Journal of Infrastructure, Policy and Development 2024, 8(8), 4567.
https://doi.org/10.24294/jipd.v8i8.4567

Article

Mutual influence of quality education and ICT skills in promoting economic growth

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CITATION

Zehri C, Bendahmane MEA, Kadja A, et al. (2024). Mutual influence of quality education and ICT skills in promoting economic growth. Journal of Infrastructure, Policy and Development. 8(8): 4567. https://doi.org/10.24294/jipd.v8i8.4567

ARTICLE INFO

Received: 5 February 2024
Accepted: 15 April 2024
Available online: 7 August 2024

Abstract: Aligned with the fourth UN Sustainable Development Goal, this study examines the potential correlation among education quality, ICT skills, and economic growth. Utilizing the Generalized Method of Moments (GMM) methodology, we analyze dynamic fixed-effect panel data spanning 2010 to 2021 across 26 low-income, 20 middle-income, and 15 high-income countries. Our results indicate a positive impact of ICT skills and education quality on economic growth, for all country groups, with education quality enhancing this effect compared to ICT skills alone. The interaction between these factors underscores their complementary role in fostering economic growth. Notably, the impact has become more pronounced in recent years, attributed to advancements in ICT facilitating improvements in education quality. When examining income levels, low-income nations exhibit more substantial coefficients for ICT skills and education quality than middle- and high-income countries, emphasizing the significant potential for progress in low-income contexts. Our findings withstand various robustness checks, affirming their reliability and providing compelling policy implications for the roles of education quality and ICT skills in propelling economic growth.

Keywords: education; ICT skills; economic growth; SDG 4
JEL Classifications: O30; O40; O57

1. Introduction

Recognizing education and skill development as pivotal drivers of economic growth is a widely acknowledged principle in both academic discourse and practical application. This recognition has prompted a substantial allocation of resources to fortify investments in human capital, driven by the expectation of catalyzing economic advancement.

Considerable progress has been achieved regarding volume and quality in the literature investigating the correlation between education, skills, and economic growth. Despite this progress, substantial room exists for innovation and development, particularly in model specification, education and skills measurement, and robustness tests. Contrary to the prevailing belief that supporting the development of human capital is fundamental to economic growth, empirical assessments yield inconclusive results. The mixed empirical evidence regarding the significance of education quality and ICT skills in elucidating economic development often presents an ambiguous landscape for policy formulation and execution (Das, 2019; Jie, 2016).

Examining the effect of education quality and ICT skills on economic development in theoretical and empirical studies has provided opposite results and delineates two primary strands of thought. One strand delves deeply into the role of education quality alone in fostering economic development. Studies within this strand, such as Barro (2001) and Hanushek and Kimko (2000), emphasize the crucial significance of education quality over quantity, underlining its positive correlation with economic growth. In contrast, the second strand widens its scope to encompass the combined role of education and skills. Researchers like Hanushek and Wößmann (2007) explore how cognitive skills influence individual earnings and economic development, shedding light on the broader interplay between education, skills, and economic institutions. Further, studies like those of Hulten (2018) and Stankić et al. (2018) focus on single-country cases, such as the US and Serbia, respectively, to delve into nuanced dynamics between education, ICT, and economic growth. This literature uncovers several pivotal concerns. Firstly, variations in the metrics used to measure independent variables (education or skills) and the dependent variable (growth) contribute to the complexity of these studies (Billon et al., 2021; Das, 2019; Hawkes and Ugur, 2012). Secondly, inconsistencies emerge in selecting countries examined in prior studies, necessitating distinct considerations for low-income countries versus high-income ones (Afrooz et al., 2010; Hanushek and Wößmann, 2007). Lastly, diverse estimation methods, incorporating various approaches, may result in disparate estimates, highlighting the need for additional categorization based on these methodological differences (Hulten, 2018; Stankić et al., 2018). Addressing these concerns, the research questions of our study comprise three investigations: Firstly, what is the relationship between education quality, ICT skills, and economic growth across three income country groups from 2010 to 2021? Secondly, how does the quality of education, as measured by SDG 4, influence economic growth within each income group? Lastly, is the impact of education quality reinforced by ICT skills?

