# Digital health: ICT and health In Africa

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# DIGITAL HEALTH: ICT AND HEALTH IN AFRICA

***This study examines the relationship and causality between ICT and health in Africa for the period 1995-2015 using panel generalized method of moments (GMM) and Toda-Yamamoto causality tests. The empirical results show that ICT has a positive and statistically significant relationship with health, showing that the higher the levels of ICT, the higher the level of health. There is also a bi-directional causality between ICT and health. This indicates that ICT spurs health which, in turn, boosts ICT usage even further. Moreover, health expenditure has significant positive effects, suggesting that the higher the scale of health expenditure, the higher the level of health. Unemployment rate has significant negative effects, meaning that the higher the level of unemployment, the lower the level of health. The level of education, measured by adult literacy rate, has significant positive effects, depicting that the higher the level of education, the higher the level of health. On the contrary, environmental pollution, measured by carbon dioxide emissions per capita, has significant negative effects, indicating that the higher the level of environmental pollution, the lower the level of health.***

***Keywords:*** *Digital health; mobile penetration; Internet usage; ICT, Health, Health production function.*

***JEL classification: O13, O33, Q11, Q13, D83, Q16***

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# ЦИФРОВЕ ЗДОРОВ'Я: ІКТ ТА ОХОРОНА ЗДОРОВ'Я В АФРИЦІ

***У статті досліджено взаємозв'язки та причинно-наслідковий зв'язок між ІКТ та здоров'ям в Африці за період 1995-2015 рр. З використанням панельних узагальнених методів моментів і тестів причинності Тода-Ямамото. Емпіричні результати показують, що ІКТ має позитивний і статистично значимий зв'язок зі здоров'ям, що показує, що чим вище рівень ІКТ, тим вищий рівень здоров'я. Існує також двонаправлена причинність між ІКТ та здоров'ям. Це свідчить про те, що ІКТ стимулює здоров'я, що, в свою чергу, ще більше посилює використання ІКТ. Крім того, витрати на охорону здоров'я мають суттєві позитивні наслідки, що свідчить про те, що чим вищий рівень витрат на охорону здоров'я, тим вищий рівень здоров'я. Рівень безробіття має значні негативні наслідки, що означає, що чим вище рівень безробіття, тим нижче рівень здоров'я. Рівень освіти, виміряний за рівнем грамотності дорослих, має суттєві позитивні ефекти, що свідчить про те, що чим вищий рівень освіти, тим вищий рівень здоров'я. Навпаки, забруднення навколишнього середовища, виміряне викидами двоокису вуглецю на душу населення, має значні негативні наслідки, що свідчить про те, що чим вище рівень забруднення навколишнього середовища, тим нижче рівень здоров'я.***

***Ключові слова:*** *цифрове здоров'я; мобільне проникнення; використання Інтернету; ІКТ, здоров'я, функція виробництва здоров'я.*

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**О. Адеола, О. Эванс**

# ЦИФРОВОЕ ЗДОРОВЬЕ: ИКТ И ЗДРАВООХРАНЕНИЕ В АФРИКЕ

***В статье рассмотрены взаимосвязи и причинно-следственную связь между ИКТ и здоровьем в Африке за период 1995-2015 гг. С использованием панельных обобщенных методов моментов и тестов причинности Тода-Ямамото. Эмпирические результаты***

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***показывают, что ИКТ имеет положительный и статистически значимую связь со здоровьем, показывает, что чем выше уровень ИКТ, тем выше уровень здоровья. Существует также двунаправленная причинность между ИКТ и здоровьем. Это свидетельствует о том, что ИКТ стимулирует здоровья, что, в свою очередь, еще больше усиливает использования ИКТ. Кроме того, расходы на здравоохранение имеют существенные положительные последствия, свидетельствует о том, что чем выше уровень расходов на здравоохранение, тем выше уровень здоровья. Уровень безработицы имеет значительные негативные последствия, что означает, что чем выше уровень безработицы, тем ниже уровень здоровья. Уровень образования, измеренный по уровню грамотности взрослых, имеет существенные положительные эффекты, свидетельствует о том, что чем выше уровень образования, тем выше уровень здоровья. Напротив, загрязнение окружающей среды, измеренное выбросами двуокиси углерода на душу населения, имеет значительные негативные последствия, свидетельствует о том, что чем выше уровень загрязнения окружающей среды, тем ниже уровень здоровья.***

***Ключевые слова:*** *цифровое здоровья; мобильное проникновения; использование Интернета; ИКТ; здравоохранение; функция здравоохранения.*

**Introduction.** Africa has performed low in healthcare, as health indicators are lower in Africa compared to other world regions. As shown in Figure 1, in 2015, life expectancy was 59.94 in Africa and 68.46 in South Asia, while in other regions of the world such as Latin America and the Caribbean, and Europe and Central Asia, it was 75.34 and 77.16 respectively. Africa confronts the world's most intense health issues. HIV/AIDS continues to distress the region, which has 11% of the global population but 60% of the people living with HIV/AIDS. More than 90% of the estimated worldwide 300-500 million yearly malaria cases occur in Africa. Of the 20 countries with the highest maternal mortality ratios worldwide, 19 are in Africa (World Health Organization, 2018). The region also has the highest neonatal death rate in the world.

