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Impact of ICT Diffusion on the Economic Growth and Its Volatility: A Case Study on African and MENA Countries

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ABSTRACT

In this paper, we examine the empirical relationship between ICT diffusion and the interaction between economic growth and its volatility for 30 African and MENA countries between 1998 and 2020. To achieve this, we calculated the interaction between mean growth and its fluctuations over different non-overlapping intervals (3 years) using inverse hyperbolic sine calculations. A composite ICT indicator was used, including access to ICT, capacity to use ICT and ICT-related skills. Using the S-GMM technique that addresses multiple econometric questions, the results show that ICT penetration has a statistically negative effect on the interaction of growth and its turnover. This means that higher ICT penetration may lead to slower and more volatile growth.

However, by introducing an interaction variable (defined as the base level of GDP multiplied by the ICT development index), the estimates reveal that these variables have a statistically positive effect on the interaction between growth and its volatility. When ICT diffusion interacts with a country's level of economic development, it can have a positive impact on economic growth and its volatility. The results show that the impact of ICT diffusion depends on the specific characteristics of a country, especially its level of economic development. In particular, the marginal effects of ICT are significant for high-income countries.

Keywords: Information and Communication Technologies (ICT), growth, volatility, S-GMM

JEL Classification: O11 · O43 · C13 · C23

INTRODUCTION

Over the past ten years, there has been a remarkable surge in the development of information and communication technologies (ICT). A mobile network covers more than 90% of the world's population, with half of the population using cell phones. The pandemic accelerated the growth of Internet usage, according to ITU statistics. Currently, over 4.1 billion people are utilizing the Internet, which accounts for 54% of the world's inhabitants. The number of users has jumped by 782 million, reaching a total of 4.9 billion, or 63% of the population, in 2021. 96% of people who are not connected to the internet live in developing countries, leaving approximately 2.9 billion individuals unconnected. Access is just one of the many barriers non-users encounter.

The development of ICT has seen spectacular growth over the past decade. The situation has changed radically, with a mobile network covering more than 90% of the world's population, and more than half the population using cell phones. ITU statistics show that Internet use accelerated during the pandemic. By 2019, 4.1 billion people (54% of the world's population) were using the Internet. Since then, the number of users has risen by 782 million to reach 4.9 billion in 2021, or 63% of the population. This means that some 2.9 billion people remain offline, 96% of whom live in developing countries. Those not yet connected face multiple obstacles, including lack of access.

Developed countries have been quick to introduce digitization into most of their sectors in order to maintain their dominance and progress on the world stage. However, the progress of African countries in the field of ICT and technological development is not yet clear.

Although cell phone use has been growing rapidly in African nations, with an annual rate of 65% over the past five years (twice the global average), the development of information and communication technology (ICT) is still considered the world's most deficient.

The promotion of ICT in a singular manner is seen as a potential catalyst for increasing the dependence of impoverished nations, as well as widening gaps between urban and rural areas, generations, and socioeconomic statuses. Some individuals who hold less favorable views about the direct advantages of ICT are of this opinion. These countries lag behind in the Human Development Index (HDI) rankings and there are huge disparities even within the continent's countries. Some believe that less emphasis should be placed on access to the Internet and ICTs, and more on reliable electricity, medical care, food and water supplies, which are not within everyone's reach.

Achievement of development goals can be facilitated by ICTs according to the more hopeful. They view ICTs as a tool to surpass developmental stages and technological roadblocks that would permit economic growth and encourage comprehensive development in underdeveloped countries. By providing users with new communication possibilities through voice services and emerging technologies, such as Internet access via mobile phones, the need for a computer to connect to the World Wide Web can be eliminated.

The question of whether or not ICT investments contribute to economic growth has been debated in the literature over time, with varying degrees of empirical evidence for developed and developing countries. Based on empirical studies, the results are mixed and are not without ambiguity. According to Enowbi (2008), there is a significant and positive correlation between telecommunication infrastructure and regional growth in Africa, after controlling for a number of other factors. Several years later, Okogun (2012) shows that, for most African countries, the contribution of ICT to economic growth may be insufficient or minimal due to the inability of these countries to adapt to digital change. Indeed, due to low internet usage, ICTs are often considered secondary and the topic fuels heated debates.

Despite significant progress in empirical analysis of the impact of ICTs on economic growth, Solomon and van Klyton (2020) point out that there are three gaps. First, qualitative studies on digitization (e.g. Dewa et al., 2018; Grunig, 2009) do not fully establish the causal effects of digitization on productivity. In addition, these studies have not examined the mechanisms by which ICT hinders or enhances economic growth. Second, while many empirical studies carried out in developed countries establish a strong correlation between digital infrastructure, productivity, employment and economic growth (Baquero Forero, 2013; Castellacci, 2011; Evangelista et al., 2014), there are few empirical studies of the effects of this relationship in African countries, particularly with regard to the impact of ICT use on economic growth. Myovella et al. (2020) indicate that the mixed results of the empirical tests support the idea that the effect of ICT is not automatic and depends strongly on country-specific characteristics. Finally, previous studies such as Evangelista et al. (2014) and Counted and Arawole (2016) suggest that it is better to study the impact of ICT use on growth rather than ICT access.

In addition to these three shortcomings, the contribution of our work must be understood from a triple observation. First, these empirical works have sought to study the effects of ICTs on economic growth, productivity and employment (Gómez-Barroso & Marbán-Flores, 2020; Vu et al., 2020), but do not directly address the impact of the diffusion of ICT on the interaction of growth and its volatility. Little research has examined the effects on the volatility of economic growth induced by ICT diffusion. DaSilva et al. (2017) criticized the use of standard deviation of economic growth as a measure of growth volatility, showing the inability to

compare fluctuation between economies with different average growth levels. For this reason, we investigate whether the ICT revolution has a significant influence on both growth and its volatility. As shown by Ferraro (2017), countries whose growth rate of real GDP per capita is more volatile, have a relatively long time in ICT adoption and therefore show low growth. Second, the majority of studies use different ICT indicators separately (e.g., Internet users, imports of ICT goods, and mobile service subscriptions). This choice risks neglecting the level of ICT literacy in the economy can also be an important determinant of Internet use by businesses, as creating a website requires more than basic computer skills. Taking into account its effects, we construct the ICT index from these components capture a general measure of the ICT revolution. This could produce consistency of results regardless of the included ICT surrogates.

Finally, econometric studies of African growth have highlighted the role of geographical factors such as climate, natural resource endowment and location, (Bloom & Sachs, 1998) and institutional factors such as political regime and legal system (Temple, 1998). In this study, we assume that a country's growth opportunities are determined by ICT development. For a dataset covering 30 MENA and African countries, we apply the two-stage generalized method of moments (S-GMM) estimator. With this in mind, the paper highlights the specific features of the countries in the sample. It considers an interaction variable which is a variable of interest in our study. The interaction term is defined as the product between the ICT development index and economic development measured by the initial GDP level. We expect a positive and significant sign for this interaction term.

