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Does ICT Development, Innovation Dissemination Promote Economic Growth and Human Capital? An Econometric Approach Based on East African Countries

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Abstract

The East African Countries' economic landscape has been significantly transformed over the last two decades as a result of the Information revolution, innovation, fostering sustainable economic growth. The dynamics between ICT development, innovation diffusion, and long-term economic growth have not been given substantial consideration in previous literature. In addition, there are prospective gaps in the nature of the ICT-innovation-growth nexus that current empirical studies have not thoroughly considered. This paper examines causal relationships among ICT development, Innovation diffusion, sustainable economic growth, and human capital development in East African countries from 2000 to 2020. The aim is to explore the direction of causality relationships among variables that runs both ways, one way, or not at all. We employed the Dynamic Order Least Square (DOLS) and Panel Vector Error Correction Model (VECM) models and a Granger causality test. Results from the DOLS show that both ICT development and innovation contribute positively to sustainable growth and human capital development in all East African countries. However, the marginal effects of innovation on sustainable growth are very small compared to ICT development, especially for some countries. The VECM result confirms significant causal relationships among the studied variables in the short and long run. The findings shed light on the types of policies and approaches that would be necessary for sustainable economic growth in East African economies. This can be achieved if organizations engaged in the East African agenda for prosperity provide the support needed to complement different govern-

ments' efforts in advancing ICT penetration and innovation diffusion in East Africa.

Keywords

ICT Development, Innovation Diffusion, Economic Growth, Panel VECM, East Africa, Human Capital

1. Introduction

Information and Communication Technology (ICT) and Innovation can be connected to different themes and concepts across different disciplines. For instance, they are highly associated with the term sustainability (Kumar & Kumar, 2017; Akkemik, 2015). Sustainability is the quality and ability to be maintained at a specific rate or level over time (Kumar & Kumar, 2017). A systematic approach toward sustainability constitutes economic, social, and environmental aspects (Ejemeyovwi et al., 2019a; Zhao et al., 2021; The et al., 2021). Several extant pieces of literature can be found on the relationship between ICT or Innovation and any of the aspects of sustainability (Toader et al., 2018; Boot & Marinc, 2010; Agbemabiese, Nkomo, & Sokona, 2012; Shehzad et al., 2021). The focus of the present study is on the role of ICT and innovation diffusion in economic sustainability in the East African countries setting. Therefore, we mention that innovation diffusion and ICT development are the prerequisites for necessitating progress and competitiveness and, through them, sustainable economic growth and human capital.

It is hard to deny the fact that technology and invention have played a noteworthy role in the advancement of economies across the globe (Karakara & Osabuohien, 2019; Adeleye & Eboagu, 2019; Kurniawati, 2020). In most emerging and less developed countries, innovation takes center stage in sustainable economic growth. Developing countries, particularly those subject to climate change (Ejemeyovwi, Gershon, & Doyah, 2018), and energy scarcity (Ejemeyovwi, Adiat, & Ekong, 2019a) face numerous contemporary and substantial hurdles to innovation. Innovation and technological adoption accelerated at an extraordinary rate in the 21st century, compared with any time in history. The fact that economies have benefitted greatly from the adoption of efficient ICT and Innovation cannot be overstated (Akerkar, Joshi, & Fordham, 2016).

Africa is a developing and frontline economy for utilizing the fourth industrial revolution (industry 4.0) and achieving rapid economic growth and progress (Myovella, Karacuka, & Haucap, 2020). Realizing rapid and sustainable growth through industry 4.0 depends on the degree of the "smartness" of these economies (Asongu & Odhiambo, 2019). The maximum interconnection of most African countries can be attributed to the adoption of modern ICT and Innovation (Solomon & van Klyton, 2020; Maneejuk & Yamaka, 2020). Studies have established reciprocal relationships between ICT and growth (Yousefi, 2011; Iscan, 2012; Asongu & Le Roux, 2016; Ejemeyovwi et al., 2021; Pradhan, Mallik, & Bagchi, 2018), innovation and growth (Maradana et al., 2017; Ejemeyovwi et al., 2021) ICT and Innovation (Ejemeyovwi et al., 2021; Shehzad et al., 2021). Other studies characterize the ICT-led growth nexus (Vu, Hanafizadeh, & Bohlin, 2020; Alimi & Adediran, 2020), and innovation-led growth nexus (Nazir, Tan, & Nazir, 2021; Boot & Marinc, 2010). The reasons for ICT development and innovation diffusion for sustainable economic growth and progress in East Africa are described as the device for realizing: 1) a "smart society" where establishing digitalization minimizes the inequality gap in the East African region (Asongu & Tchamyou, 2018); and 2) "value-added" to add value to labor productivity for enhanced sustainable growth and human capital development (Tchamyou, 2017; Oluwatobi, 2015; Karakara & Osabuohien, 2019).

Most East African economies have relaxed limitations and liberalized the ICT sector since the late 1990s, resulting in an upward trend in ICT infrastructure development in the continent (Asongu & Le Roux, 2016). ICTs' investment in Africa has been boosted by market forces. Investors from across the globe view Africa as a financial hotspot and investment destination because of the continent's large population and the better rate of return on investment it offers than other developing economies (Ejemeyovwi & Osabuohien, 2020).

Due to the advancement of wireless mobile communication technologies and the trend of liberalization, the ICT sector in East Africa has experienced a significant insurgence in the past twenty years. Capital investment from both the public and private sectors has poured in as a result of the aforementioned progress. In addition, drastic cost reductions and improved capacity have enabled swift diffusion of innovation (Ejemeyovwi et al., 2019b). Consequently, the mobile penetration rate in the East Africa region has more than doubled since the year 2000. Countries like Rwanda, Kenya, the Democratic Republic of Congo, Uganda, and Ethiopia have more mobile phone lines than fixed lines, and this trend is expected to continue (Ejemeyovwi et al., 2021).

In general, Gross Domestic Index per capita reflects a country's economic status, and it is calculated by dividing a country's final income (before income tax) by its population in a year in US dollars. In 2019, Kenya had the highest Gross Domestic Index per capita, and Burundi had the lowest. The human capital index (HDI) is a metric that measures a country's overall progress in terms of social and economic development, including health, education, and economic prosperity. Despite advancements in human development, East Africa continues to lag behind other countries and regions. Seventy percent of the world's poor people live in ten countries, two of which are in East Africa: Burundi and the Democratic Republic of Congo.

It is also clear from the foregoing that studies that consider all four factors at the same time in a study framework are scarce, particularly for the countries included in this study. To fill this knowledge vacuum, we used panel Dynamic Ordinary Least Squares (DOLS) estimation to look at the long- and short-run links between innovation diffusion, ICT development, sustainable economic growth, and human capital in East Africa. The panel vector error correction model (VECM) was also utilized to capture the direction of causality in the study framework.