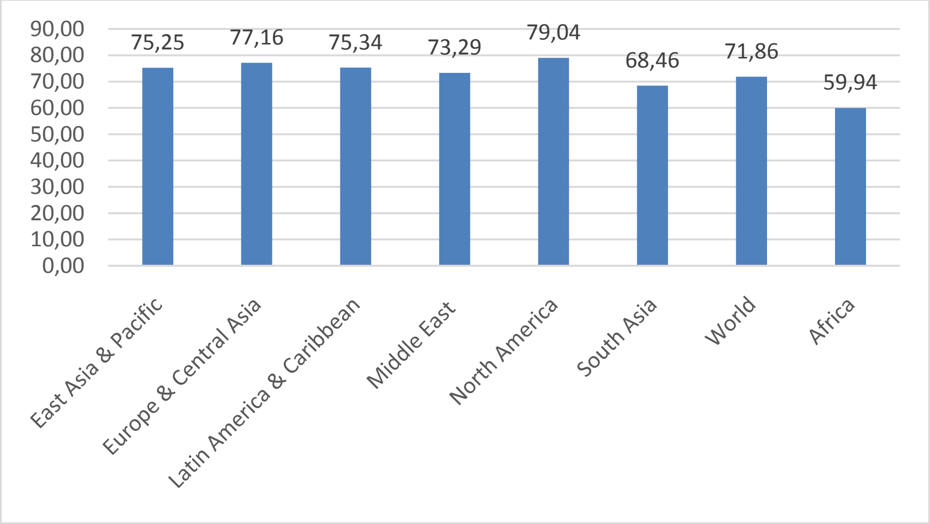


*Figure 1.* **Life Expectancy Across World Regions (2015),** *World Bank (2017)*

However, in recent years, internet has experienced a fast growth trajectory in Africa, while mobile phones have risen to become the commonest technological device in the history of the continent in a short time, and they are still growing (Figure 2). Moreover, mobile phones and internet have brought various innovations (Evans, 2018a, Evans, 2018b; Evans, 2019). As a result of these, a variety of innovations that integrate mobile phones and the internet into healthcare have been developed at local, national and regional levels in Africa. For example, in many parts of the continent, the use of mobile phones and ICT technologies to improve disease surveillance in public health has been reported, including Zambia, Madagascar, Uganda, and Kenya (Zurovac, Talisuna and Snow, 2012). In Uganda, the growth in ICT has benefited the rural communities, creating opportunities for new innovations, and their applications into healthcare have shown positive results, especially in the areas of disease control and prevention through disease surveillance (Kiberu, Mars and Scott, 2017).

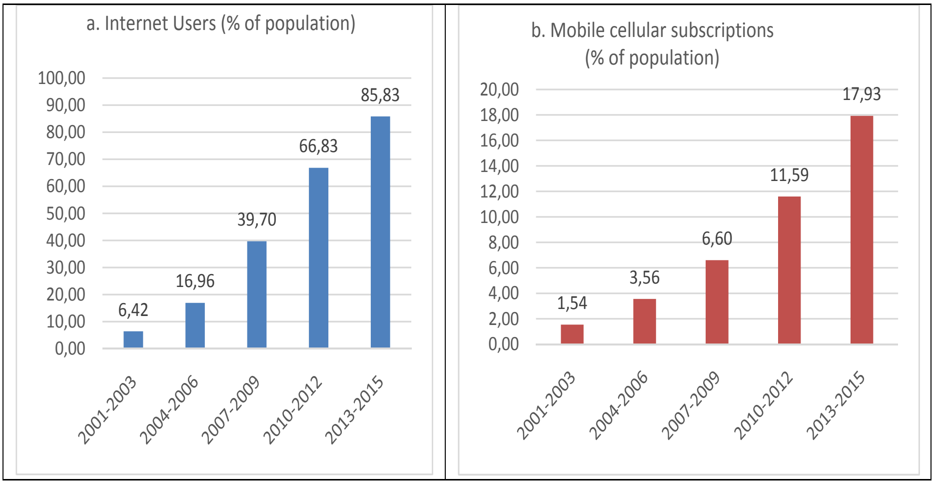


*Figure 2.* **Mobile Usage and Internet Penetration in Africa (2001-2015),** *World Bank (2017)*

As ICT infrastructure (both internet and mobile phone based) expands and becomes cheaper, speculations and optimism have been aroused on the opportunities that abound in digital health. (LeFevre et al., 2017; Mehl, Tamrat, Bhardwaj, Blaschke and Labrique, 2018). Digital health involves the development of interconnected health systems using computational technologies, smart devices, and communication media to aid healthcare professionals and patients in managing illnesses and health risks, as well as in promoting health and wellbeing. In other words, digital health is the utilization of information and communication technologies (ICT) to help address the health problems and challenges faced by patients. Such ICT encompasses both hardware sensors and software sensing technologies, including web-based analysis, microprocessors and integrated circuits, mobile phones and applications, telemedicine, wearable devices, personal genetic information and health information technology.