The empirical analysis was inspired by the work of Da Silva et al. (2017) and Nguyen et al. (2022). We calculated the interaction of mean growth and its fluctuations over different non-excess intervals (3-year periods) using the inverse calculation of the hyperbolic sine. ICT development indicators were developed for all sample countries and for the period 1998-2020. The index combines three dimensions (access, use and skills) and takes into account the importance of ICT investment, use and adaptation to ICT.

This paper is organized as follows. In section 2, we present a brief review of the theoretical and empirical literature on the link between ICT development and the interaction between growth and macroeconomic volatility. The data and methodologies are described in section 3, followed by the empirical results in section 4. The final section concludes the paper.

LITERATURE REVIEW

In recent years, the effect of ICT diffusion on economic growth has been widely discussed by researchers. The debate on the contribution of ICT to economic growth remains topical and controversial. This theoretical controversy has also given rise to a great deal of empirical work, and the debate is still not conclusive.

A Theoretical Analysis

Research on ICT and economic growth is mainly based on two theoretical frameworks that refer to two economic approaches, namely the exogenous theory and the endogenous theory.

Both postulates emphasize the importance of technological change in economic growth, but differ in their nature.

In the case of the exogenous theory, technological change is not explained in the model, which gives rise to the "Solow residual". Solow (1987) shows the negative effect of ICT on the accessibility of financial services. Neoclassical theory, however, holds that technical progress in one industry is not expected to promote total factor productivity (TFP) growth in other industries. On the contrary, the endogenous theory provides an explanation of technological change and negates the condition of the exogenous variable (outside the model).

However, according to neoclassical theory, technical progress in one industry is not supposed to promote total factor productivity (TFP) growth in other industries.

According to Imbs (2007), the link between economic growth and volatility is theoretically ambiguous. Endogenous growth is affected by the volatility of the business cycle, negatively in the presence of diminishing returns on investment and positively in the presence of precautionary savings, innovative creative destruction, liquidity constraints or if high-return technologies are highly risky. In their study, Ramey and Ramey (1995) showed that countries with highly volatile GDP have lower growth rates, particularly during economic downturns, particularly in a sample of smaller OECD countries.

The literature suggests different ways in which ICT can generate economic growth. Although these proposals are not completely homogeneous, traces of consensus can be identified. Indeed, two main types of effects are put forward: direct effects and indirect effects. Direct effects generally refer to productivity improvements that arise explicitly from the application of ICT, while the indirect effects represent the materialization of the externalities generated by the application and development of ICT. In this sense, Skorupinska and Torrent-Sellens (2014) show that ICTs increase both productivity and economic growth in a direct way, but also in an indirect way through the creation of complementary innovations that influence the total productivity factor.

Albiman and Sulong (2017) specify some theoretical ways in which ICT influences economic growth. First, the efficiency and flexibility of banking and personal transactions, through the use of e-commerce and e-business, which, combined with improved personal communications, can increase productivity and economic growth. Second, the innovations and research and development that result from ICT development have a positive impact on economic growth.

Venturini (2009) points out that ICT development has a dual effect. On the one hand, ICT development improves communication, information efficiency and access to external knowledge about the technology, but collaterally, in some cases, it generates additional productivity returns. On the other hand, industries that develop ICT generate important knowledge in the process.

ICTs are a source of knowledge diffusion, due to their ability to create a network effect and foster knowledge externalities. From this perspective, Vu distinguishes three channels through which ICT can contribute to economic growth. The first channel affects the diffusion of knowledge and innovation, driven by ICT penetration, and is distributed mainly from advanced to developing countries. The second channel concerns the efficiency of resource allocation, as ICT improves decision making. The last channel concerns the reduction of production costs, the promotion of demand and the increase of investments generated by ICT penetration.

In summary, the explanations provided fall into five groups. While growth theories, the theory of contestable markets, the transaction cost theory of financial innovation, and the diffusion of innovation theory show the positive effect of ICT on access to financial services, Solow (1987) shows the negative effect of ICT on the accessibility of financial services. Neoclassical theory, however, holds that technical progress in one industry is not expected to promote total factor productivity (TFP) growth in other industries.

The main theoretical analyses of the links between ICT and growth suggest a number of transmission channels whose effects may differ according to the time horizon. Indeed, the diffusion of ICTs can have lasting effects on potential growth in the medium and long term, via capital-labor substitution effects and multifactor productivity gains, and more transitory effects in the short and medium term, linked to the delayed adjustment of wages to productivity gains. ICTs transform the production chain on the supply side by improving the production

process since they change the form of capital (input) as well as the technology used or the quality of work.

In recent decades, macroeconomists have tended to analyze the causes of fluctuations and the drivers of growth separately. However, recent theoretical and empirical work has challenged this conventional wisdom by concluding that volatility can be associated with growth (Kroft & Lloyd-Ellis, 2002).

However, the theoretical relationship between economic growth and its volatility is not conclusive.

In this paper, in addition to the relationship between ICT penetration and economic growth, we are interested in another possible influence of ICT diffusion on growth volatility.

Our proposition is that the impact of ICT diffusion on economic growth depends on the volatility of growth and the level of economic development of a country. For this reason, we use a new variable to assess the interaction between economic growth and its volatility. We have integrated growth and its volatility into an overall indicator to provide sufficient aspects of the efficiency of the activity. In other words, growth and its volatility need to be included in a single indicator in order to obtain a complete picture of the driving effect of ICT-related factors on the interaction between economic growth and its fluctuations.

The question is: Does ICT diffusion have an effect on both the rate of economic growth and its volatility? We note that the answer to this research question could enable us to better understand the impact of ICT on economic growth and its volatility. However, the effect of ICT on economic growth depends on economic instability, so the effect is negative if the increase in volatility outweighs that of economic growth. In this case, increased growth would be followed by greater instability, so the contribution of ICTs would be low. On the contrary, it would be possible to record a strong contribution from ICTs to economic growth if volatility is high.

This paper examines the relationship between ICT diffusion and the interaction between economic growth and its volatility. Our main finding is that, at high levels of economic development, the impact of ICTs becomes positive for economic growth.

Empirical Review of Literature

Empirically speaking, the contribution of ICTs to economic growth has been the subject of a number of studies. Several studies have confirmed a positive relationship between ICT and economic growth and productivity (Jorgenson, 2001; Nasab & Aghaei; 2009, Vu, 2011; Timmer & van Ark, 2005; Kretschmer, 2012; Cheng et al., 2021).

Other studies have highlighted the negligible or even negative impact of ICT diffusion on economic growth and employment (Dewan & Kraemer, 2000; Hassan & Islam, 2005; Ishida, 2015; Lee et al., 2005; Pohjola, 2001; Yousefi, 2011).