Moreover, most studies viewed ICT measurements and innovation diffusion measurements as disaggregated indicators in which the variables in ICT and innovation proxies are not aggregated together; however, their components may have a significant causal effect. For instance, aggregating the ICT indicators (ICT access, ICT use, and ICT skills) into a single dimension in this study will yield appealing results. In the case of innovation diffusion, we have used scientific and practical paper articles as a proxy which we later justify in this study. Real per capita output in East Africa is a measure of sustainable economic growth and human capital in this study. The same measure has been used for sustainable economic growth and human capital for the European Union and for Saudi Arabia (Pradhan et al., 2020; Belloumi & Alshehry, 2020). Given the above, the study poses the following questions: Does ICT development stimulate sustainable growth in East Africa? Does innovation diffusion stimulate sustainable growth in East Africa? Does ICT development and innovation diffusion promote human capital development in East Africa? Are there any causal relationships between ICT development, innovation diffusion, sustainable growth, and human capital in East Africa? These are the questions that this study seeks to answer through DOLS and Panel Causality Approaches. This gap in the literature has gone unnoticed in previous investigations. The fundamental goal of this study is therefore, to comprehensively assess the current state of affairs of these four variables in this study framework. The other sections of this paper are the literature review and develop the hypothesis, materials and methods, results, conclusion, and implications.

2. Literature Review and Forming of Hypothesis

The literature on the Granger-causal relationship between innovation dissemination, ICT development, economic growth, and human capital development is reviewed in this section. This section also reviews and highlights the specific contributions of this research to the literature in light of inconsistent results from previous investigations (Pradhan et al., 2017a). However, in the extant literature, furthermost of the empirical studies on the subject have intensive on industrialized and emerging economies from both single country and panel or cross-country perspectives. The single country perspective studies include, but are not limited to those conducted for Brazil (Jung & López-Bazo, 2019), Greece (Tsakanikas, Dimas, & Stamopoulos, 2021), Italy (Daniele, 2006), USA (Whitacre, Gallardo, & Strover, 2014), Japan (Ishida, 2015), Türkiye (Iscan, 2012), Australia (Gretton et al., 2002), Singapore (Vu, Hanafizadeh, & Bohlin, 2020), India (Reddy & Mehjabeen, 2019; Rahman et al., 2021), Pakistan (Rahman et al., 2021) and UAE (Omran et al., 2013). Similarly, most empirical studies have looked at it from a panel or cross-country perspective.

The first strand of literature focuses on the relationship between Innovation and economic growth (Furman, Porter, & Stern, 2002; Cetin, 2013; Yang, 2006; Pradhan et al., 2016). Even though most of the studies looked at the effect of innovation on economic growth, characterizing the supply-driven approach, in fact, it is the rise in economic activity that has the potential to boost the level of innovation in the process of growth and development. This indicates that innovation and economic growth can reinforce each other, which means they can have a bidirectional relationship (Pradhan et al., 2016). In the same line of investigation studied the impact of innovation on economic growth in 19 European countries for the 1989 and 2014 periods (Maradana et al., 2017). Their findings show a positive contribution of innovation to per capita income growth. They further confirm the bidirectional causal connection between Innovation and income per capita growth.

The second strand of the literature considers ICT and growth as the main variables in their studies. For instance, a study conducted for the NEXT-11 countries verified the causal connection between ICT and growth (Pradhan et al. 2017b). They also argued that the direction of causality was dependent on the level of penetration of the IT indicators used. Similarly, the connection between financial development, ICT, and growth was examined by Cheng, Chien, and Lee (2020). For 72 countries for the 2000 and 2015 periods. From their findings, they were able to establish that ICT diffusion can boost growth in high-income economies, but its influence is unclear in medium- and low-income countries. Between 1991 and 2012, a panel VAR model was also used to examine the relationship between ICT development and four other economic indicators for G-20 countries (Pradhan et al., 2014). Their findings show a positive correlation between the expansion of ICT infrastructure and economic growth. In addition, there were long-term causal relationships established between these variables.

The third strand of the literature has pointed out a few studies that studied the relationships among the four variables (ICT, Innovation, growth, and human capital). In a 15-year study with a sample of 13 G-20 countries examined the impact of ICT and Innovation on carbon dioxide emissions and economic growth. From among their findings, ICT and financial development are the key drivers of economic growth (Nguyen, Pham, & Tram, 2020). Also, studied the contribution of innovation, venture capital, and ICT to sustainable growth in 25 European countries for the 1989 and 2016 periods (Pradhan et al., 2017c). By employing the VECM approach, they found a long-run impact of the three variables on sustainable economic growth. The results from their short-run analysis of ICT and innovation dissemination show that the direction of causality varies based on the precise indicators employed to measure ICT and Innovation. Similarly, investigated the link between ICT, Innovation, and financial development in Africa (Ejemeyovwi et al., 2021). They employed the Bayesian Vector Auto-Regressive approach. They found the interaction of ICT and Innovation to contribute positively to financial development. However, they did not account for how ICT and Innovation can both contribute to growth.

In the fourth strand, regardless of the state of the economy, economists continue to argue that human capital is the most important component in the growth equation (Solow, 1956; Nelson & Phelps, 1966). Human capital development has become one of the key ingredients for fostering economic growth through technological innovation and adaptation, reducing inequality, and enhancing labor productivity, as proposed by (Lucas, 1988; Romer, 1986; Barro, 1997), because of the presence of human capital in the economic structure fosters economic growth. Work force productivity is heavily reliant on population knowledge and skill, which transforms the population into labor as a productive input in the production function. Skilled labor, on the other hand, not only boosts productivity but also adds dynamism to economic activities.

2.1. Innovation Diffusion and Economic Growth

Over the previous half-century, the rapid digitalization of the global economy has had a substantial impact on countries' inventive potential and economic growth. The interrelationships between these variables are quite complex. Numerous researches have examined the theoretical basis of the dynamic interaction between the variables. This present study examines the relationship between ICT development, innovation, sustainable economic growth, and human capital development. According to Schumpeter (1942), technology and innovation diffusion are vital for long-term economic progress. He further stated that the creation of new knowledge through research and development (R&D) and the use of contemporary technology is essential. The endogenous growth model, technology, and innovation are major factors in increasing productivity and thus economic growth. Consequently, the study found that countries with a higher level of economic development tend to invest more in innovation and technology (Romer, 1994). Below, we explain the theoretical basis of the association among the four variables in consideration.

The connections between Innovation, ICT development, and economic growth can be categorized into three distinct categories. First, is the innovation-growth connection, which has attracted a lot of attention in academic circles? Known for its ability to produce new inventions and discoveries, research and development (R&D) is a key contributor to a country's economic growth. There is also evidence that the wealthiest countries are spending in R&D to maintain their position at the top of the innovation value chain. Recently, some studies have looked at the relationship between these two variables for the OECD countries. Sokolov-Mladenovic et al. (2016) and Kacprzyk and Swieczewska (2019) studied the relationship for EU28 countries, and Chawla (2020) studied the relationship for all the OECD countries together. Sokolov-Mladenovic et al. (2016), for example, used a dynamic panel data approach to evaluate the relationship between innovation and economic growth by incorporating other macroeconomic variables and found innovation to contribute positively to growth. The GMM approach was used to examine the linkage between R&D and economic growth and control for other indicators (Kacprzyk & Swieczewska, 2019). The findings confirm a positive association between R&D and growth. Similarly, using panel data modeling, Chawla (2020) found a substantial dynamic link between population, R&D, and economic growth. Thus, it is proposed that the following hypotheses be evaluated in this research:

Hypothesis 1 Innovation diffusion increases economic growth in East Africa.

H1AB: Innovation diffusion "Granger Causes" Economic Growth and Vice Versa.