This study contributes to the existing literature and addresses key gaps by tackling the mentioned issues. Primarily, we emphasize education quality rather than the broader global concept or sheer quantity of education. This decision is based on studies suggesting that quality of education has a more substantial effect on economic development than the mere quantity of education (Barro and Lee, 1998; Barro, 2001; Hanushek and Kimko, 2000). To address the challenge of measuring the quality of education, we leverage Sustainable Development Goal 4 (SDG 4), forming part of the seventeen goals outlined in the Sustainable Development Agenda set by the United Nations for 2030. This goal underscores the necessity to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all". Specifically, we utilize indicator 4.7.1 from SDG 4 to construct our measure of quality education. Utilizing the United Nations' Sustainable Development Goal 4 to examine the correlation between education quality, ICT skills, and economic growth offers a comprehensive framework that emphasizes inclusive and equitable education for all. SDG 4 specifically targets quality education, highlighting the importance of improving learning outcomes, enhancing digital literacy, and promoting lifelong learning opportunities. By aligning with SDG 4, researchers can not only assess the impact of education and ICT skills on economic growth but also evaluate progress towards broader global development goals, ensuring a holistic approach that considers social, economic, and environmental dimensions. Thus, employing SDG 4 provides a standardized and internationally recognized framework that enables comparative analysis and facilitates policy alignment towards sustainable development.

Moreover, in contrast to the existing literature, our emphasis lies on a specific set of skills—Information and Communication Technology skills (ICT skills)—rather than the broad overarching concept of skills. Recent progress in educational techniques and methods is closely linked to the acquisition of advanced ICT skills by both students and teachers (Das, 2019). Consequently, there may be a direct correlation between ICT skills and the quality of education. Hawkes and Ugur (2012) advocate for an increased focus on the growth effects by incorporating interaction variables in regression analyses. They underscore a notable scarcity of studies integrating interaction terms, posing a challenge in examining the pathways through which investments in education and skills impact economic growth. Recognizing this connection, we have explored the interaction between these two variables—ICT skills and education quality—to comprehensively assess their combined impact on economic growth.

Our study addresses key issues observed in prior research concerning endogeneity, as highlighted by Hanushek and Wößmann (2007), Hanushek and Woessmann (2010), Habibi and Zabardast (2020), Awad and Albaity (2022). The endogeneity challenge in growth regressions involving human capital arises from the potential bidirectional relationship between quality of education, ICT skills, and economic growth. This reciprocal relationship may bias upward the reported estimates. We employ the Generalized Method of Moments (GMM) estimator to mitigate the endogeneity problem.

Our empirical methodology relies on an endogenous growth model that we have expanded to incorporate our key variables of interest: the quality of education and ICT skills. Our primary objective is to evaluate the individual impacts of ICT skills and education quality, as outlined by SDG 4, on economic growth. Following this, our study thoroughly examines the interplay between these key variables. By incorporating an interaction term, we aim to discern their collective impact on economic growth. We conduct regression analyses for two sub-periods, recognizing that the recent period may have witnessed more substantial advancements in ICT skills and education quality compared to the initial phase. This segmentation enables us to capture potential changes over time. Subsequently, we broaden our analysis by classifying our sample into low, middle, and high-income economies, encompassing diverse global income groups. This classification helps to examine whether our initial findings remain consistent across various economic contexts. In a further stage of our analysis, we employ a PVAR approach along with its impulse response analysis to investigate the effects of shocks on education quality and ICT skills indicators. This examination is crucial for a comprehensive understanding of the complexities of economic growth in low-income and high-income countries. To ensure the robustness of our model specification, we integrate multiple checks, affirming the reliability of our results. Moreover, we explore the nuanced dynamics between education quality and ICT skills in the specific national context of Saudi Arabia. This country presents an intriguing case study for examining the correlation between education quality, ICT skills, and economic growth from 2010 to 2021. Economic reforms in Saudi Arabia, notably the Vision 2030 initiative, highlight a shift towards diversification, making it pertinent to analyze the impact of education and ICT investments during this transitional phase. With significant government investments in education and digital infrastructure, particularly targeting the young and growing population, Saudi Arabia provides an ideal setting to understand how improvements in these areas influence economic productivity, especially within the context of a regional digital transformation agenda. Hence, studying Saudi Arabia offers insights into the dynamics between human capital development and economic advancement, not only for the country itself but also for the broader Middle East region.