A considerable number of empirical studies have sought to find a linear relationship between ICT and economic growth. Several indicators have been used such as cell phones, personal computers and Internet use. The results show that these indicators taken separately have a positive impact on economic growth in many countries, especially in industrialized countries (Gruber & Koutroumpis, 2010; Inklaar et al., 2005; Koutroumpis, 2009; Vu, 2011). Andrianaivo and Kpodar (2011) show a significant contribution of ICT to economic growth in African countries between 1988 and 2007, using various measures of ICT such as mobile and fixed line adoption rates, as well as local call costs. Waverman et al. (2005) conducted a study of 92 countries, both developed and developing. Their results showed that ICTs have a positive and significant impact on economic growth, and that this impact can be twice as great in developing countries as in developed ones.

Guitat and Drine (2007) used estimates of ICT capital stock (hardware, software and telecommunications equipment) to estimate the direct and indirect contributions of ICT to

growth in 14 countries in North Africa and the Middle East (MENA) between 1992 and 2004. They concluded that ICT had a positive and significant direct impact on GDP (especially for oil-producing countries). Comparing these results with those of other regions, they showed that the overall contribution of ICT investment to GDP was positive and significant for OECD and Asian countries, while it was negative and significant for sub-Saharan African countries.

The second strand of the literature has focused on the causal link between ICT and economic growth. For example, Roller and Waverman (2001), showed a significant positive causal link between investment in telecommunications infrastructure and subsequent economic success in 21 OECD countries over a 20-year period (1970-1990). Similarly, Vu (2011) indicates that the penetration of personal computers, cell phones, and Internet users has a strong causal effect on economic growth. In addition, Pradhan et al. (2018) using a sample of G-20 countries covering the period 2001-2012, show empirical evidence of a causal effect of ICT infrastructure on economic growth. Stanley, T. D. et al (2018) investigated the question: is there really a link between ICT and national economic growth? They showed that ICT has indeed made a positive contribution to economic growth, at least on average. Both developed and developing countries benefit from landline and cellular technologies, with the growth effect of cellular technologies being around twice that of landlines. However, developed countries benefit significantly more from computing than developing countries. On the other hand, they concluded that there was little evidence of the positive impact of the Internet on growth.

After that, several works started exploring a possible non-linear relation between ICT development and growth, originating the third main related line of work. For example, Sassi and Goaied (2013) show that in the MENA region, above a threshold of Internet users explosive economic growth occurs. In the same idea, Albiman and Sulong (2017) indicate the existence of non-linear links between ICT and economic growth in Sub-Saharan Africa. Using data for 27 countries over the period 1990-2014, the authors show that only Internet development has a positive impact across all income groups, while the effect of other ICT indicators is mixed depending on the level of economic development.

Finally, the fourth strand of literature studied the impact of ICT development on economic growth volatility, measured by the standard deviation of GDP per capita growth. More recently, Nguyen et al. (2022) study the role of ICT on the interaction between growth and its volatility. Using a comprehensive panel of 122 economies covering the period 2000–2019, the authors found that all proxies for the ICT revolution show positive impacts on the product of growth and its volatility. This means that an increase in ICT diffusion could lead to both higher growth and lower growth volatility.

In this paper, we extend the previous literature by capturing both aspects of growth. We examine the impact of ICT diffusion on economic growth and its volatility by using a ICT development index comprising three sub – index which capture ICT readiness, ICT intensity and capabilities or skills. ICT development index is used to monitor and compare developments in information and communication technology (ICT) between countries and over time.

DATA AND METHODOLOGY

Data

We use a comprehensive country-level sample of 30 economies covering the period of 1998–2020. The list of countries is reported in Table A1 of the Appendix. The statistics are those published by the World Bank and the International Telecommunications Union. We choose the ICT Development Index (Idi), the domestic credit to the private sector/GDP ratio, trade openness, the inflation rate and the initial real GDP per capita.

Before presenting and discussing the estimation results, we use the graphs to describe the ICT development indices (Idi), economic growth rate and economic volatility in each country group.

The Idi Index is based on a three-step conceptual framework, which aims to comprehensively represent the dynamics of economic and social impacts produced by ICTs. The first step is to have an ICT infrastructure in place and widely accessible. As part of the second stage, the ICT infrastructure must be used, skills having an impact on the quality of use. These two steps then produce impacts (third step).

The Idi Index focuses on the first two stages, and its framework has three dimensions, namely ICT access, ICT use and ICT skills. In our case, the method used to calculate the ICT development index is the same as that used to calculate the revised Idi index and the original Idi index. The most important problem with the Idi index is the very low availability of data. In the context of a composite indicator, it is essential to optimize the availability of data for the countries considered if the comparison is to be meaningful.

Some indicators were excluded due to insufficient data quality. For this reason, instead of excluding a country due to low data availability we preferred to calculate an aggregate index score based on a small amount of data.

The ICT skills indicator includes the gross enrolment rate in primary, secondary and tertiary. The indicator related to access to ICT includes Number of fixed telephone subscriptions per 100 inhabitants Number of mobile cellular subscriptions per 100 inhabitants. The indicator related to ICT use includes the percentage of individuals using the Internet.

The first group of countries has an average Idi value of 5.51, while it is only 2.78 for the second group, almost half as much.

The Idi index for Africa is the lowest, with only five countries – South Africa (4.21), Tunisia (4.18), Algeria (3.48) and Gabon (3.57). The four Gulf countries (Bahrain, Kuwait, Qatar, and Saudi Arabia) have an average Idi value of 6.4.

Several African countries are considered among the least connected countries. The bottom countries in the Idi ranking are all African countries, including Guinea, Angola Mozambique, Burundi and Burkina F, five countries with an average Idi value of 2.