2.2. ICT Development and Economic Growth

The second viewpoint focuses on the relationship between ICT and economic growth. There are two possible ways in which ICT can contribute to economic growth in this situation. First, as a means of enhancing economic agents' efficiency and productivity. Using ICT, agents can have access to new resources, information, market opportunities, and other advantages. Second, because of the increasing worldwide demand for ICT, the sector has grown to be an important source of income for many countries (Arvin & Pradhan, 2014). ICT services get increasingly complex as economies grow, which means that modern services are required by both customers and enterprises. ICT spending by governments across the globe has increased to suit the needs of a wide range of stakeholders in the economy. There have been several recent pieces of research that looked at the relationship between economic growth and ICT in Sub-Saharan Africa and the OECD countries. Using dynamic panel data modeling, for example, looked at the relationship between innovation, investment, trade openness, ICT infrastructure, and economic growth. In a similar study used a production function technique to show that capital, labor, broadband, and economic growth have a strong link (Koutroumpis, 2019). Using dynamic panel data modeling discovered a favorable correlation between digitalization and economic growth (Myovella, Karacuka, & Haucap, 2020). Thus, it is proposed that the following hypotheses be evaluated in this research:

Hypothesis 2 ICT development increases economic growth in East Africa.

H2AB: Economic growth is triggered by ICT development and vice versa.

2.3. Human Capital Development and Economic Growth

A numeral of empirical studies has looked into the positive relationship between human capital development and economic improvement over the last few decades (Ahsan & Haque, 2017; Isola & Alani, 2010; Arabi & Abdalla, 2013; Chen & Fang, 2017; Amir, Mehmood, & Shahid, 2012; Eigbiremolen & Anaduaka, 2014; Sulaiman et al., 2015). Human capital development necessitates continuing significant investment in capacity building through the implementation of skill development programs that raise educational standards (Romele, 2013). Human capital development has a positive impact on economic tangible capital development because it reduces income inequality in society (Heckman & Jacobs, 2010) and ensures better quality manpower for the economic system (Deere & Vesovic, 2006), resulting in long-term sustainable economic growth. As a result, human capital is considered a key driver of economic growth in developing countries (Lucas, 1990; Ning & Shun, 2021).

Hypothesis 3 Human capital development promotes economic growth in East Africa.

H3AB: Human capital Development "Granger Causes" Economic Growth and Vice Versa.

2.4. ICT Development and Innovation Diffusion

The third viewpoint studies the Innovation-ICT nexus, which has gotten less consideration in the academic literature. Over time, governments and corporations have been encouraged to spend on R&D in the ICT sector due to ICT's ability to boost economic growth and productivity. ICT innovation has increased, which has allowed the various economic actors to raise their production and efficiency. ICT infrastructure investment has also resulted in decreased prices for ICT services, allowing for greater use of ICT in various sectors and fields (Roger, Shulin, & Sesay, 2022; Fernández-Portillo, et al., 2022; Adelakun, 2011). Increased funding for new ICT activities like software and application tools has resulted from this. Fernández-Portillo et al. (2022) found a greater impact on Europe's economy from R&D investments in ICT companies than from R&D investments in non-ICT industries. This has pushed ICT companies to invest more in R&D. Adelakun (2011) studied the link between these two variables for 50 selected industries. Similarly, Koutroumpia, Leiponen, and Thomas (2020) examined the dynamic link between these two variables in selected high-income countries, whereas Edquist and Henrekson (2017) examined the relationship in selected 105 countries. Thus, it is proposed that the following hypotheses be evaluated in this research:

Hypothesis 4 Innovation Diffusion can positively influence ICT Development.

H4AB: Innovation Diffusion "Granger Causes" ICT Development and Vice Versa.

2.5. ICT Development and Human Capital Development

A few researchers looked into the factors that influence human capital development (Saidi & Mongi, 2018; Choi & Yi, 2018; Tsaurai, 2018). Information and communication technology (ICT) has been recognized as a critical determinant of human capital development because it provides people with technological knowledge, skill acquisition, and educational opportunities (Praise & George-Anokwuru, 2018). Human capital and available investment derivatives were used to create a new variable on different economic innovators and determine their long-term impact on economic growth, proving the endogenous growth model's argument (Rastogi & Gaikwad, 2017). More credits for education and skill enhancement were identified as a key factor associated with human capital development by providing more credits in the economic sector (De Grip & Sauermann, 2013). As a result, the combination of ICT and economic growth is inextricably linked to human development. In the literature, the link between ICT and human capital investment has been well-established (Chou & Chinn, 2001; Kargbo, Ding, & Kargbo, 2016). Also discussed is the two-way causality between these two variables. Prior research has found a positive relationship between ICT and human development (Matekenya, Moyo, & Jeke, 2021; Kuri & Laha, 2011), with one study of frontier countries from 2005 to 2014 finding a link between low human development and low ICT participation (Raichoudhury, 2016). Thus, it is proposed that the following hypotheses be evaluated in this research:

Hypothesis 5 ICT Development can positively influence Human capital development.

H5AB: ICT Development "Granger Causes" Human capital development and Vice Versa.

2.6. Innovation Diffusion and Human Capital Development

The impact of innovation and human capital development on economic growth in transition economies is examined in this point of information. Despite skepticism about transition economies' innovative potential, this study examines the importance of research and development (R&D), technological innovation, education, the social-economic environment, and spillovers. The majority of the literature on innovation diffusion has focused on firms' R&D activities, patent activity, or collaboration strategies (Datta & Singh, 2019; Ababio et al., 2021; Li et al., 2008; Klingebiel & Rammer, 2013). Human capital, on the other hand, has received less attention. Recent studies primarily use human capital as a control (a stylized positive relationship) or as a proxy of absorptive capacity, with the exception of Noseleit & de Faria (2013), who investigate the importance and substitutability of human capital diversity (Kim et al., 2016; Faems & Subramanian, 2013; Kneller & Stevens, 2006). Recognizing human capital as a strategic resource that must be properly allocated, on the other hand, can yield significant results, as innovation activities rely heavily on employee knowledge and expertise (Escribano, Fosfuri, & Tribó, 2009). This study will propose a novel approach in innovation management studies by unbundling human capital into actual task activities performed by employees within firms. Existing literature pays little attention to firm diversity in terms of innovation diffusion instead of focusing on education levels or the proportion of employees who are scientists or engineers (Grimpe & Kaiser, 2010; Kneller & Stevens, 2006). As a result, it falls short of describing the actual combination of activities carried out by manpower. This limitation can be overcome by using a task-based approach. Thus, it is proposed that the following hypotheses be evaluated in this research:

Hypothesis 6 Innovation Diffusion can positively influence Human capital development.

H6AB: Innovation Diffusion "Granger Causes" Human capital development and Vice Versa.