Our results show a favorable effect of ICT skills and education quality on economic growth. The introduction of education quality amplifies this influence compared to ICT skills alone, emphasizing the pivotal role of high-quality education. Furthermore, the interaction term between ICT skills and education quality highlights their complementary relationship in fostering economic growth. Besides, we find a more pronounced impact of ICT skills and education quality on economic growth in recent years compared to the initial years of our analysis period. This heightened influence can be attributed to substantial progress in the field of ICT, which, in turn, has facilitated improvements in education quality, contributing to enhanced economic growth outcomes. When examining countries' income levels, the results demonstrate more robust coefficients for ICT skills and education quality in low-income nations than their middle- and high-income counterparts. This seemingly counterintuitive outcome is clarified by the significant room for progress in low-income countries, enabling a more substantial impact on economic growth through ICT and education quality advancements.

The paper is structured as follows: Section 2 sets the foundation by examining the literature on education quality, ICT skills, and economic growth. Section 3 establishes the empirical base with data and variables. Section 4 details the empirical methodology, leading to Section 5, which introduces and explains empirical results and policy implications. Section 6 ensures robustness through checks, and Section 7 explores the case of Saudi Arabia. The concluding Section 8 succinctly encapsulates the study's key findings and implications, providing a cohesive summary.

2. Literature review

The evolution of "endogenous-growth" models marks a significant advancement, particularly in determining the long-term growth rate. These models significantly integrate a theory emphasizing the crucial role of quality of education and ICT skills (or human capital in general) in fostering economic growth (Aghion et al., 1998; Barro, 2001; Bosworth and Collins, 2003; Billon et al., 2021; Dessus, 2001; Hanushek and Wößmann, 2007; Hulten, 2018; Okpala, 2007; Prettner, 2013; Stankić et al., 2018). This theory has identified the diverse channels and causal mechanisms that shape the interconnection among education, skills, and economic growth. Theoretical and analytical studies on growth, as well as those examining determinants of changes in factors that vary across countries or over time, frequently emphasize the indirect impacts of human capital on growth[1]. These indirect impacts result from the spillover effects of education and skills, alternatively, how human capital integrates into the production system through interactions with labor, innovation, and technology. **Figure 1** explicitly considers these interactions, summarizing the indirect effects and referencing relevant literature.