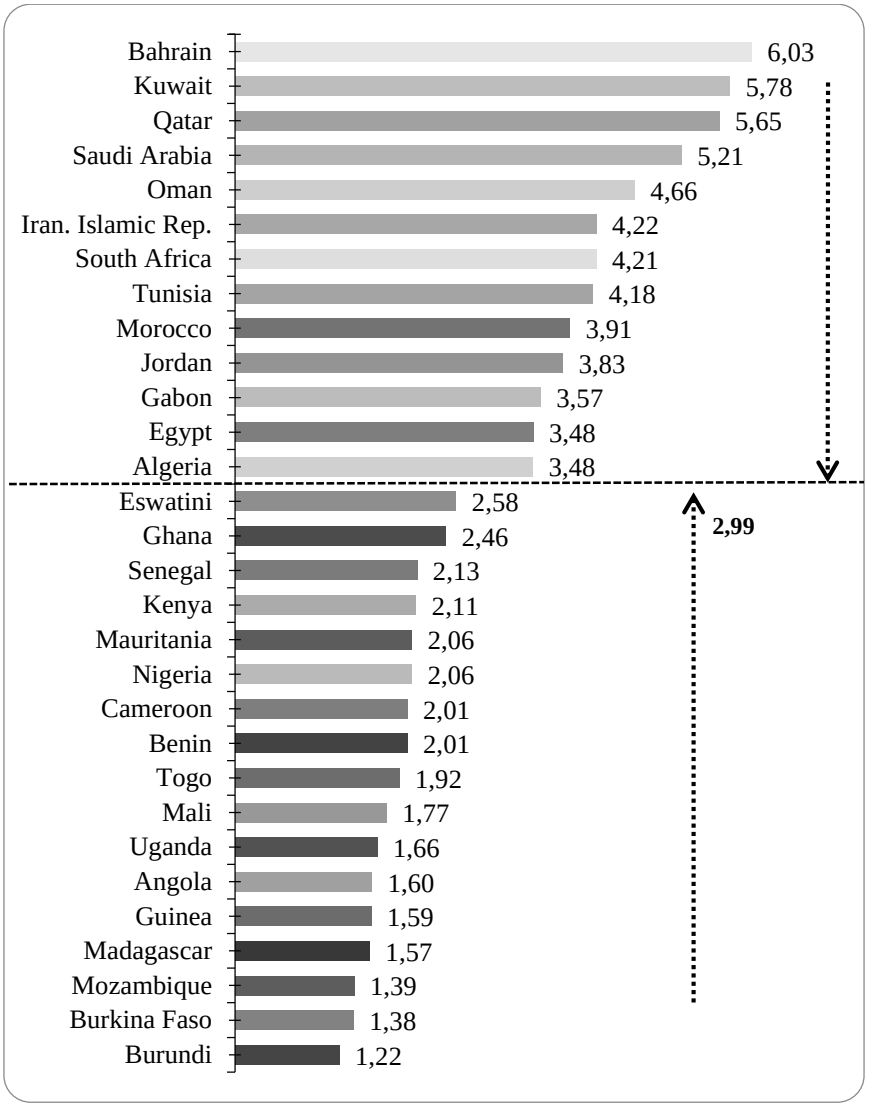

Figure 1: Classification by level of ICT development

There is a remarkable gap between connected and less-connected countries in terms of access to certain information and communication technologies. Statistics from the International Telecommunication Union (ITU) clearly show that, compared with MENA countries, the African population has not yet fully entered the digital age. The spread of other digital technologies, such as the Internet, has not seen the same progress as the mobile telephony sector.

In implementing an ICT development strategy, some African countries are lagging behind, as the disparity between African and MENA countries suggests, despite the rise in the ICT indicator shown in Figure 2. It is worth noting, however, that all countries in the sample have been successful in digitizing.

The International Telecommunication Union (ITU) in 2021 revealed that the Internet access targets of the least developed countries remain out of reach despite the boost in cell phone network accessibility.

African adults face various obstacles when it comes to obtaining services and managing expenses. One of the reasons why is due to lack of digital literacy and internet know-how. Additionally, a significant factor in this dilemma is the expensive cost of services that are required for online access. Despite these challenges, cellular phone usage is popular throughout the continent, but it does not translate to the majority of the population having internet access.

Actually, less than half (45%) of African adults have access to the internet. Their phone, with the power of the internet, is always in their grasp.

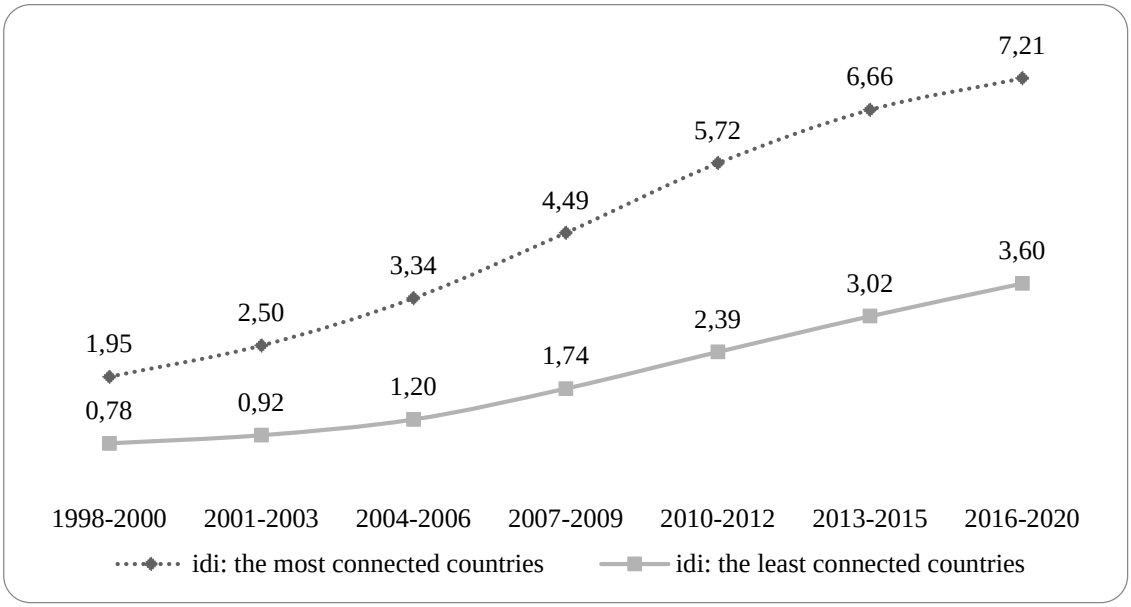

Figure 2: The evolution over time of ICT developments within countries

Measuring macroeconomic volatility entails the utilization of a standard deviation. Such a measure calculates the extent and distribution of a variable surrounding a central value within a specific time frame. To determine production volatility, we calculate the standard deviation of a 3-year period ranging from 1998-2020.

The volatility of production is directly related to the fluctuations in production. Keep in mind that the more fluctuations in production, the greater the volatility. When growth rates are higher, the impact of economic growth volatility is not as significant.

Take this scenario as an instance: it is not the same thing when the growth rate averages fluctuate between 10 and 20 percent despite the volatility in growth over time, compared to when the growth percentage ranges between 1 and 5 percent. Calculating the volatility and average GDP growth rates for both the least and most connected countries is presented in Figure 3.

The evolution of real GDP growth rates is unstable and fluctuating, making it impossible to describe a trend most of the time. The convergence of growth trajectories (volatility and average rate) between the two groups of countries is a result worth highlighting. Growth patterns clearly reveal structural differences between these two groups of countries over the seven periods. The average annual GDP growth rates of the least connected countries compared to the most connected countries are significantly higher.

For the least connected countries, we observe a negative relationship between volatility and average growth rate of real GDP per capita growth. For example, the period 2016-2020 is characterized by a phase of low growth but also of high volatility.