3. Materials and Methods

3.1. Model Specification

As previously mentioned, endogenous growth models have demonstrated the importance of ICT and Innovation in boosting economic growth (Ejemeyovwi et al., 2021; Tsakanikas, Dimas, & Stamopoulos, 2021). In the preceding section of this work, we discussed the interplay among these variables. However, there is a paucity of research on the impact of ICT, innovation on economic growth, and human capital that at the same time, accounted for the direction of causality among them. The present study extends the model of Youndt et al. (1996) by aggregating the different measures of ICT and Innovation. Consequently, the following is a description of the research model that was used via the Cobb-Douglas production function:

$$\text{RGDP}_{it} = A_0 \text{ID}_{it}^{\beta_{1i}} \text{ICT}_{it}^{\beta_{2i}} e^{\varepsilon_{it}} \quad (1)$$

After the log transformation, Equation (1) can be shown as follows:

$$\ln\left(\text{RGDP}_{it}\right) = \beta_0 + \beta_{1i} \ln\left(\text{ID}_{it}\right) + \beta_{2i} \ln\left(\text{ICT}_{it}\right) + \varepsilon_{it} \quad (2)$$

where $\beta_0 = \ln(A_0)$; i (1, 2, ⋯, N) Denotes a country in the sample; t (1, 2, ⋯, T) Signifies the time for each country; and β_i (for i = 1, 2) signifies the parameters

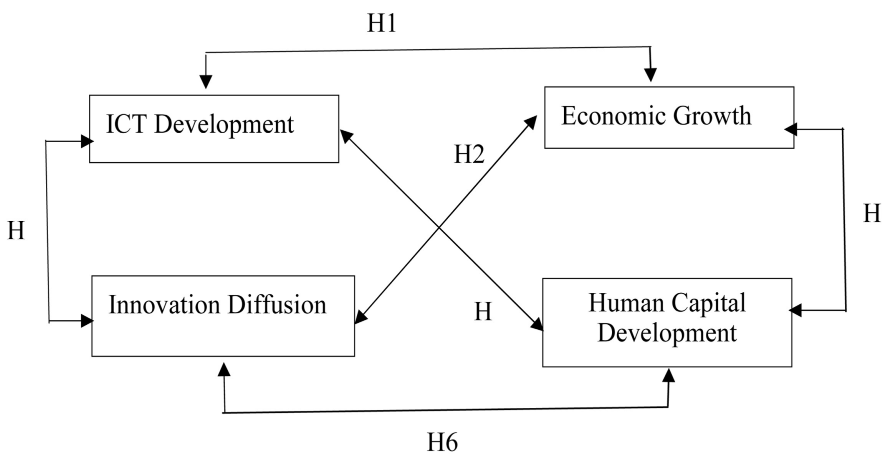

Figure 1. Summary of the hypothesized model.

of the model. The onus is to evaluate the parameters in Equation (2) and compute for some panel estimations tests on the causal relationships among real GDP per capita (RGDP), innovation diffusion (ID), and ICT development (ICT). The a priori expectation of theory state that ICT and Innovation should have a significant positive impact on sustainable growth in East Africa as indicated in Figure 1.

3.2. Data and Sample

We present our empirical approach to investigate the impacts of ICT, Innovation on sustainable growth, and human capital and the direction of causal relationships among them. We have used annual time-series data that were obtained from the World Development Indicators (WDI) published by the World Bank for a sample of 10 East African countries selected based on data availability for all the indicators used in the study. The data set used spans from 2000 to 2020. We further categorized the data into income groups based on the World Bank classification (Upper Middle Income, Lower Middle income, and low-income countries). Based on their classification, in the first panel of countries, no East African country is listed. The second panel consists of Kenya and Sudan. The third panel contains Burundi, Congo Dem Rep, Djibouti, Eritrea, Ethiopia, Rwanda, Tanzania, South Sudan, and Uganda.

3.3. Variables Description

The variables used in this study are innovation diffusion (ID), ICT development (ICT), and real per capita GDP (RGDP) as a proxy for sustainable growth Human Capital Development (HCD) (Belloumi & Alshehry, 2020). The innovation diffusion measure was captured by scientific journal articles due to data availability for R&D activities in East African countries. The same measure has been used by Sofka, Shehu, and de Faria (2014). They argued that, apart from data availability, output from innovation can be captured by scientific journal articles as opposed to other measures because of the following reasons: 1) innovative individuals from diverse fields spontaneously convey their ideas through scientific journal papers. Beneficial innovative ideas that emerge from other disciplines other than the engineering areas can readily be kept for reference. Such unique ideas may not need patenting; consequently, scientific and technical journal articles will be an accurate venue for the presentation of such innovative ideas. 2) The procedure of getting a patent and trademark, such as requirements and certifications, is very tedious, notably in most East African countries. For instance, in countries like Kenya, the process contains bureaucratic requirements, which cause delays in obtaining the security and protection of innovative ideas. Several innovative outputs and ideas may consequently end up becoming insecure and stolen. Others may end up becoming outdated and unnecessary before they are registered. 3) Profits are typically the driving force behind patenting. As a result, new ideas are protected by patents so that they can be licensed and sold for a profit. This profit-driven approach excludes new concepts that may not initially appear to have profit potential. ICT is captured via three different ICT development indicators as an aggregated index. The three ICT development indicators are a) fixed telephone subscription per 100 people (ICT access), b) fixed broadband subscriptions per 100 people (ICT use), and c) gross secondary school enrollment gender parity ratio (ICT skills). The aggregated index of ICT is represented by ICT in the model.

Principal component analysis (PCA) was applied to compute the index for ICT development. PCA helps to convert the fundamental set of indicators into a reduced set of linear factors. The technique of obtaining this index includes numerous phases. It involves data matrix building, standardized variable creation, correlation matrix computation, identification of eigenvectors, and the principal components (PCs) selection for more details. The results of the PC are shown in appendix A. In this paper, ICT is the weighted index of the three ICT development indicators, namely, ICT access, ICT use, and ICT skills. A detailed definition of these variables is available in the WDI database and we summarized them in Table 1.

3.4. Econometric Methodology

3.4.1. Panel Unit Root Test

LLC, IPS, and Hadri's standard stationarity tests become ineffective if cross-sections between countries in the panels are not independent. To accommodate for cross-country dependencies and give robust results that are consistently consistent, Dickey fuller and Im, Pesaran, and Shin introduced new approaches in their respective fields. Cross-sectional Augmented Dickey-Fuller (CADF) and Cross-sectional Im, Pesaran, and Shin (CIPS) are the names of two new approaches that have just been developed. The test entails estimating the following equation:

$$\Delta Y_{it} = \mu_i + \gamma_i Y_{it-1} + \rho_i R \sum_{j=1}^{n} \vartheta_{ij} y_{it-j} + \varepsilon_{it} \tag{3}$$

Table 1. Variables description.

Variable	Description	Source
Sustainable Growth	Real GDP divided by population	WDI
Human capital development	HCDI	HCDR
Innovation Diffusion	Scientific and Technical Journal	WDI
ICT Development	ICT Development Index computed via PCA	Author
ICT access	Fixed telephone subscription per 100 people	WDI
ICT use	Fixed broadband subscription per 100 people	WDI
ICT skills	Gross secondary school enrollment gender parity ratio	WDI

where y_{it} denotes the variables analyzed in the equation, ε_{it} signifies the error term, Δ denotes the difference operator and μ_p and R denotes the constants and trends, respectively. The null hypothesis is that all of the panel member variables have a unit root. The alternative hypothesis state that at least one panel has no unit root. A suitable lag length is chosen using Schwarz Bayesian criterion (SBC).