As a reaction to the state of healthcare in Africa, many studies, experts and the media have clamored for digital health in the fashion of developed countries such as the US (e.g. Huang, Blaschke and Lucas, 2017; LeFevre et al., 2017; Mehl et al., 2018). Learning from these developed countries, African countries can embrace digital health as a means to aid access to quality and equitable healthcare, particularly for poor and vulnerable communities. This is buttressed by Figure 3 and 4 which show the correlation of life expectancy with internet usage and mobile penetration in some selected African countries. Countries with higher internet usage and mobile penetration also have higher life expectancy (e.g., Algeria, Morocco and Tunisia). In many African countries, it is believed that the use of technologies such as smartphones and internet applications can provide innovative ways to monitor health and well-being. Together, these advancements can lead to a convergence of information, technology and connectivity to improve health care and health outcomes in such countries.

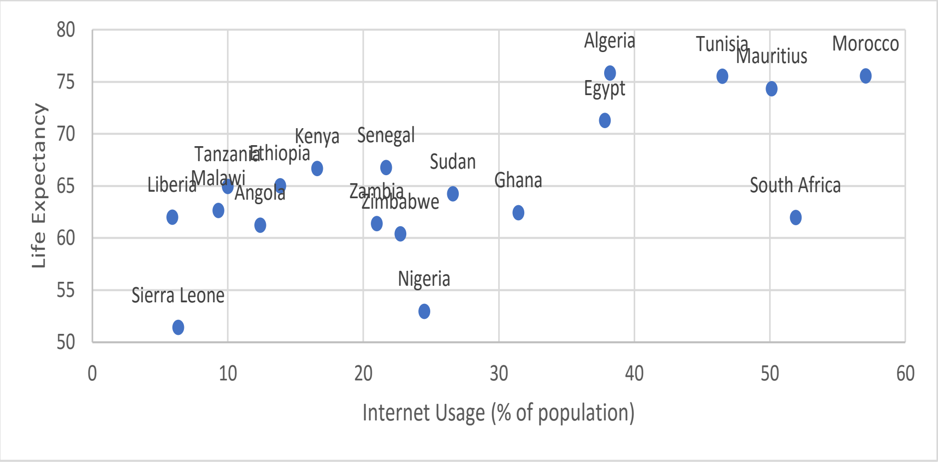


*Figure 3.* **Internet Usage and Health (2015),** *World Bank (2017)*

Though the potentials of digital health for Africa is great, its application has been meagre. A number of factors have been identified for this: the excessive burden of disease in Africa; the shortage of health professionals; high telecommunication cost; unstable power provision; and lack of government will (Kiberu et al., 2017). Moreover, despite the recent growth in ICT and health informatics, the use of ICT by healthcare providers in resource-limited settings like Africa has been slow and inequitable, and many local institutions that have excellent ICT capacity do not usually provide such services to the healthcare providers (Osoti et al., 2017). For most developing countries and especially Africa, digital health remains a proof-of-concept activity, with only modest value shown within small pilot projects.

However, while many African countries may recognize digital health as a tool to improve health services delivery to its populace, the impact of ICT on health has not been well documented, especially for Africa. Largely, the literature on digital health in Africa is limited to individual communities/countries and is not generalizable. This study thus fills the gap by examining the relationship and causality between ICT and health across a panel of 49 African economies using panel generalized method of moments (GMM). Most importantly, this enquiry is key to any effort to understand and anticipate the potentials of ICT for healthcare on the continent. This will inform policymakers about important areas of focus when designing and implementing digital innovations to strengthen healthcare delivery on the continent. The rest of the paper is organized as follows. Section 2 presents an overview of the theory and existing literature regarding the relationship between ICT and health. Section 3 explains the methodology and data. Section 4 gives the empirical analysis results, and Section 5 provides the discussion of results and the implications. Section 6 concludes the research.