For the most connected countries, figure 3 shows that during the periods 2007-2009, 2010-2012, 2013-2015 and 2016-2020, economic growth and its volatility have a negative relationship.

High growth volatility is a characteristic of the most connected countries (MENA countries) compared to other African countries, due to their dependence on oil exports, which increases their vulnerability to external shocks and creates uncertainties about growth. With the exception of a few oil-importing countries, the rest of the region depends on oil exports. In two-thirds of the 18 countries in the region, the oil sector is the main source of income: oil

revenues account for some 60-90% of their total export earnings, and more than 60% of their tax revenues.

In summary, examination of the data for the reference period shows that trend GDP growth is negatively correlated with output volatility. However, for the periods 2004-2006 and 2010-2012, countries recorded a high growth rate for a low level of volatility. The effect of volatility on trend growth is weaker. However, for the periods 2007-2009 and 2010-2012 and 2016-2020, the gap between growth and volatility is greater for the most connected countries. The least connected countries recorded a high growth rate for a low level of volatility. The effect of volatility on trend growth is weaker.

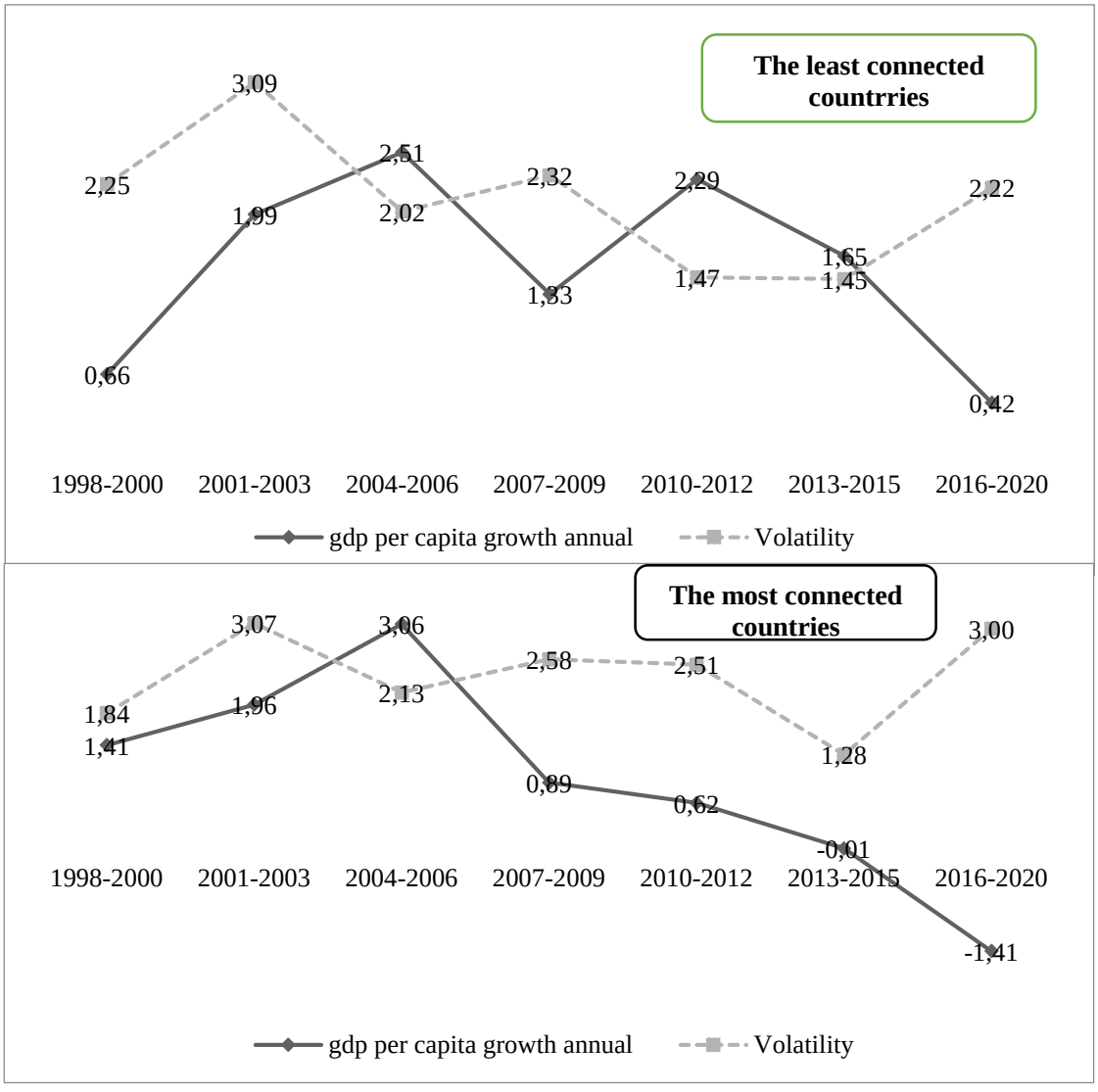

Figure 3: Evolution of the volatility and the average growth rate of real GDP per capita (mobile over 3 years)

Methodology

Following Tang et al. (2022) and Da Silva et al. (2017), we propose a new indicator by integrating the average value of growth and its volatility in a single measure (Zi) to capture the two dimensions of growth such as the real growth rate of gross domestic product per capita (Δ) and its fluctuation (σ).

For a given country i, we calculate

$$Z_i = \frac{\Delta_i}{\sigma_i} \tag{1}$$

Where

$$\Delta_i = \frac{\sum_{t=1}^{T_i} RGDPCG_{it}}{T_i} \tag{2}$$

and

$$\sigma_i = \sqrt{\frac{\sum_{t=1}^{T_i} \left(RGDPCG_{it} - \Delta_i\right)}{T_i - 1}} \tag{3}$$

Z is defined as the inverse hyperbolic sine transformation of the interaction of Δ and $1/\sigma$, for a period.

The choice to calculate volatility and average GDP growth rates over three years was made because of the rapid nature of fluctuations in these countries. This measure could facilitate the comparison between economies having different average values of growth.

The inverse hyperbolic sine (IHS) transformation, which is a logarithmic-type transformation, preserves negative and zero observations. It is preferable to the old method of MaCurdy and Pencavel (1986) or another variant of this method. Specifically, $IHS(x) = \ln\left(x + \sqrt{(x^2+1)}\right)$. Econometricians frequently apply the inverse hyperbolic sine (i.e., arcsinh) transformation to a variable because it approximates the natural logarithm of that variable and keeps observations at zero (Bellemare, 2018). The most used transformation for right-skewed variables is the logarithmic transformation, while the IHS transformation is generally recommended if the variables include a zero or even negative.

The IHS transformation of a variable z is defined as:

$$Z_i(trans) = \arcsin h(Z) = \ln\left(Z_i + \sqrt{(Z_i^2+1)}\right) \tag{4}$$

The graph of sh having parabolic branches of vertical direction, the graph of Argsh has parabolic branches of horizontal direction.