3.4.2. Panel Cointegration Tests

A cointegration test is utilized to assess if the variables have a long-run equilibrium relationship. To put it differently, whenever two or more series are co-integrated, their variables are in a long-run equilibrium relationship. A lack of cointegration, on the other hand, indicates that the variables have no long-term link and can conceivably move arbitrarily far apart. Assume that the variables are integrated on a one-to-one basis. If this is the case, cointegration analysis will be employed to determine whether the set of potentially "integrated" variables has a long-term relationship. To check for this, an estimated cointegration equation of the following form is used:

$$Y_{it} = \beta_{i0} + \beta_{i1} X_{i1t} + \beta_{i2} X_{i2t} + \cdots + \beta_{ik} X_{ikt} + \varepsilon_{it} \tag{4}$$

This equation could be rewritten as follows:

$$\varepsilon_{it} = Y_{it} - \left(\beta_{i0} + \beta_{i1} X_{i1t} + \beta_{i2} X_{i2t} + \cdots + \beta_{ik} X_{ikt}\right) \tag{5}$$

The cointegration vector is defined as follows:

$$\left[1 - \beta_{i0} - \beta_{i1} - \beta_{i2} \cdots - \beta_{ik}\right] \tag{6}$$

The above test, as written by Ofori and Asongu (2021), fails to handle a panel set. As a result, the Oluwatobi et al. (2014); Johansen (1988); Pedroni (1999) panel cointegration test is used to define if the variables are cointegrated. On the time-series panel regression configuration below, the Pedroni panel cointegration test is applied:

$$\Delta Y_{i,t} = \alpha_i + \sum\nolimits_{j=1}^{p_i} \beta_{ji} X_{jit} + \varepsilon_{it} \tag{7}$$

$$\varepsilon_{it} = \rho_i \varepsilon_{it-1} + w_{it} \tag{8}$$

Y_{it} and X_{jit} are the observable variables; it is the panel regression's disturb-ance term, and I is the number of country-specific fixed effects. The coefficients ji compensate for the individual country difference. The null hypothesis is that the cointegration of the pooled, within dimension approximation does not occur. Signified by:

$$\text{H}_0\text{:}\quad \rho_i = 1 \quad \text{for all } i \text{ against } \text{H}_1\text{:}\quad \rho_i = \rho < 1\text{:} \tag{9}$$

In the first hypothesis, the within-dimensional approximation assumes a common value for ρ_i (= ρ). To summarize, this procedure eliminates any further sources of discrepancy between the panel's country members. The null hypothesis for no cointegration in the pooled, between-dimensions estimation is:

$$\text{H}_0\text{:}\quad \rho_i = 1 \quad \text{for all } i \text{ against } \text{H}_0\text{:}\quad \rho_i = \rho < 1\text{:} \tag{10}$$

In the alternative hypothesis, the between-dimensions estimation does not assume a common value for pi. As a result, it offers another source of potential variation among some of the panel's country members.

To determine whether the cointegration vector is various, Pedroni recommends two types of testing. "The first is a test that employs a within-dimension strategy (i.e., a panel test). The panel v-statistic, panel ρ-statistic, panel PP-statistic, and panel ADF-statistic are the four statistics used in this test. The unit root tests on the calculated residuals are performed using these statistics, which pool the autoregressive coefficients across multiple panel members. The second test is a group test that uses a between-dimensions technique and comprises three statistics: a group ρ-statistic, a group PP-statistic, and a group ADF-statistic. These figures are based on estimators that average the individually estimated autoregressive coefficients of each panel member" (Pedroni, 2000).

3.4.3. Long-Run Structural Parameter Estimation

It is well known that once the long-run balance among the variables has been achieved, the long-run operational coefficients of the exogenous variables can be computed. Cointegration analysis has an extra advantage in that once it is established; the evaluations on the exogenous variables for the endogenous variable are realistic in both arithmetical and economic terms. Nevertheless, as there are numerous types of long-run estimators, the problem is which one should be used. There are several regularly used, and popular estimators; among them is the Ordinary Least Squares (OLS). The OLS has been replaced by the Dynamic Ordinary Least Squares (DOLS) and the Fully Modified Ordinary Least Squares (FMOLS) because of their superiority in addressing the potential endogeneity issue of explanatory residual autocorrelation and variables, allowing the variables to be made asymptotically asymptotic (Pedroni, 2004). When it comes to dealing with the issues of endogeneity and sequential correlation, the FMOLS estimate uses a non-parametric method, although the DOLS estimator employs a parametric method. In this situation, the DOLS estimator outperforms both the OLS and FMOLS estimators in terms of performance and efficiency, particularly in small samples (Kao & Chiang, 2000; Aghaei & Rezagholizadeh, 2017; Narayan & Smyth, 2007; Fei et al., 2011). It is worth noting that the coefficients derived by the DOLS are unbiased and consistent, according to Ofori and Asongu (2021). Also, According to Herrerias, Joyeux, Girardin (2013), the implementation of the DOLS estimator is the most appropriate way to handle the lack of cross-sectional unconventionality between panel series. The DOLS is the best estimator for studying the ICT-growth relationships. Thus, given the above-mentioned advantages, the DOLS estimator is used in this study to account for the intrinsic variability in long-run variances.

3.4.4. VECM Estimation

A VECM can be used to do a cause-effect evaluation if the variables are cointegrated (Pesaran, Shin, & Smith, 1999). Cointegrating regression can be used in a two-step method to acquire the error terms (Granger, 1988). F-statistic signifies the short-run causality for the short-run explanatory variables, while λ_{ik}, which is the coefficient of ECT_{Ik-1}, captures the long-run causality. If λ_{ik}, which is the coefficient of ECT_{Ik-1}, is statistically significant, it, therefore, suggests a long-run causal link between the variables. After establishing that, the following stage is to explore the direction of causality by utilizing the ECT obtained by the long-run VECM.

Here, we will use the panel-based VECM for determining the direction of causality between the variables, namely economic growth, Innovation diffusion, ICT development, and Human Capital, as follows:

$$\begin{bmatrix} \Delta \ln \mathrm{RGDP}_{it} \\ \Delta \ln \mathrm{ID}_{it} \\ \Delta \ln \mathrm{ICTD}_{it} \\ \Delta \ln \mathrm{HCD}_{it} \end{bmatrix} = \begin{bmatrix} n_{1j} \\ n_{2j} \\ n_{3j} \\ n_{4j} \end{bmatrix} + \sum_{k=1}^{p} \begin{bmatrix} \alpha_{1ik} & \beta_{1ik} & (L) \\ \alpha_{2ik} & \beta_{2ik} & (L) \\ \alpha_{3ik} & \beta_{3ik} & (L) \\ \alpha_{4ik} & \beta_{4ik} & (L) \end{bmatrix} \begin{bmatrix} \Delta \ln \mathrm{RGDP}_{it-k} \\ \Delta \ln \mathrm{ID}_{it-k} \\ \Delta \ln \mathrm{ICTD}_{it-k} \\ \Delta \ln \mathrm{HCD}_{it-k} \end{bmatrix} + \begin{bmatrix} \lambda_{1ik} & \mathrm{ECT}_{1IK-1} \\ \lambda_{2ik} & \mathrm{ECT}_{2IK-1} \\ \lambda_{3ik} & \mathrm{ECT}_{3IK-1} \\ \lambda_{4ik} & \mathrm{ECT}_{4IK-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \\ \varepsilon_{4it} \end{bmatrix} \quad (11)$$

Lag lengths are an important consideration when attempting to estimate VECM, as causality tests can be heavily influenced by the lag structure used. Bias occurs when there are too few or too many lags. However, short latencies may mean that key variables are being left out of the model, and this can lead to biased regression results, which can lead to incorrect conclusions. While this can save time and reduce the standard error of the estimates, it also reduces the reliability of the data because it wastes observations. The optimal lag length can't be determined with certainty, yet valid formal model definition criteria exist. This would significantly increase the computing load on a large panel like ours. Although the maximum lag lengths for all four variables can vary between countries, this will not be allowed in our VECM. We will utilize the well-known Akaike Information Criterion (AIC) to find the best lag structure for our model in this study.