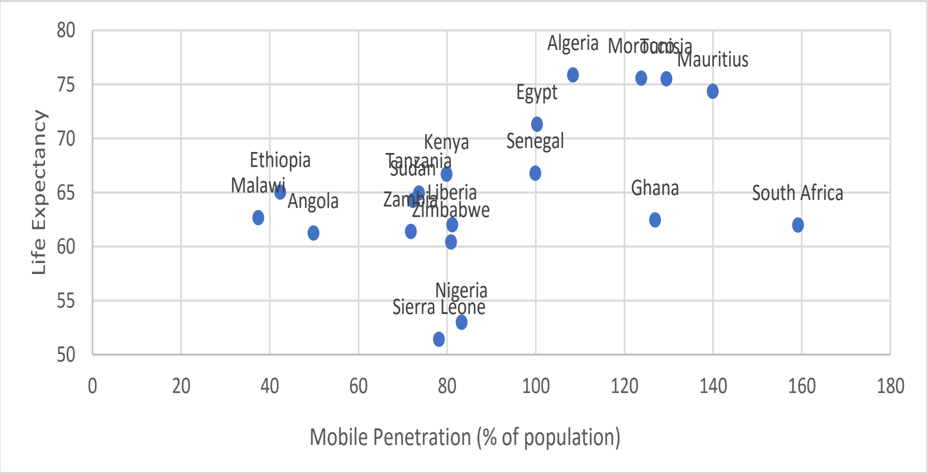


*Figure 4.* **Mobile Penetration and Health (2015),** *World Bank (2017)*

**Theory & Literature Review.** Among the theories of information technology, the Technology Acceptance Model (TAM) is the most widely used model to describe consumer acceptance of information technology. In recent years, TAM has been adapted to study various factors affecting consumers' behavior in the context of health information technology (e.g., Briz-Ponce and Garcia-Penalvo, 2015; Gao, Li and Luo, 2015; Garavand et al., 2015; Chen and Lin, 2018; Razmak and Belanger, 2018). TAM has been continuously expanded, and each of these expansions was motivated by the need to predict the use of new information technology (Venkatesh and Bala, 2008; Kim and Park, 2012). Taking cultural trends and social context as the main factors, TAM focuses on what attributes of a particular technology drive consumers' acceptance of the technology. Therefore, TAM is a useful model for "developing strategies to increase the acceptance of information technology, as it provides a direct relationship between acceptance of the technology, and the technology's perceived usability and ease of use" (Kim and Park, 2012, p. 2).

An increasing number of studies in the literature have therefore applied TAM to study health information systems (e.g., Briz-Ponce and Garcia-Penalvo, 2015; Gao, Li and Luo, 2015; Garavand et al., 2015; Chen and Lin, 2018; Razmak and Belanger, 2018). For example, Kim and Park (2012) showed that an extended TAM in the health information systems is valid to describe health consumers' behavioral intention. Based on TAM, Dunnebeil et al. (2012) showed that the perceived importance of IT utilization is one of the most significant drivers for accepting electronic health services. Orruno, Gagnon, Asua and Abdeljelil (2011) showed that TAM is good at predicting physicians' intention to use teledermatology, and the most important variable is the perception of facilitators to using the technology (e.g., infrastructure, training and support). These findings suggest that TAM can be effectively integrated with other theoretical approaches to understand the acceptance of digital health better.

Digital technology can assess, monitor, prevent, diagnose or treat diseases, monitor patients, for rehabilitation or long-term care (Dallery, Kurti and Erb, 2015; Jenssen et al., 2016; Manganello et al., 2017; George et al., 2018). For example, assistive technologies and rehabilitation robotics including unobtrusive monitoring sensors and wearable devices are used for people with disabilities to aid in their independence to perform their daily tasks. Computational simulations and modeling approaches can model health-related outcomes. Digital health can provide health information services to aid data transmission, storage and retrieval for clinical purposes (Massey, 2016; Nicholas, Huntington and Williams, 2016; Manganello et al, 2017). Mobile health, telehealth, telemedicine, telecare, telecoaching and telerehabilitation are various forms of patient care that can be useful for health care systems in Africa. Since ICT aids public health and primary healthcare through activities such as disease surveillance, health data acquisition and analysis, support of health workers, teleconsultation, tele-education, research and patient management, ICT can be used to manage patients remotely as a more efficient means of providing healthcare than transporting a patient/medical specialist to rural areas (Golbeck et al, 2011; Jaana and Sherrard, 2018). Along these lines, some of the important ICT and technological solutions include online media, radio, television, fixed telephones, and other devices for text messaging, video conferencing, teleconferencing, and e-mail.

Various studies in the literature have therefore explored the acceptance of ICT in healthcare (De Rosis and Vainieri, 2017; Fagerstrцm, Tuvesson, Axelsson and Nilsson, 2017; Haluza and Jungwirth, 2018; Holderried, Hoeper, Holderried and Kraus, 2018). For example, Cocosila and Archer (2010) studied user reasons for accepting or resisting a mobile ICT application for health promotion. The authors showed that intrinsic motivation is a sufficient reason for adoption: "Accordingly, when usefulness is less apparent, enjoyment may be a key factor for the adoption of mobile ICT for health promotion" (p. 241). Shiferaw and Zolfo (2012) showed that telemedicine implementation does not depend only on technological factors, rather on multisectoral involvement, e-government readiness, enabling policies, and capacity building processes: "There is no perfect 'one size fits all' technology and the use of combined interoperable applications, according to the local context, is highly recommended" (p. 156). Haluza and Jungwirth (2015) expected ICT-supported health promotion strategies to improve living standard, quality of health care, and patient's knowledge. Nevertheless, monetary aspects, acceptance by patient advocates, and data security and privacy were considered as the three most key impeding factors for ICT applications.