Economists generally use the inverse hyperbolic sine transformation (IHS or arcsinh) in empirical studies to reduce the bias of variables with zero or negative values. Thus, the country achieves higher levels of growth and lower growth volatility if the values of (trans) are higher. In other words, a high *Z* implies that the country is less vulnerable to economic recessions.

Estimation Method

An estimation was carried out, using a two-step system generalized method of moments (GMM) estimator, suggested by Blundell and Bond (1998). Estimates are applied to a sample of 30 countries. Our estimation variables are constructed in three-year sub-periods (1998–2000, 2001–2003, 2004–2006, 2007–2009, 2010–2012, 2013–2015, and 2016–2020) from 1998 to 2020.

Our data are taken from the World Development Indicators (WDI, 2021) and the World Telecommunication Indicators (WTI, 2020).

Sargan or Hansen tests can be used to determine whether instruments are globally exogenous or not. Under the null hypothesis (Ho), the first Sargan over-identification test tests the validity of lagged variables as instruments. The second test is Arrelano and Bond's second-order AR (2) autocorrelation test under the null hypothesis of no correlation.

To test the impact of ICT diffusion on economic growth and its volatility, we propose the following model:

$$Z(Trans)_{it} = \beta_0 + \beta_1 Idi_{it} + \beta_2 Inflation_{it} + \beta_3 GDPpc_0 + \beta_4 Trade_{it} + \beta_5 Credit_{it} + \beta_6 Govcons_{it} + \xi_{it} \quad (5)$$

Where Idi (ICT index) is used us a proxy for development technology. Following the model of Da Silva et al. (2017) capturing other control variables affecting the interaction of growth and its volatility, we employ initial GDP*pc*,0 as the level of per capita GDP at the beginning of each three-year period; Govcons stands for general government's consumption expenditure divided by GDP; Trade is the sum of exports and imports for goods and services as a share of GDP and Dom.credit: Credit as the banks' credit to the private sector as a proportion of GDP as proposed by Easterly et al. (2000).

Definition of variables is reported in Table 1, while pairwise correlation matrix is illustrated in Table 2. For more details, all pairwise correlations among explanatory variables are lower than the threshold of 0.8, showing no concern of multicollinearity in the regression model. The pairwise correlation greater than 0.8 (for example, the value of 0.863 for association between internet and mobile) would enter a separate model to avoid spurious regression.

RESULTS AND DISCUSSION

Descriptive Statistics and Correlation Matrix

The descriptive statistics of the variables in the model are presented in Table 1. The number of observations for each series is 210, obtained by multiplying the number of countries (30) by the number of periods (7).

On the average, Z(trans) constitutes 0.722 over the study period. It is worth noting that a high Z(trans) indicates that the country is less susceptible to economic downturns. It could be observed that the average level of ICT development index of the sampled countries is 2.99 out of 10.

Moreover, the variance is quite large for the entire series, as indicated by the substantial differences between the maximum and the minimum values of the variables. This is further underpinned by the standard deviation statistic for each variable, indicating a case of possible heterogeneity among the countries in the sample.

Table 1. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Z(trans)	210	0,722	1,12	-3,49	3,81
Idi	210	2,99	2,08	0,39	8,89
Trade	210	71,82	29,62	23,34	174,12
Inflation	210	7,71	18,10	-0,94	226,83
Dom.credit	210	28,85	21,53	2,67	95,81
Govcons	210	15,50	4,74	1,43	26,67
Initial GDP*pc*,0	210	7,79	1,39	5,75	11,01

Source: Compiled by the authors

Correlation matrix is illustrated in Table 2. For more details, all correlations among explanatory variables are lower than the threshold of 0.8, showing no concern of multicollinearity in the regression model.

Table 2. Correlation Matrix

	Idi	Trade	Inflation	Govcons	Initial GDP*pc*,0	Dom.credit
Idi	1,00					
Trade	0,36	1,00				
Inflation	-0,17	0,15	1,00			
Govcons	0,24	0,37	0,04	1,00		
Initial GDP*pc*,0	0,66	0,49	-0,09	0,31	1,00	
Dom.credit	0,70	0,39	-0,19	0,42	0,63	1,00

Source: Compiled by the authors

Panel S-GMM Estimation

To control for such possible biases, we run regression of the interaction of growth and its volatility Z (Trans) against ICT development index (Idi) and different control variables: initial GDP*pc*,0, Govcons, Dom.credit, Inflation, Trade.

The interaction of growth and its volatility tends to be influenced positively by its previous level, confirming the dynamic nature of models.

Furthermore, the coefficient of ICT development index variable (Idi) is found to be negative and significant, at the 1% level. This indicates the effect of ICT development index on decreasing growth and increasing output volatility which is not in line with Thanh Phuc Nguyen et al. (2022). These authors have shown that the three ICT indicators taken separately (import of ICT goods, mobile cellular subscriptions and internet users) positively stimulate growth while reducing fluctuations in economic growth.

The control variables, initial GDP per capita and inflation have a significant negative impact on the growth product and its evolution. This implies that an increase in per capita income and inflation could lead to a decrease in growth and an increase in growth fluctuation. This suggests that inflation, as an indicator of monetary and economic stability, has an important effect on economic growth and its volatility.

In contrast, we find relatively strong evidence that, for the sample as a whole, trade and final consumption expenditure of general government (% of GDP) (Govcons) have a positive and significant effect on real GDP per capita growth.

This result shows that greater trade openness and an increase in government consumption expenditure could create a favourable environment for increased economic growth and reduced growth volatility. We also find that the impact of bank credit to the private sector (credit) is positive but not significant.

To verify the consistency of our GMM estimator, two specification tests were conducted, namely the Sargan test for over-identifying restriction and the Arellano–Bond (AR (2)) test for autocorrelation in the disturbances. While the former tests the overall validity of the instruments employed, the latter tests the null hypothesis that the model does not suffer from second-order serial correlation.

Given the statistical insignificance of the Hansen J-statistic, as shown in the table, we cannot reject the null hypothesis that our instruments are valid. Furthermore, the null hypothesis that the residuals do not suffer from second-order autocorrelation cannot be rejected, based on the insignificance of the AR (2) test.

Table 3. Two-step system generalized method of moments (GMM) results.

Dependant Variable Z(trans)	Model (1)	Model (2)
Z(trans) (-1)	0.369***	0.227***
Idi	-0.213***	-0.243***
Initial GDP*pc*,0	-0.050***	-0.314***
Inflation	---------	-0.013***
Trade	---------	0.018***
Govcons	--------	0.033***
Dom.credit	--------	0.002
Constant	1.53***	1.90***
Test AR (1)(P-value)	0.035	0.054
Test AR (2) (P-value)	0.871	0.646
Test de Sargan (P-value)	0.887	0.896
Number of instruments	41	45
Observation	180	180

Note: The symbols ***, **, and * represent statistical significance at 1%, 5%, and 10%, respectively.