4. Analysis of the Results

After grouping the countries by income groups based on the World Bank classification, we presented the empirical findings in four steps. First, we survey the nature of the time series factors' stationarity, as shown in **Table 2**. Second, we reveal the mechanism of their cointegration, as shown in **Table 3**. Third, we estimated the long-run structural parameters via the DOLS regression, as shown in **Table 4**. Finally, as shown in **Table 5**, the study shows evidence of the direction of Granger causality between the cointegrated variables using the VECM.

In the context of long-run analysis, it is possible to use cointegration to tackle the problem of series differentiation. By doing the cointegration test, the long-run information about unit root series may gleam more clearly. After determining that the variables have a panel unit root and are of the first difference, the step that follows next is to assess if there is a long-run interaction between the three variables. Panel long-run tests are used to determine whether or not

Table 2. Cross-sectional Augmented Dickey-Fuller (CADF) and Cross-sectional Im, Pesaran and Shin (CIPS) panel unit root test.

Variable	CADF		CIPS		Inference
	Overall Sample of EA.				
	Level	ΔLevel	Level	ΔLevel	
lnRGDP	−0.2284	−5.2881***	−0.2382	−4.2888***	I (1)
lnHCD	−0.2842	−5.2782***	−0.2298	−4.3002***	I (1)
lnID	−0.4953	−4.8364***	−0.5930	6.1391***	I (1)
lnICT	−0.5582	−4.8960***	−0.4573	−5.3751***	I (1)
Lower Middle-Income Countries (LMIC)					
lnRGDP	−0.1233	−3.0821***	−0.1528	−4.4372***	I (1)
lnHCD	−0.1431	−3.1120***	−0.1657	−4.6231***	I (1)
lnID	−0.1982	−4.3001***	−0.1901	−4.8291***	I (1)
lnICT	−0.2183	−4.6381***	−0.2891	−4.1922***	I (1)
Low-Income Countries (LIC)					
lnRGDP	−0.1528	−3.8171***	−0.1028	−3.9272***	I (1)
lnHCD	−0.1682	−4.171***	−0.1181	−4.0721***	I (1)
lnID	−0.1220	−3.9201***	−0.2819	5.0291***	I (1)
lnICT	−0.1882	−4.4891***	−0.1928	−4.4271***	I (1)

***Denotes statistically significant at the 1% level.

the variables used in the model are co-integrated (Sofka, Shehu, & de Faria, 2014; Ofori & Asongu, 2021; Oluwatobi et al., 2014). There are two classifications of cointegration analyses suggested by Pedroni. The V-statistic, -statistic, Philips Perron-statistic, and Augmented Dickey-Fuller statistic are the four tests that make up the first classification. These test statistics are clustered on the "within-dimension" and account for the panel countries' cross-sectional autoregressive estimations. The second categorization is based on the "between-dimension" and is defined by three tests: the Group statistic, the Group Philips-Perron-statistic, and the Group Augmented Dickey Fuller-statistic. These three tests are based on each panel country's common autoregressive estimations. The hypothesis of no difference in all tests states that there is no cointegration among the variables, whereas the hypothesis of different states that there is cointegration. In contrast to other homogeneous cointegration techniques like (Youndt et al., 1996) and (Johansen, 1988), Pedroni cointegration analysis considers the heterogeneity of the series across cross-sections. The results of the Pedroni cointegration analysis are shown in **Table 3**. The results show that the hypothesis of no difference or non-existence of cointegration is rejected at the 1% significance level. Therefore, the Pedroni panel cointegration test suggests a long-run relationship between innovation diffusion, ICT development, sustainable growth, and Human capital for the overall sample of East Africa and the sub-income groups.

Table 3. Pedroni panel co-integration test results.

Test statistics	No Intercept	With Intercept	With Intercept & trend
Overall Sample of EA.			
Alternative hypothesis (AH): common AR coefficients (within-dimension)			
Pv-s	−1.35 [0.47]	−1.27 [0.64]	−1.72 [0.79]
Pρ-s	−2.49 [0.03]**	−2.13 [0.08]*	−0.75 [0.07]*
PPP-s	−6.15 [0.00]***	−3.24 [0.00]***	−5.61 [0.00]***
PADF-s	−4.36 [0.01]***	−4.17 [0.00]***	−2.74 [0.02]**
A.H.: common A.R. coefficients (between-dimension)			
Gρ-s	−3.54 [0.00]***	−5.01 [0.00]***	−2.01 [0.08]*
GPP-s	−7.35 [0.00]***	−4.34 [0.00]***	−4.15 [0.00]***
GADF-s	−6.07 [0.00]***	−5.05 [0.00]***	−4.02 [0.00]***
Lower Middle-Income Countries (LMIC)			
A.H.: common A.R. coefficients (within-dimension)			
Pv-s	−1.59 [0.63]	−1.38 [0.69]	−1.36 [0.59]
Pρ-s	−5.50 [0.00]***	−2.09 [0.07]*	−3.42 [0.02]**
PPP-s	−5.58 [0.00]***	−4.43 [0.01]***	−4.52 [0.00]***
PADF-s	−4.92 [0.00]***	−3.56 [0.02]**	−3.63 [0.01]***
A.H.: common A.R. coefficients (between-dimension)			
Gρ-s	−4.18 [0.00]***	−3.14 [0.03]**	2.05 [0.08]*
GPP-s	−8.90 [0.00]***	−7.37 [0.00]***	−7.83 [0.00]***
GADF-s	−7.65 [0.00]***	−5.76 [0.00]***	−4.58 [0.00]***
Low-Income Countries (LIC)			
A.H.: common A.R. coefficients (within-dimension)			
Pv-s	−1.65 [0.29]	−1.62 [0.65]	−1.43 [0.72]
Pρ-s	−1.96 [0.08]*	−2.51 [0.02]**	−1.95 [0.07]*
PPP-s	−4.68 [0.00]***	−4.17 [0.00]***	−6.39 [0.00]***
PADF-s	−6.32 [0.00]***	−5.59 [0.00]***	−5.83 [0.00]***
A.H.: common A.R. coefficients (between-dimension)			
Gρ-s	−4.79 [0.00]***	−5.75 [0.00]***	−4.53 [0.00]***
GPP-s	−7.33 [0.00]***	−5.83 [0.00]***	−5.53 [0.00]***
GADF-s	−5.59 [0.00]***	−4.61 [0.00]***	−5.73 [0.00]***

***Denotes significant at the 1% level; **denotes significant at the 5% level; *denotes significant at the 10% level. PV-S = Panel v-statistics, Pρ-s = Panel ρ-statistics, PPP-S = Panel PP-statistics, PADF-S = Panel ADF-statistics, Gρ-s = Group ρ-statistics, GPP-s = Group PP-statistics, GADF-s = Group ADF-statistics, AR = Auto regression. Probability values are in parenthesis.