Reinecke et al. (2017) showed that communication load resulting from private e-mails and social media messages as well as internet multitasking are positively related to perceived stress and had significant indirect effects on burnout, depression, and anxiety. They also showed that perceived social pressure and the fear of missing out on information and social interaction are key drivers of communication load and internet multitasking. In their study, age significantly moderates the health effects of digital stress as well as the motivational drivers of communication load and internet multitasking. Damant, Knapp, Freddolino and Lombard (2017) found that older people's use of ICT has both positive and negative impacts on several aspects of quality of life. Majeed and Khan (2018) showed a positive and significant impact of ICT on population health.

A stand of the literature considers developing countries (Agarwal, Perry, Long and Labrique, 2015; Iyawa, Herselman and Botha, 2017). For example, Lewis, Synowiec, Lagomarsino and Schweitzer (2012) showed that, in many low-and-middle-income countries, ICT is being increasingly employed for different health programmes: "42% use it to extend geographic access to health care, 38% to improve data management and 31% to facilitate communication between patients and physicians outside the physician's office. Other purposes include improving diagnosis and treatment (17%), mitigating fraud and abuse (8%) and streamlining financial transactions (4%). The most common devices used in technology-enabled programmes are phones and computers; 71% and 39% of programmes use them, respectively, and the most common applications are voice (34%), software (32%) and text messages (31%). Donors are the primary funders of 47% of ICT-based health programmes" (p. 332). Also, Kallander et al. (2013) showed that very few formal outcome evaluations of digital health exist in low-income countries. They showed that although vast documentation of project process evaluations exists, there is a lack of digital health applications and services operating at scale. The most commonly documented use of digital health is 1-way text-message and phone reminders to encourage follow-up appointments, healthy behaviors, and data gathering, while innovative digital health applications for community health workers include the use of clinical decision support tools, mobile phones as job aides, and for data submission and instant feedback on performance.

A stream studies have emanated from Africa (e.g., Jimoh, Pate, Lin and Schulman, 2012; Kallander et al, 2013; Kiberu, Mars and Scott, 2017; Karimuribo et al, 2017; Makinde, Ogundele and Bello, 2018; Saleh et al, 2018; Watkins, Goudge, Gomez-Olive and Griffiths, 2018). For example, Jimoh et al. (2012) showed that knowledge and attitude are not predictive of perceived ease of use or perceived usefulness among health workers in Nigeria, and that technological barrier is a key addition to the TAM in low-resource settings. Karimuribo et al. (2017) described the development and achievements of a participatory disease surveillance system that depend on mobile technology to aid Community Level One Health Security in Africa. The authors showed that ICT–based solutions can contribute to disease detection and response, thereby complementing strategies to advance the efficiency of infectious disease surveillance at national, regional, and global levels. Makinde et al. (2018) investigated the impact of ICT on health care system in Nigeria using State Hospital Asubiaro Osogbo as a case study. The authors showed that faster access to relevant medical information, easier exchange of information, and increased efficiency are the key impacts of ICT usage on healthcare delivery. The authors also showed that the major challenges in ICT use are the erratic power supply and inadequate access to ICT facilities. There are a few other studies that have considered digital health in Africa (e.g., Hampshire et al., 2015; Peter, Barron and Pillay, 2016; Gambo and Soriyan, 2017; Saleh et al., 2018; Watkins et al., 2018). However, most of the studies are conceptual and micro-based, with little empirical attention to the relationship and the causality between ICT and health. This study fills the gap.

**Data & Methodology**

*Model.* In the literature, different methodologies are used to model health, based either on the use of econometric techniques or the univariate time series analysis. In the recent decade, the most rigorous studies in the health literature are based on the health production function founded on the Grossman theoretical model. The key postulation of the Grossman model is that health is a capital good. According to Bayati, Akbarian and Kavosi (2013, p. 2): "In this model individuals are born with an initial inventory of health which depreciates over time, and they can invest in it with consuming medical care. When the health inventory decreases to a definite level, death will happen". At the macro level, the general specification of the health production function is:

$$Hea_{i,t} = \tau_0 + \tau_1 Econ_{i,t} + \tau_2 Soc_{i,t} + \tau_3 Env_{i,t} + \xi_{i,t} \quad (1)$$

Where *Hea* represents health status, *Econ* represents economic factors, *Soc* represents social factors, and *Env* represents environmental factors. Identification and proxies of the variables are based on the existing literature (e.g., Lei et al., 2009; Halicioglu, 2011; Bayati et al. 2013; Rad et al., 2013, Sede and Ohemeng, 2015). The proxy for health is life expectancy. Health expenditure, income per capita, and unemployment rate are the proxy for economic factors. Adult literacy is the proxy for the social factor while carbon dioxide emissions per capita is the proxy for the environmental factor.