We average all variables by country for each group of 3 years between 1998 and 2020, except for the last 5-year period (2016-2020) and run panel estimations. The dependent variable (trans) equals the inverse hyperbolic sine transformation of the ratio between average per capita real GDP growth and its standard deviation.

ROBUSTNESS CHECKS

For our robustness analysis, we utilize interaction variable between the ICT development index and the initial level of GDP (Idi*InitialGDPpc0) to capture the effect of ICT development according to the initial level of GDP and therefore to verify the hypothesis of decreasing returns from ICT development.

$$Z(Trans)_{it} = \beta_0 + \beta_1 Idi_{it} + \beta_2 Idi_{it} * InitialGDPpc_0 + \beta_3 Inflation_{it} + \beta_4 InitialGDPpc_0 + \beta_5 Trade_{it} + \beta_6 Dom.credit_{it} + \beta_7 Govcons_{it} + \xi_{it} \quad (6)$$

Equation (6) shows that the marginal effect of ICT development on economic growth depends on the initial level of GDP.

In this framework, ρ in Equation (7) indicates the responsiveness of the interaction of growth and its volatility to level of ICT. Specifically, by differentiating Equation (6) with respect to level of ICT, we derive the marginal effect of level of ICT on the interaction of growth and its volatility to level of ICT as follows:

$$\rho = \frac{\partial Z(Trans)}{\partial Idi} = (\beta_1 + \beta_2 InitialGDPpc_0) \quad (7)$$

The assumptions in this specification revolve around the coefficients β1 and β2, with the following three possibilities:

If β1 and β2 are all positive then the development of ICT has a positive effect on economic growth and the level of ICT development favourably affects this impact.

If β1 is positive and β2 is negative, the development of ICT has a favourable impact on economic growth but the level of development of ICT reduces this impact.

If β1 and β2 both is negative and is positive, ICT development has a negative impact on economic growth, but the level of ICT development in this case plays an important role in mitigating negative effects of ICT development. The ICT level exacerbates this negative effect. The results of the estimations of model 6 are recorded in Table 4 below.

Column 1 indicates the estimates for the variables of greatest importance, i.e., Initial GDPpc,0, ICT development index, and their interactions. We find that the interaction with the level of development and ICT development index is positive and significant. This positive effect indicated that in the countries with higher economic development level, ICT development increases growth and decreases output volatility.

The results in column 2 are those of the coefficient estimates for the control variables. The variables, open rate and general government final consumption expenditure (% of GDP), positively influence growth and its volatility. Inflation and credit and Initial GDPpc,0, will all decrease growth and increase volatility.

If we introduce the interaction variable (Idi*InitialGDPpc0) to check the robustness of our results, we show that:

- The coefficient of the Idi variable is negative and significant, while that of the cross-variable (Idi*InitialGDPpc0) is positive and significant.

- The development of ICT promotes more growth in countries with a high level of economic development.

- Economic growth is more sensitive to the development of ICT than to other macroeconomic factors.

Hansen's test and d'Arrelano and Bond's second-order autocorrelation test cannot reject the hypothesis of the validity of lagged variables as instruments and the hypothesis of the absence of second-order autocorrelation.

As an example in column (1), Hansen's autocorrelation test is p=0.179 and Arrelano and Bond's second-order autocorrelation test is 0.799.

Table 4. Two-step system generalized method of moments (GMM) results.

Dependant Variable Z(trans)	**Model (1)**	**Model (2)**
Z(trans) (-1)	0.402***	0.246***
Idi	-0.666***	-0.625***
Idi*InitialGDPpc,0	0.054***	0.052***
Initial GDPpc,0	-0.190***	-0.386***
Inflation	---------	-0.02***
Trade	----------	0.0208***
Govcons	----------	0.057***
Dom.credit	---------	-0.012***
Constant	2.58***	2.27***
Test AR (1)(P-value)	0.033	0.034
Test AR (2) (P-value)	0.799	0.431
Test de Sargan (P-value)	0.179	0.207
Number of instruments	26	30
Observation	180	180

In sum, trade and final consumption expenditure of general government (% of GDP) have a positive and significant effect on real GDP per capita growth. The country' average income, inflation and bank credit to the private sector have a negative and significant effect on real GDP per capita growth. We find that the interaction variable (income per capita and Idi) could cause an increase in growth and a decrease in growth fluctuation. These empirical results provide potential justification for the conflicting results of previous research in which both positive and negative impacts of ICT penetration are observed. My conclusion is that the contribution of

ICT diffusion combined with the level of development of the country is significant for economic growth and its volatility.

To justify this conclusion, we calculate the marginal effects of ICT on economic growth and its volatility for the different countries in the sample.

Table 5 lists these marginal effects for level of countries in ICT from 1 to 2. The first column under each model lists the lower-bound estimates of the 95% confidence interval for function (7); the second column lists the estimates of the mean marginal effect, and column three lists the upper bound of the 95% confidence interval. The lower-bound estimates and the estimates of the mean marginal effect remain below zero for any level of economic development. It is the upper bound that we are most interested in. For all level, the upper-bound is significant.

One interesting thing to note about the results is that no matter what the conditioning set, the upper bound is always positive. This indicates that ICT development index will significantly lower economic volatility for relatively advanced countries.

Table 5. Marginal effects of ICT development index on growth and volatility for the size of a country's economy, including 95% confidence interval