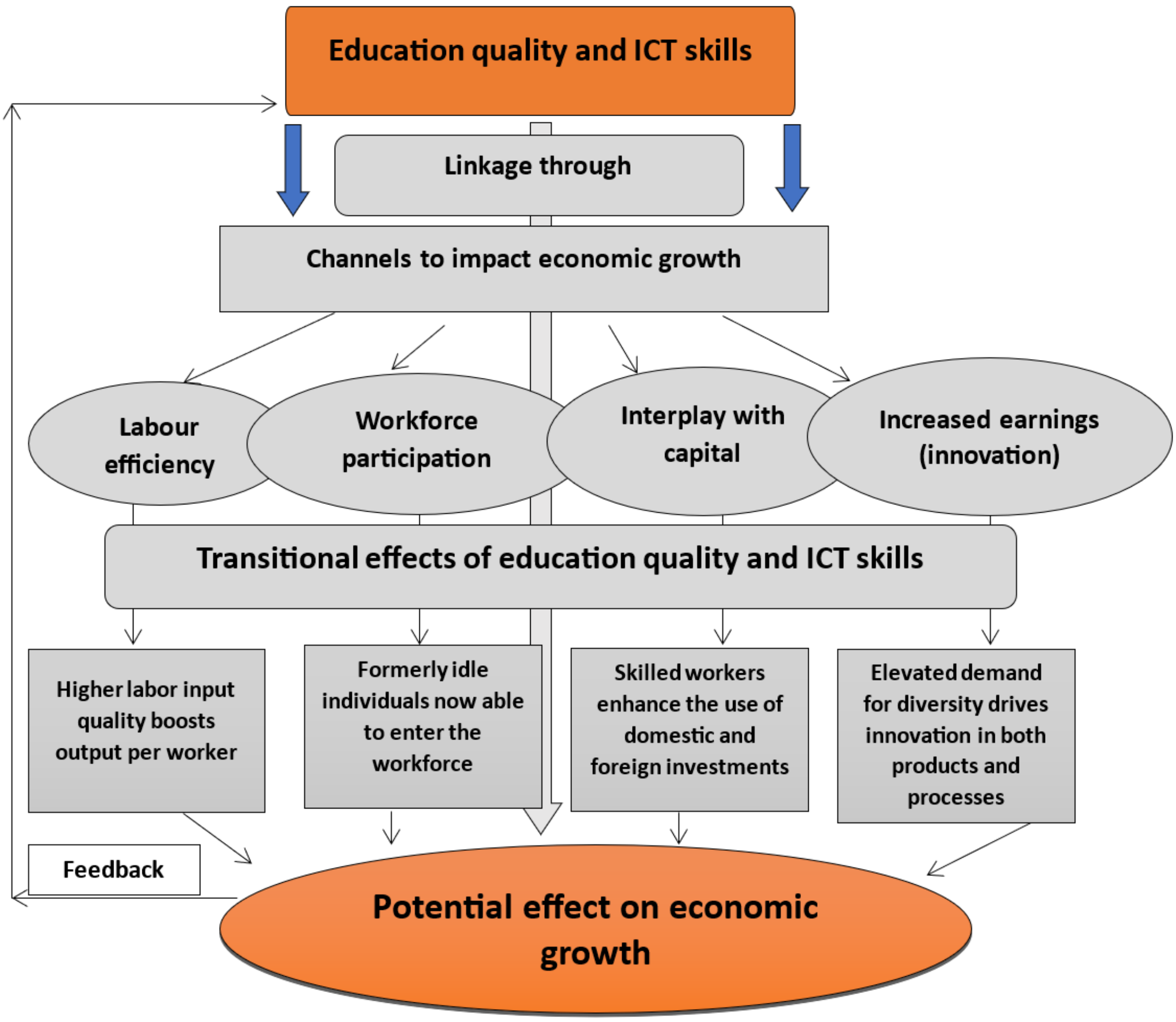

Figure 1. Pathways by which education quality and ICT skills impact economic growth.

Source: authors' presentation.

The four channels highlighted in understanding the association between quality of education, ICT skills and economic growth, collectively present a comprehensive picture of the intricate dynamics at play. The first channel establishes a foundational link by emphasizing the positive relationship between human capital and labor productivity; educated workers exhibit higher productivity, as evidenced by studies (Afrooz et al., 2010; Benos and Karagiannis, 2016). This productivity serves as a fundamental driver for the subsequent pathways. The second channel explores the connection between human capital and labor market participation. Investing in education increases the probability of finding employment and entering the labor market (Glewwe, 2002; Klasen, 2002). This pathway introduces a crucial aspect where educated individuals enhance productivity and actively contribute to the workforce, fostering economic growth. The third channel explores the correlation between investment and human capital. A skilled workforce is better equipped to leverage capital from both domestic and foreign sources (Matsa, 2018), emphasizing that education enhances individual productivity and affects economic growth. Building upon these economic impacts, the fourth channel explores human capital's income effect, fostering product diversity and supporting innovation. Hummels and Klenow (2005) argue that rich nations generally produce more goods, reflecting a transition from individual productivity to a more comprehensive economic influence. The income effect enhances product variety and propels growth through product and process innovations (Romer, 1990).

The empirical literature investigating the impact of education quality and ICT skills on economic growth is divided into two primary strands.

The first focuses solely on the role of education quality in fostering economic development. For instance, Barro (2001) determines that education is a key driver of economic growth and underscores the differentiation between the quality of education (assessed by scores on internationally comparable examinations) and the quantity of education (measured by years of attainment at various levels). The findings of his study indicate that economic growth is influenced by both quality and quantity of education, with a greater emphasis on the significance of quality. Furthermore, Barro (2001) explores alternative education quantity and quality measures, such as "primary school attainment", "female attainment", and "results on internationally comparable examinations". Likewise, additional research indicates that the significance of education quality surpasses its quantity. For instance, Hanushek and Kimko (2000) find that performance on international assessments, an indicator of education quality, holds more significance than "years of attainment" in influencing economic growth.

In contrast, the second strand of this literature is broader and encompasses the combined role of education and skills. For instance, Hanushek and Wößmann (2007) explored the connection between the quality of education and social well-being. They found that cognitive skills, not just educational attainment, strongly influence individual earnings, income distribution, and economic development. The study highlights the importance of basic and advanced skills, highlighting their interplay with economic institutions. International comparisons, incorporating comprehensive cognitive skills data, reveal significant skill gaps in developing countries beyond enrollment and attainment statistics. Addressing this requires substantial structural reforms in education to reduce the economic disparity with industrialized nations. Hanushek and Wößmann (2007) point out that the primary hurdle in many studies examining the link between education, skills, and growth is the lack of comprehensive school quality data. The central question revolves around whether utilizing a cumulative indicator, such as "mean duration of schooling" genuinely encapsulates the extent of human capital progress. This concern is notably accentuated in analyses that involve multiple countries, where variations in schooling experiences are anticipated to be more substantial than those observed in cross-sectional studies within a specific nation. Such a matter stands out prominently in the existing literature, underscoring the importance of addressing diverse educational contexts when conducting comparative analyses.