Therefore, the model includes our variable of interest, ICT, and is specified as follows:

$$Hea_{i,t} = \tau_0 + \tau_1 Ict_{i,t} + \tau_2 Hee_{i,t} + \tau_3 Inc_{i,t} + \tau_4 Une_{i,t} + \tau_5 Adl_{i,t} + \tau_6 Co_{i,t} + \xi_{i,t} \quad (2)$$

Where *Hee* is health expenditure; *Inc* is income per capita; *Une* is unemployment rate; Adl is adult literacy; and *Co* is carbon dioxide emissions per capita. ICT is a multi-dimensional concept which no single variable can capture. In this study, therefore, the ICT index (*Ict*) is constructed from the two commonly used ICT indicators in the literature: (i) (ii) log of mobile cellular subscriptions (% of population), and (ii) log of number of internet users (% of population). Theoretically, this index of ICT captures most of the information in the original dataset which consists of two ICT indicators. The results from the principal component analysis are shown in Table 1. The eigenvalues show that the first principal component explains the variations better and therefore is the best indicator of ICT in this case. After rescaling, the individual contributions of internet usage and mobile subscriptions are 51.4% and 48.6% respectively. This serves as the basis of weighting to construct the ICT index, denoted as Ict.

*Table 1.* **Principal component analysis for the ICT index,** *author's*

| | PCA 1 | PCA 2 |
|---|---|---|
| Eigenvalues | 2.711 | 0.134 |
| % of variance | 0.958 | 0.042 |
| Cumulative % | 0.958 | 1.000 |
| Variable | Vector 1 | Vector 2 |
| Log of number of Internet users (% of population) | −0.539 | −0.113 |
| Log of mobile cellular subscriptions (% of population) | −0.564 | 0.350 |

*Method*

The method of data analysis employed is the panel generalized method of moments (GMM). Health in any economy is dynamic, and this necessitates a dynamic-type estimation, which can better capture dynamics in the system (See Bircher, 2005). To estimate such a dynamic panel data model, Arellano and Bover (1995) and Blundell and Bond (1998) proposed a system general method of moments (system GMM) which avoids these issues by combining the regression in differences with the regression in levels and using the lagged values of the dependent and other explanatory variables as the instruments for the regression in differences and the lagged differences of the explanatory variables as the instruments for the regression in levels. In addition, there are two important robustness tests in GMM estimation: the Sargan test and Arellano-Bond test. In this study, the Sargan test is used to test for over-identifying restrictions while Arellano-Bond test is used to test for autocorrelation.

The Toda-Yamamoto approach to causality technique is used to estimate the causality between ICT and health. The Toda-Yamamoto causality technique is more advanced than other causality techniques such as the conventional Granger causality test (Granger, 1969). The two main advantages of this causality technique are: it is applicable irrespective of the order of integration of underlying variables and irrespective of whether or not the variables are cointegrated. (Toda and Yamamoto, 1995).

*Data*

This study employs annual data for the period 1995-2015. This study is limited to this period and a sample of 49 African countries because of data inadequacy. The African countries included in the study are: Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Egypt, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia and Zimbabwe. The data were acquired from several sources: World Bank, United Nations, World Health Organization, and International Labour Organization.

*Empirical Analysis*

In carrying out the estimations, GMM with and without robust standard error is used in order to ensure that the results are robust to different specifications (Table 2).

*Table 2.* **Estimates of the Health Production Function (System GMM),** *author's*

| Variables | Dynamic Estimator based GMM without Robust Standard Error | Dynamic Estimator based GMM with Robust Standard Error |
|---|---|---|
| *ICT* | 2.61* | 2.35*** |
| | (0.90) | (0.90) |
| **Economic Factors** | | |
| *Health expenditure* | 0.73 | 1.05*** |
| | (0.62) | (0.62) |
| *Income per capita* | 1.18* | 1.11* |
| | (0.11) | (0.10) |
| *Unemployment rate* | -0.92*** | -0.93*** |
| | (0.57) | (0.57) |
| **Social Factors** | | |
| *Adult Literacy* | 0.59* | 0.53* |
| | (0.03) | (0.03) |
| **Environmental Factors** | | |
| *Carbon dioxide emissions per capita* | -3.06 | -3.11* |
| | (0.40) | (0.38) |
| Wald Chi-Square | 0.71** | 2.55** |
| | [0.03] | [0.04] |
| Sargan Test | 1.04 | 1.65 |
| | [0.74] | [0.74] |
| AR(1) | 2.94 | 1.19 |
| | [0.34] | [0.17] |
| AR(2) | 0.74 | 0.19 |
| | [0.15] | [0.43] |

Note: *, ** and *** denote the significance level of 1%, 5% and 10% respectively. ( ) denote standard errors and [ ] denote p-value.

ICT has a positive and statistically significant relationship with health, showing that the higher the levels of ICT in the region, the higher the level of health. Further, health expenditure has significant positive effects, suggesting that the higher the scale of health expenditure, the higher the level of health. Unemployment rate has significant negative effects, meaning that the higher the level of unemployment, the lower the level of health. The level of education, measured by adult literacy rate, has significant positive effects, meaning that the higher the level of education, the higher the level of health. On the contrary, environmental pollution, measured by carbon dioxide emissions per capita, has significant negative effects, meaning that the higher the level of environmental pollution, the lower the level of health.