		Model (1)			Model (2)		
Countries	**GDP**	**LB**	**ME**	**UB**	**LB**	**ME**	**UB**
Burundi	5,723165	-0,80137	-0,35695	0,086469	-1,05855	-0,3274	0,407763
Mozambique	6,071488	-0,79336	-0,33814	0,116077	-1,05786	-0,30928	0,443292
Madagascar	6,159627	-0,79133	-0,33338	0,123568	-1,05768	-0,3047	0,452282
Togo	6,246954	-0,78932	-0,32866	0,130991	-1,05751	-0,30016	0,461189
Burkina Faso	6,316785	-0,78771	-0,32489	0,136927	-1,05737	-0,29653	0,468312
Uganda	6,533733	-0,78272	-0,31318	0,155367	-1,05693	-0,28525	0,490441
Mali	6,539394	-0,78259	-0,31287	0,155848	-1,05692	-0,28495	0,491018
Guinea	6,563475	-0,78204	-0,31157	0,157895	-1,05687	-0,2837	0,493474
Benin	6,901995	-0,77425	-0,29329	0,18667	-1,0562	-0,2661	0,528003
Senegal	7,044708	-0,77097	-0,28559	0,1988	-1,05591	-0,25868	0,54256
Cameroon	7,126608	-0,76909	-0,28116	0,205762	-1,05575	-0,25442	0,550914
Kenya	7,164922	-0,76821	-0,27909	0,209018	-1,05567	-0,25242	0,554822
Ghana	7,22419	-0,76684	-0,27589	0,214056	-1,05555	-0,24934	0,560867
Mauritania	7,260714	-0,766	-0,27392	0,217161	-1,05548	-0,24744	0,564593
Nigeria	7,636754	-0,75735	-0,25362	0,249124	-1,05473	-0,22789	0,602949
Morocco	7,753283	-0,75467	-0,24732	0,259029	-1,05449	-0,22183	0,614835
Angola	7,836103	-0,75277	-0,24285	0,266069	-1,05433	-0,21752	0,623283
Eswatini	8,036446	-0,74816	-0,23203	0,283098	-1,05393	-0,2071	0,643717
Egypt	8,047569	-0,74791	-0,23143	0,284043	-1,0539	-0,20653	0,644852
Tunisia	8,171577	-0,74505	-0,22473	0,294584	-1,05366	-0,20008	0,657501
Algeria	8,21786	-0,74399	-0,22224	0,298518	-1,05356	-0,19767	0,662222
Jordan	8,333736	-0,74132	-0,21598	0,308368	-1,05333	-0,19165	0,674041
Iran. Islamic Rep.	8,488557	-0,73776	-0,20762	0,321527	-1,05302	-0,1836	0,689833
South Africa	8,649295	-0,73407	-0,19894	0,33519	-1,0527	-0,17524	0,706228
Gabon	8,910167	-0,72807	-0,18485	0,357364	-1,05218	-0,16167	0,732837
Saudi Arabia	9,83793	-0,70673	-0,13475	0,436224	-1,05032	-0,11343	0,827469
Oman	9,88221	-0,70571	-0,13236	0,439988	-1,05024	-0,11113	0,831985
Bahrain	10,00113	-0,70297	-0,12594	0,450096	-1,05	-0,10494	0,844115
Kuwait	10,39688	-0,69387	-0,10457	0,483735	-1,04921	-0,08436	0,884482
Qatar	11,00403	-0,67991	-0,07178	0,535343	-1,04799	-0,05279	0,946411

CONCLUSION

In this paper, we assess the impact of the ICT Development Index (Idi) on the interaction between economic growth and its volatility. We introduce a new variable Z that measures the ratio of the average growth rate to its volatility.

Using the S-GMM estimator, the results show that ICT development has a statistically negative effect on the interaction of growth and its volatility. This result does not confirm that of Nguyen et al. (2022) studied the relationship between ICT penetration and economic growth and its volatility in 122 countries from 2000 to 2019, and found that there is a positive and significant relationship between ICT indicators considered alone and growth and its volatility.

The negative relationship between ICT diffusion and economic growth is explained by the neglect of the importance of a country's level of development. Niebel (2018) points out that developing countries and emerging economies do not benefit as much from ICT investment as developed economies. For this reason, a new regression is used to study the impact of the interaction between ICT development and the size of the economy on the interaction between growth and its volatility. We show that the effect of ICT diffusion on the interaction of economic growth and its volatility is conditioned by the level of economic development. This means that, even if ICT development decreases the interaction of economic growth and its volatility, the size of economy exacerbates this negative effect. Specifically, we find that increasing the ICT diffusion will have a dependent effect on growth and its volatility simultaneously at higher levels of development.

We note that the level of development of the country is a prerequisite for the significant contribution of ICT diffusion. In other words, ICT diffusion combined with the country's level of development stimulates economic growth and reduces the volatility of the economy.

In our analysis, an interactive term between the ICT development index and the initial level of per capita income is used to measure how the impact of ICT on growth and its volatility is influenced by the country's level of development.

However, some researchers have reported that the majority of scientific research indicates that ICTs have a positive effect on economic development (Fernández-Portillo et al., 2020). This study shows that the effects of ICT exist and that they are conditioned by factors such as the level of development of the country.

In summary, while the majority of research indicates that ICT has a positive effect on economic development (Fernández-Portillo et al., 2020), this study shows that the effects of ICT are conditioned by factors such as the level of development of the country. We conclude that an increase ICT diffusion, accompanied by a policy aimed at improving the country's level of development, could lead to both higher growth and lower growth volatility.

Advice on national ICT policies should also be provided. The results of this study show that in African and MENA countries, the more economically developed the country, the more important the effect of ICT diffusion. Bahrini et al. (2019) showed that MENA countries outperformed sub-Saharan African countries in terms of Internet use and broadband adoption between 2007 and 2016. To benefit from ICT as an engine of economic growth, the authors recommend some key actions to develop the financial sector, promote more effective and transparent regulation and institutionalization, and prioritize resource allocation for ICT infrastructure development.

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APPENDIX

Table 1. ICT Development Index

	ICT Development Index (Idi)	
ICT access sub-index (40%)	**ICT use sub-index (40%)**	**ICT skills sub-index (20%)**
1. Fixed telephone subscriptions per 100 inhabitants 2. Mobile phone subscriptions per 100 inhabitants 3. International Internet bandwidth (bits/s) per Internet user 4. Percentage of households with a computer 5. Percentage of households with Internet access	6. Percentage of people using the Internet 7. Fixed broadband subscriptions per 100 inhabitants 8. Mobile broadband subscriptions per 100 inhabitants	9. Adult literacy rate 10. Secondary school gross enrollment ratio 11. Gross tertiary enrollment rate

Table 2. Data Sources

Variable	**Variable definition**	**Source**
ΔGDP*pc*	GDP per capita growth	World Bank WDI
***σi*(ΔGDP*pc*)**	The standard deviation of GDP per capita growth	Own calculation
***Z*(trans)**	The inverse hyperbolic sine transformation of the average GDP per capita growth divided by the standard deviation of GDP per capita growth	Own calculation
ICTindex	The ICT development index is a composite index combined three sub index (Acces, Competences and Use)	International Telecommunication Union
Dom. Credit	Domestic credit to the private sector by banks (% of GDP)	World Bank WDI
GOVCONS	Final consumption expenditure of general government (% of GDP	World Bank WDI
Trade	The sum of imports and exports of goods and services (% of GDP)	World Bank WDI
Inflation	Consumer price index inflation	World Bank WDI
Initial GDP*pc*,0	Log of GDP per capita from the first year of the period (2015 prices)	World Bank WD

Middle East and North Africa: Algeria, Egypt, Mauritania, Morocco, Tunisia, Saudi Arabia, Oman, Qatar Bahrain, Kuwait, Iran. Islamic Rep., Jordan.
Central Africa: Cameroon, Gabon.
East Africa: Burundi, Kenya, Madagascar, Uganda.
Southern Africa: Angola, Eswatini, Mozambique, South Africa.
West Africa: Benin, Burkina Faso, Ghana, Guinea, Mali, Nigeria, Senegal, Togo.