In a comprehensive synthetic review encompassing thirty-three empirical papers, Hawkes and Ugur (2012) concur that education and skills contribute to economic growth. While acknowledging this correlation, their review also reveals significant gaps. The authors emphasize that a critical concern in numerous prior studies revolves around selecting measurements for education and skills. They argue that academics frequently choose specific metrics based on the availability of data instead of their suitability to proxy a regulatory measure. Hence, a dialogue between academics and policymakers regarding the definition of education and skills and the best measurement methods is crucial to enhance the usefulness of academic literature in guiding policy decisions. Hawkes and Ugur (2012) report a positive effect of investing in human capital on the economic growth of low-income countries. The authors classify education measures into nine groups, specifically focusing on education quality, which is particularly pertinent to our study and encompasses various indicators, such as the ratio of teachers to students and the qualifications of teachers.

Conducting a single-country study on the influence of education quality and ICT skills on economic growth enables a detailed exploration of contextual factors, unveiling nuances often overlooked in broader samples. This focused approach provides targeted insights for tailored policy recommendations, aligning with the observation that some studies have concentrated on individual countries. For instance, Hulten (2018) focused on the case of the US economy, scrutinizing the swift advancements in information technology and globalization that have led to substantial structural changes in the country. He explores two perspectives, the neoclassical and the activity-analysis models, and delves into the latter, emphasizing the crucial function of skill development and education in the economy. The activity-analysis perspective underscores that workers with diverse skills and educational backgrounds are essential components tailored to specific requirements within the economic system. A deficiency in either skills or associated capital can hinder the operation or growth of activities. Hulten (2018) emphasizes the importance of a well-educated workforce in the current knowledge economy, asserting that a lack of educational attainment would impede the functioning of such an economy. Besides, Stankić et al. (2018) scrutinize the case of the Republic of Serbia. They delve into the intricate dynamics between ICT, population education, and economic growth. Their study emphasizes the challenges confronting Serbia's academic system, which faces a transformative wave of technological innovation reshaping employment characteristics and necessitating novel knowledge and skills. The findings of this study show that education and ICT are pivotal drivers for broader social and economic development. Our study aligns with Hulten (2018) and Stankić et al. (2018) as we investigate a single-country case, precisely that of Saudi Arabia.

Similarly to Stankić et al. (2018), recent studies have explored the impact of telecommunications infrastructure, including mobile phones and Internet, on promoting economic development. These investigations correlate the effect of telecommunications with improved access to education. For instance, Donou-Adonsou (2019) investigates the association of developing telecommunications infrastructure with economic growth in nations with different degrees of educational accessibility. He analyzed data from 45 Sub-Saharan African nations between 1993 and 2015 through a dynamic panel model. The findings indicate that in nations with enhanced education accessibility, the Internet plays a role in fostering economic growth. Conversely, mobile phone use does not have a similar impact. Likewise, Billon et al. (2021) investigate the influence of disparities in internet usage for educational purposes and analyze how these effects vary depending on the level of economic development. They utilize a logit regression model for 69 economies from 2005 to 2015. Their results reveal an inverse correlation between internet usage and educational inequality, affirming a less pronounced effect on internet use in high-income countries than in middle-income ones.

3. Data and variables

The standard explanatory variables for the GDP growth rate are well-established within the framework of neoclassical growth theory. Consistent with the approach taken by Barro (2001), our model incorporates various economic growth factors, including government consumption (CONS), an indicator measuring adherence to the rule of law (RULE), an index of international openness (IO), and the inflation rate (INF). Furthermore, the model encompasses additional variables such as global investment (INV), terms of trade (TRADE), and fertility rate (FERT).

The primary concern revolves around the choice of education and skills measurements, often selected by academics based on the availability of data instead of their effectiveness as measures for regulatory action. Commonly employed measures of human capital often concentrate on inputs into the education process. These measures include enrollment rates, which measure cost instead of evaluating learning outcomes. Consequently, fostering a meaningful discussion between academics and policymakers on the definition of education and skills and the optimal measurement approaches could be fruitful. This dialogue can potentially enhance the relevance of academic literature in this field for policymakers.