4.1. DOLS Results

After validating the existence of long-run relationships, we estimated the long-run coefficients via the DOLS, and the results are reported in Table 4. We

Table 4. Results of panel DOLS estimates.

Variable	Coefficient	Standard error	t-statistic	Probability
		Overall Sample of EA.		
lnID	0.075871***	0.009805	7.737817	0.0000
lnICT	0.226311***	0.051869	4.363102	0.0000
		Diagnostic checking		
R-squared	0.849596			
Adj. R-squared	0.837234			
LM = 3.6381 (0.5731); RESET = 2.7382 (0.4391); WHET = 4.7261 (0.4829)				
		Lower Middle-Income Countries (LMIC)		
lnID	0.052287**	0.021941	2.383118	0.0175
lnICT	0.119045***	0.037490	3.175371	0.0010
		Diagnostic checking		
R-squared	0.815159			
Adj. R-squared	0.750373			
LM = 3.4382 (0.2510); RESET = 3.4261 (0.6372); WHET = 4.5229 (0.4739)				
		Low-Income Countries (LIC)		
lnID	0.041248**	0.018364	2.246184	0.0251
lnICT	0.060473***	0.021548	2.806394	0.0052
		Diagnostic checking		
R-squared	0.821889			
Adj. R-squared	0.706783			
LM = 3.2991 (0.3829); RESET = 4.6320 (0.3922); WHET = 3.5362 (0.2839)				

LM = Lagrange multiplier test for serial correlation; RESET = misspecification test; WHET = heteroscedasticity test (White); ***denotes significant at the 1%; **denotes significant at the 5%.

used the overall sample, which includes the 10 East African countries selected for the study. To capture differences in income levels, we divide East African countries into three groups based on the World Bank classification: UMIC, LMIC, and LIC.

In the estimation, we look at the effect of innovation diffusion and ICT development on sustainable growth. The long-run approximations of the DOLS model analysis are reported in Table 4. The empirical study results show that ICT development significantly increases sustainable growth in all the groups (EA, UMIC, LMIC, and LIC). This implies that a 1% increase in ICT development in EA, UMIC, LMIC, and LIC increases sustainable growth by approximately 0.23%, 0.24%, 0.12%, and 0.06%, respectively. These estimates support the findings of Cheng, Chien, and Lee (2020); Pradhan et al. (2014). A possible explanation of this effect of ICT development on sustainable growth could be that since fixed telephone subscriptions, and fixed broadband subscriptions are some of the main components of ICT development, this could be a pointer to the fact that more of the telecommunication indicators have been used in the development of ICT as a whole in East Africa, which is an indication that many of the East African countries can rely on ICT development to boost their economies.

With regards to the relationship between innovation diffusion and sustainable growth, the results follow a similar pattern, just as in the relationship between ICT development and sustainable growth. From the DOLS model estimates, innovation diffusion has a positive and significant impact on sustainable growth in all the groups (EA countries, UMIC, LMIC, and LIC). This suggests that a 1% growth in innovation diffusion in EA, UMIC, LMIC and LIC increases sustainable growth by approximately 0.08%, 0.15%, 0.05% and 0.04% respectively. These estimates support the findings of Pradhan et al. (2016).

On the whole, these results indicate that ICT development and innovation diffusion in terms of the DOLS are capable of spurring sustainable growth. However, the magnitude of the long-run elasticity of sustainable growth with respect to ICT development and innovation diffusion in the DOLS is much greater in the model for UMIC than in the models for LMIC and LIC, respectively. It appears that, although the merits of ICT development and innovation diffusion are evident, however, the diffusion of innovation has been at a slow rate as opposed to ICT development. This implies that ICT development contributes more to sustainable growth, followed by innovation diffusion in UMIC, LMIC, and LIC, respectively. This confirms the different roles of ICT development and innovation in the sustainable growth process. The finding is in line with the works of Pradhan and Nguyen, who obtained the same results for G-20 countries (Pradhan et al., 2014; Nguyen, Pham, & Tram, 2020). Nguyen observes that ICT development is more sensitive to variations in economic growth (Nguyen, Pham, & Tram, 2020). This greater sensitivity occurs because ICT development activities through the acceleration of fixed telephone subscriptions and fixed broadband subscriptions speed up economic growth. Rudra has a similar result on the role of ICT development, Innovation diffusion, and venture capital in speeding up economic growth in European countries and consequently agrees with the theoretical underpinning.

4.2. Panel VECM Granger Causality Results

In **Table 5**, we present the output from the VECM Granger causality for both the short and long run. The short-run results presented in **Table 5** reveal two-way causality between innovation diffusion and sustainable growth and between ICT development and sustainable growth for the overall EA sample. Moreover, the output reveals the existence of one-way causation from ICT development to innovation diffusion in the short run for the overall EA sample. In other words, ICT development had a substantial impact on innovation diffusion

Table 5. Results of VECM Granger-causality test.

	$LnRGDP_{t-i}$	$lnHCD_{t-i}$	$lnID_{t-i}$	$lnICT_{t-i}$	$ECT_{(-1)}$
Overall Sample of EA.					
lnRGDP	-	3.8921*** [0.001]	5.1879*** [0.005]	2.0871** [0.030]	−0.15328*** [−5.537]
lnHCD	4.6721*** [0.005]	-	2.9523*** [0.012]	3.9287*** [0.004]	−0.0867*** [−3.534]
lnID	4.0575*** [0.003]	4.0259*** [0.034]	-	4.2262*** [0.002]	−0.0926*** [−7.939]
lnICT	7.1612*** [0.000]	5.4209*** [0.007]	1.0227 [0.266]	-	−0.0738*** [−5.083]
Lower Middle Income Countries (LMIC)					
lnRGDP	-	6.3271*** [0.000]	5.6822*** [0.000]	6.6392*** [0.000]	−0.0233*** [−4.2649]
lnHCD	5.0137*** [0.001]	-	5.0061*** [0.000]	6.9281*** [0.006]	−0.0981*** [−5.964]
lnID	6.2681*** [0.000]	4.9936*** [0.003]	-	9.5720*** [0.000]	−0.0682*** [−5.652]
lnICT	4.5219*** [0.001]	4.0632*** [0.005]	7.6388*** [0.000]	-	−0.1088*** [−7.536]
Low Income Countries (LIC)					
lnRGDP	-	5.1748*** [0.004]	4.9083*** [0.000]	5.0637*** [0.000]	−0.0773*** [−6.736]
lnHCD	3.9870*** [0.021]	-	5.3402*** [0.001]	4.8561*** [0.003]	−0.0634*** [−6.120]
lnID	2.0822** [0.041]	2.8346*** [0.000]	-	5.1832*** [0.000]	−0.0473*** [−5.748]
lnICT	5.4252*** [0.000]	4.7128*** [0.007]	5.4381*** [0.000]	-	−0.0914*** [−6.643]

in the short run and not the other way around. This is not surprising because so many new and innovative activities are heavily dependent on ICT services. The demand for greater ICT development appears to rise in tandem with the rate of innovation dissemination, and this relationship was proven to have an effect on ICT development.