The diagnostic tests show that the Wald $\chi^2$ of all models are significant at 5% level of significance, meaning that the observations are fitted perfectly to the models. Sargan test for over-identifying restriction of GMM with and without robust standard error is not significant for one and two step system respectively. Arellano and Bond test for autocorrelation with the AR (1) and AR(2) processes for the two step GMM with and without robust standard error, and one step GMM with and without robust standard error are not significant as well.

The results of the Toda-Yamamoto causality tests are summarized in Table 3. The empirical results show that there is bi-directional causality between ICT and health. This indicates that ICT spurs health which, in turn, spurs ICT usage even further in these countries.

*Table 3.* **Toda-Yamamoto Causality Test Results,** *author's*

| *Direction of Causality* | *$\chi^2$-stat* |
|---|---|
| ICT ⟶ Health | 11.49* |
| Health ⟶ ICT | 6.27*** |

Notes: * and *** indicate statistical significance at 1and 10 percent. The optimal lag length was selected using the Schwarz information criteria.

**Discussion and Implications.** The purpose of this study is to investigate the relationship between ICT and health in Africa. Although the effects of drivers of health have been studied in the past, growing ICT in the continent may have inspired a new set of behaviors and effects. The study is therefore different in examining the relationship between ICT and health in Africa.

The empirical evidence has shown that ICT has a positive and statistically significant effect, meaning that the higher the levels of ICT in the region, the higher the level of health. In other words, an increase in ICT is associated with an increase in health. This finding is consistent with previous research on digital health adoption, and provide insights into the way forward for accelerating digital health policy implementation. First, ICT infrastructure is a prerequisite for digital health implementation. Since ICT is a composite measure of internet and mobile penetration, ICT usage for digital health must embrace not only mobile network coverage or mobile phone subscriptions but also internet technology and web applications.

There is also a bi-directional causality between ICT and health. This indicates that ICT spurs health which, in turn, boosts ICT usage even further in these countries. That is, ICT is a function of health while health is also a function of ICT. This evidence is supported by many studies (e.g., Gopalan et al., 2016; Sims et al., 2017; Majeed and Khan, 2018; Rana, Alam and Gow, 2018) which suggested that ICT improves healthcare delivery and public health. In other words, ICT such as hardware sensors and software sensing technologies, including web-based analysis, microprocessors and integrated circuits, mobile phones and applications, telemedicine, wearable devices, personal genetic information and health information technology improve health care and health outcomes. By reducing inefficiencies, improving access, reducing costs, increasing quality, and making medicine more personalized for patients, digital health empowers people to better track, manage, and improve their health, live better, and more productive lives.

The study has also shown that economic factors such as income, health expenses and unemployment have significant effects, suggesting that economic factors are important for health. These findings are comparable to studies such as Conti, Heckman and Urzua (2010), Cutler and Lleras-Muney (2010), and McCrary and Royer (2011). Especially, income is an important factor for health, as individuals of low-income status have higher prevalence rates of morbidity and mortality. This is because individuals of limited economic resources are likely to reside in neighborhoods with higher exposure to pollutants and toxic conditions that have adverse effects on their health. They also have limited access to good nutrition and medical care, or information resources concerning health risk and healthcare (Kwabi-Addo, 2017). Another noticeable result is that social factors such as the level of education and literacy have significant effects, suggesting that social factors are important for health. Educational investments in formal schooling and on-the-job training are recognized means to improve health outcomes (Kwabi-Addo, 2017). Educated people are generally known to be healthier, have fewer comorbidities and live longer than people with less education (Davies, 2018).

Similarly, environmental factors such as pollution have significant effects, suggesting that environmental factors are important for health. This finding is consistent with other studies in the literature such as Li et al. (2014), Knittel, Miller and Sanders (2016), Ahmad et al (2018), and Garg et al (2018). Pollution is a major cause of death and disease globally; health effects range from increased hospital admissions and emergency room visits, to increased risk of premature death. Millions of premature deaths globally are linked to air pollution, mainly from heart disease, stroke, lung cancer, chronic obstructive pulmonary disease, and acute respiratory infections in children. According to World Health Organization (2018), in children and adults, both short- and long-term exposure to air pollution can lead to respiratory infections, reduced lung function, and aggravated asthma.

**Concluding Remarks.** This study has examined the relationship and causality between ICT and health in Africa for the period 1995-2015 using panel GMM model and Toda-Yamamoto causality tests. The empirical results have shown that ICT has a positive and statistically significant relationship with health, showing that the higher the levels of ICT in the region, the higher the level of health. There is also a bi-directional causality between ICT and health, suggesting that ICT spurs health which, in turn, spurs ICT usage even further in these countries. Further, health expenditure has significant positive effects, suggesting that the higher the scale of health expenditure, the higher the level of health. Unemployment rate has significant negative effects, meaning that increase in unemployment is associated with lower levels of health. The level of education, measured by adult literacy rate, has significant positive effects, meaning that higher levels of education are associated with higher levels of health. On the contrary, environmental pollution, measured by carbon dioxide emissions per capita, has significant negative effects, meaning that the higher the level of environmental pollution, the lower the level of health.

