas Niger is the latest country with 0.19 (per 100 people). This, however, supports previous empirical findings showing that there is a discrepancy in the use of ICT causing a digital divide among ECOWAS (Pratama & Al-Shaikh, 2012; Veiga *et al.*, 2018), which, in turn, causes lower economic development in the region through the network effect.

Conclusions

In this study, we investigated the impact of Information and Communication Technologies (ICT) penetration on human development for 14 ECOWAS countries by using bootstrap cointegration and causality tests for the period 2000–2018. In doing so, this paper aimed at extending previous analyses and analyzing the relationship between ICT penetration and human development in several important aspects. Firstly, we developed a two-way perspective regarding the impact of ICT penetration on human development since there is a longitudinal dynamic relationship among them. As ECOWAS nations have not reached their saturation levels in using and benefiting ICT developments, countries in the region have the potential to develop their infrastructure through increasing the living standard of people, investing more in human capital, and research and development. Secondly, we used bootstrap cointegration and causality tests, which deliver more accurate results for our research subject and sample size. Finally, we carried out separate analyses for each country in the region. That is, rather than a generalized way of analyzing, we attempted to explain the impact of ICT penetration for each analysed member of ECOWAS in a context-specific way.

The results of cointegration analysis demonstrate that ICT penetration has a positive and statistically significant impact on human development in selected countries. That is to say, the findings verify that ICT penetration improves the living standard of people by enabling them to follow up-to-date developments and using technological developments to increase education level and to enhance health services. Our findings are broadly in line with the previous studies conducted by Asongu and Le Roux (2017) and Azuh, et al. (2020), suggesting that there is a positive and statistically significant impact of ICT penetration on human development.

On the other hand, results indicate a one-way causality from internet usage to human development in Benin, Côte d'Ivoire, Nigeria, Senegal, and Sierra Leone, a one-way causality from mobile cellular subscription to human development in Côte d'Ivoire, Liberia, Niger, and Togo, and a one-way causality from human development to mobile cellular subscriptions in Benin, Cabo Verde, Gambia, and Ghana. It seems that although the analysed countries have a similar level of human development, the gap in technology use between countries causes different ICT tools to be effective. Moreover, the one-way causality from human development to mobile cellular subscription indicates that those countries should pay more attention to indicators that determine the level of human development to better benefit from ICT penetration.

It is important to note that, whatever the findings are, ICT penetration should be supported by institutional, political, and social factors to achieve the desired effect of technology diffusion. This is because even though ICT penetration is statistically significant and positively associated with human development, the estimated coefficients of variables reveal that the impact of ICT penetration on human development was rather small. Considering this, it can be inferred that not reaching the saturation level in using technological developments is a double-edged sword for analysed countries. Such a situation would offer these countries a chance to maneuver through enabling them to better exploit the benefits of investments and developments in technology. On the other side, it has been observed that technological developments in selected countries have a positive impact on human development, but not by much due to poorly rooted institutional, economic and social structure.

Policymakers need to understand that ICT development has a positive effect on modernizing societies and is helpful in improving the quality of life and consequently human development. This research highlights the crucial role that ICT can play in fostering human development. By understanding the patterns of transformations, policymakers can develop strategies to promote and sustain ICT projects and boost their outcomes. Especially in developing countries, there is an urgent need to develop a workforce with ICT expertise that is capable to respond to the increasing demands demand for ICT skills. A linkage between education and ICT policies promoted by governments must exist to facilitate the achieving of desired outcomes. Providing efficient education programs that can develop and improve ICT skills and competencies, providing financing mechanisms and supporting companies to train the labor force to develop ICT skills and developing and implementing policies and programs to support companies' digital transformation. Government expenditure policies can increase funds allocated to private and public companies to finance ICT infrastructure investments. Studies like this can help policymakers to understand that ICT can have a significant contribution to human development and can concentrate their efforts to develop ICT policy.

Academics can use this study to understand the crucial role of ICT in each society and to integrate ICTs into the teaching and learning process and also can further investigate the mechanisms through which ICT contributes to human development, especially in developing countries,

The present study is important in furthering our understanding of the asymmetric relationship between ICT penetration and human development. Prior to this study, little evidence existed to support the idea that the differences among member countries of ECOWAS, which are sharing similar economic, social and historical backgrounds may even lead to regional variations in technology use. It should be noted, therefore, that ICT penetration should be supported by a set of economic and institutional factors that would enhance the absorptive capacity of ECOWAS member countries. For this reason, further research, considering other control variables that would help better understand the causal relationship between ICT penetration and human development in ECOWAS countries is needed to be conducted.

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