The long-run causality output is denoted by $ECT_{(t-1)}$, and the results are shown in the last column in Table 5. Starting with the overall EA sample, the model where sustainable growth is the endogenous variable, the $ECT_{(t-1)}$ is −0.15328. This value exhibits that ICT development and innovation diffusion Granger-cause sustainable growth in the long run with the ability to adjust at a rapid pace of about 15.32%. Additionally, the outputs show that sustainable growth and ICT development Granger-cause innovation diffusion in the long run with the ability to adjust at a rapid pace of around 9.26%. The outcomes further show that sustainable growth and innovation diffusion Granger-cause ICT development in the long run with the ability to adjust at a rapid pace of about 7.38%.

Now moving to the income groups, the outcomes from the long-run results show that ICT development and innovation diffusion Granger-cause sustainable economic growth with the ability to adjust at a rapid pace of around 10.22%, 2.33%, and 7.73%, for UMIC, LMIC, and LIC countries respectively. Likewise, the findings show that the variables converge to a long-run steady-state by approximately 13.09%, 10.88%, and 9.14% for the ICT development model after the occurrence of a shock for UMIC, LMIC, and LIC countries, respectively. Also, the outcomes from the long-run results show sustainable economic growth and ICT development Granger-cause innovation diffusion with the ability to adjust at a rapid pace of approximately 8.26%, 6.82%, and 4.73%, for UMIC, LMIC, and LIC countries, respectively.

The overall results reveal that the outcomes of the long-run analysis via the DOLS are consistent with empirical findings in the extant literature regarding the roles of ICT development (Yousefi, 2011; Iscan, 2012; Asongu & Le Roux, 2016; Ejemeyovwi et al., 2021; Pradhan, Mallik, & Bagchi, 2018), and innovation diffusion (Ejemeyovwi et al., 2021; Cheng, Chien, & Lee, 2020) in spurring economic growth. The long-run results also confirm that innovation diffusion, ICT development, and sustainable growth reinforce each other in this research via the panel VECM.

5. Conclusion

This study contributes to the debate on how EA countries can foster sustainable growth. Consequently, we diverge from the existing debate on how this can be achieved through empirical research. Inspired by the significant rise in ICT development and the anticipated rise in innovation diffusion in EA following the drastic transformation due to the revolution of technology associated with the development of wireless, mobile communication systems and the liberalization process, we examine the long-run and short-run relationships among innovation diffusion, ICT development, sustainable economic growth, and human capital in EA We used annual time series data that spans from 2000 to 2020 for a sample of 10 EA countries selected based on data availability for all the indicators used in the study. We provide evidence robust to several specifications from the panel DOLS estimation and the panel VECM that captured the direction of causality among the variables to show that: 1) both ICT development and innovation diffusion foster sustainable economic growth and human capital development in EA, 2) ICT development, innovation diffusion sustainable growth and human capital, reinforce each other, 3) compared to innovation diffusion, ICT development is more effective in driving sustainable economic growth in EA.

Considering the progress made by most Western and East Asian countries in recent times through ICT development and innovation diffusion, our findings offer sparks of confidence in promoting collective prosperity in E.A. First, the results show that ICT can offer policymakers concerned with the growth agenda of EA countries, convincing means of addressing problems associated with ICT infrastructural development to induce sustainable growth through enhanced ICT access, ICT use, and ICT skills. Our pathway results on innovation diffusion and ICT development show that making shared prospects in EA may not just be about improving infrastructural investment but an innovative ICT infrastructure that gear toward sustainable growth and transformation in the continent.

Based on the findings above, it is proposed that policymakers should focus their efforts on improving the continent's ICT capabilities, accessibility, and adoption. This can be achieved if entities engaged in the EA agenda for prosperity, such as the ADB and the World Bank, provide the support needed to complement different governments' efforts in advancing ICT penetration in the continent. Additionally, legislative actions are needed to help grow the continent's tech hubs to aid in the marketing of high-tech products, as well as to help establish patents so that the continent's young and innovative population may help build the continent.

In summary, ICT sector advances are changing the global economy at an unprecedented rate. ICT advancement and innovations are having a greater impact on countries' sustainable economic growth. Development plans should incorporate initiatives to boost ICT penetration rates and establish national innovation systems that can have a stronger multiplier effect on the national economic gain. ICT penetration and Innovation diffusion can be bolstered by the introduction of effective governmental measures to assure long-term economic growth.

Lastly, we recommend that the United Nations database on Science, Technology, and Innovation should be a primary source of information for innovation diffusion of future research. These data can be used to test if the study's empirical model holds up when combined with additional measures of innovation, however sparse they may be. To further explore the relationship between sustainable growth and innovation, some of this data can be used as an explanatory variable and incorporated into the model.

Author Contributions

Authorship contributions: MR: Conceptualization, Data curation, formal analysis, methodology, writing-preparation of the original draft of the manuscript, and review and editing. LS: Conceptualization, methodology, review, and supervision. All authors have read and agreed to the published version of the manuscript. BE: Conceptualization, Data curation, formal analysis, methodology, writing-preparation of the original draft of the manuscript.

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Data Availability Statement

The data that support the findings of this study are available upon reasonable request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix A

Table A1. Summary results of principal component analysis of ICT development.

Overall Sample of EA.			
Correlation Matrix			
	ICT access	ICT use	ICT skills
ICT access	1.000		
ICT use	0.127	1.000	
ICT skills	0.219	0.131	1.000
Eigen Analysis of Correlation Matrix			
PCs	Eigen Value	Proportion Variance	Cumulative Percentage
1	3.019	0.942	0.942
2	0.642	0.039	0.981
3	0.083	0.019	1.000
Eigen Vectors (component loadings)			
	PC1	PC2	PC3
ICT access	0.428	−0.372	0.283
ICT use	0.510	0.049	0.527
ICT skills	0.271	0.115	0.162
Lower Middle-Income Countries (LMIC)			
Correlation Matrix			
	ICT access	ICT use	ICT skills
ICT access	1.000		
ICT use	0.206	1.000	
ICT skills	0.174	0.238	1.000
Eigen Analysis of Correlation Matrix			
PCs	Eigen Value	Proportion Variance	Cumulative Percentage
1	3.510	0.752	0.752
2	0.677	0.108	0.860
3	0.036	0.140	1.000
Eigen Vectors (component loadings)			
	PC1	PC2	PC3
ICT access	0.436	0.417	0.215
ICT use	0.448	0.183	−0.196
ICT skills	0.319	0.172	0.157

Continued

Low-Income Countries (LIC)			
Correlation Matrix			
	ICT access	ICT use	ICT skills
ICT access	1.000		
ICT use	0.142	1.000	
ICT skills	0.286	0.227	1.000
Eigen Analysis of Correlation Matrix			
PCs	Eigen Value	Proportion Variance	Cumulative Percentage
1	3.042	0.889	0.889
2	0.495	0.068	0.957
3	0.062	0.043	1.000
Eigen Vectors (component loadings)			
	PC1	PC2	PC3
ICT access	0.363	−0.366	0.226
ICT use	0.315	0.173	−0.183
ICT skills	0.287	0.191	0.149