**Theoretical Contributions.** While the literature has suggested a positive relationship between ICT and health (Damant et al., 2017; Reinecke et al., 2017; Sim et al., 2017; Majeed and Khan, 2018), this study has gone a step further and expanded the literature by empirically examining the relationship and causality between ICT and health. Additionally, the study also provided new insights into the relationship between economic, social and environmental factors and health. In other words, the study went beyond the inquiry of the relationship between ICT and health and revealed the significance of economic, social and environmental factors to health. In this manner, the study shows that ICT and economic, social and environmental factors play significant roles in health.

*Practical Contributions*

The findings of this study have several important policy implications for policymakers. The study has shown that ICT has positive and significant relationship with health. The implication is that, as many African economies begin to tread the path of sustainable healthcare delivery, digital health should be the building blocks upon which modern African health sectors are built. Through the combined use of ICT for research, data acquisition, surveillance, access to patient data and clinical care even at a distance, ICT solutions can be used to enhance the capacity of health workers, especially in resource-limited settings like Africa. This may further improve information by removing constraints such as distance and time.

In view of this, policymakers and private actors in the health industry need to pay more attention to ICT trends to ensure that the potential gains are fully maximized. All stakeholders have the responsibility to collaborate at developing policies and applications that will maximize the benefits of ICT to every level of healthcare in Africa. Obviously, many countries in Africa have taken the initiative to adopt digital health systems such as mobile applications and health information systems. ICT infrastructural enhancements aimed at reducing the costs of internet bandwidth will contribute to the speedy implementation of more digital systems, enabling tele-education, teleconsultations, and teleconferencing activities. It is important for African countries to build national digital programs to aid healthcare, such as those of Canada Health Infoway built on core systems of patient and provider registries, clinical reports and immunizations, and clinical and diagnostic imaging systems. ICT should, therefore, be employed to change the way care fundamentally is delivered, to change working practices, to enable different skill mixes in clinical teams, to empower different clinicians to make decisions about patient care, and to empower patients to self-care. It is important to apply ICT-based solutions to enhance early detection, timely reporting, and prompt response to health events in the continent.

Further, this study has shown that the level of education, measured by adult literacy rate, has significant positive effects, meaning that the higher the level of education, the higher the level of health. Social factors such as the level of education and literacy have significant effects, suggesting that social factors are important for health. Therefore, education or training for both patients and health professionals should be supported to facilitate digital health adoption. In fact, numerous studies in the literature have mentioned the importance of education for the enhancement of technical expertise and knowledge for health professionals. By providing adequate education and training, resistance to the digital health adoption will be minimized. National commitments in providing basic essential educational infrastructure and training for the health workforce is imperative. Policy readjustment of basic education to make it truly accessible to everyone is also essential.

It is important to note that developing sustainable digital health in Africa will require huge technical knowledge, experience, and financial investments. African countries will need to tap into resources and expertise of local, regional, and international participants as stakeholders. Important stakeholders must be involved in the digital health efforts: citizens (including patients), professionals, hospitals and academia, health-related businesses, governments, international agencies, technology developers, suppliers, users, and other decision-makers. For example, in Uganda and Mozambique, partnerships between patients with cell phones, technologists, local and regional governments, non-governmental organizations, academia, and industry have aided mobile health solutions (Kallander et al., 2013).

Another noticeable result is that economic factors such as income, health expenses and unemployment are important for health. The implication is that efforts to improve Africans' health should increasingly recognize the need to reach beyond the traditional health care and public health sectors to address the non-medical determinants of health. Therefore, policy change in the domains of housing, transportation, security, education, and other areas are important to shaping the contexts in which people live, learn, work, and play (Kickbusch, 2010). Health should be seen as a salient outcome of interest for policymakers both inside and outside traditional health domains (Rigby, 2013). There is a need for intensive programmes and measures geared to removing financial barriers inhibiting access to health care services and shielding poor and vulnerable populations from the ruining effects of medical expenses (Mchenga, Chirwa and Chiwaula, 2017). Lack of social and financial risk protection can lead to high levels of poverty, vulnerability and inequality in health (Saksena, Hsu and Evans, 2014). Financial risk protection should be made a key component of universal health coverage and the health system goal of ensuring quality healthcare access without suffering financial hardship.

Similarly, environmental factors such as pollution have significant negative effects, suggesting pollution is a major environmental risk to health. By reducing air pollution levels, African countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma. The less pollution, the better cardiovascular and respiratory health for the population, both long- and short-term. Policies and investments supporting cleaner transport, power generation, energy-efficient homes, industry and better municipal waste management should, therefore, be encouraged to reduce key sources of pollution.

In conclusion, the study has shown that economic, social and environmental factors influence health. Ultimately understanding why these factors impact health may inform the design of more effective programs and may inform the most important pathways by which ICT influences health. Future studies should, therefore, investigate the effects of these factors on ICT outcomes.

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