In our study, the definition and construction of ICT skills and education quality variables are grounded in the principles of the United Nations Sustainable Development Goal 4. This goal emphasizes that Quality Education is centered around "ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all". Our empirical analysis aligns precisely with Goal 4 by utilizing its indicators, specifically 4.4.1, which measures the proportion of youth and adults with ICT skills. We employ this indicator as a proxy for ICT skills acquisition (ICT). ICT skills data were gathered from diverse sources, including the Global SDG Database, World Telecommunication/ICT Indicators Database, UIS Statistics of UNESCO, and internal data from official organizations within each respective country.

Furthermore, we use the SDG Indicator 4.7.1, which measures the "Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies, (b) curricula, (c) teacher education and (d) student assessment". By employing this indicator, we ensure that our research aligns with global endeavors to improve the quality of education and promote global citizenship. Data on this indicator is sourced from reports submitted by Education Ministers responsible for relations with UNESCO. However, the availability of these data is limited in many countries within our sample. We have addressed incomplete data through our investigation, gathering information from various domestic educational sources in each country. These sources include ministries of education, national statistical offices, teacher training institutions, national education boards or councils, and educational research institutes. We constructed a composite index to evaluate education quality (EDU), assigning scores to the four components of the SDG Indicator 4.7.1: National Education Policies (NEP), Curricula (CURR), Teacher Education (TE), and Student Assessment (SA). The resulting indicator is scored on a scale from 0 to 4, where 0 represents low-quality education, and 4 indicates high-quality education[2]. We assign scores based on our self-evaluation of the progress made by each considered country in enhancing its education quality. In the context of national education policies (NEP), our scoring considers explicit mentions, dedicated programs, and alignment with broader educational goals. The Curricular Alignment (CURR) score involves assessing the incorporation of relevant topics, themes, and learning objectives within curricula. Regarding the teacher education variable (TE), the evaluation focuses on the presence and extent of training programs designed for teachers in global citizenship education and sustainable development. Specifically, our score is based on the number of teachers who have undergone specific training related to these concepts. The student assessment (SA) score is determined by analyzing multiple factors like exam questions, projects, or performance assessments to ascertain how well they reflect an understanding of global citizenship education and sustainable development concepts.

The selected study period, ranging from 2010 to 2021, encompasses 61 countries, representing a spectrum of income levels categorized as low, middle, and high. This timeframe holds significant global relevance, capturing a dynamic era characterized by substantial technological advancements and shifts in the global economic landscape. Including countries with different income levels facilitates a thorough analysis spanning various economic conditions and developmental stages. Furthermore, it offers valuable insights into the interplay between education, ICT skills, and global economic growth. **Table 1** presents the sample country under consideration. To gain a comprehensive understanding of the variables used in our baseline model, **Table 2** offers a detailed overview. Subsequently, in **Table 3**, we present the corresponding summary statistics for these variables. In **Table 4**, we present the ADF test statistics at different confidence levels to assess the rejection of the null hypothesis of a unit root. *P*-values less than 0.05 indicate rejection of the null hypothesis, implying that our variables are first-order integrated. Therefore, we adopt a strategy of regressing our models using the first difference of the variables. This approach addresses the presence of unit roots and ensures data stationarity, enhancing the reliability of our analyses. We aim to visually represent the variations in ICT skills and education quality in correlation with changes in the GDP growth rate. **Figures 2** and **3** illustrate these variables for low-income countries, while **Figures 4** and **5** depict the same for high-income countries. The graphical representations are based on the average values for each country from 2010 to 2021. The values of GDP economic growth are presented on the right axes, while the left axes showcase the values of the aggregate ratio of index 4.4.1, acting as a proxy for ICT skills, along with our constructed education quality index.

Table 1. Sample country.

Low income	**Middle income**	**High income**
Afghanistan	Albania	Australia
Burundi	Argentina	Austria
Burkina Faso	Belarus	Belgium
Central African Republic	Brazil	Bahrain
Congo, Dem. Rep.	China	Canada
Eritrea	Colombia	Switzerland
Ethiopia	Costa Rica	Germany
Gambia	Indonesia	Denmark
Guinea-Bissau	Maldives	Spain
Liberia	Mexico	Finland
Madagascar	Montenegro	France
Mali	Malaysia	Croatia
Mozambique	Peru	Hungary
Malawi	Paraguay	Saudi Arabia
Niger	Russian Federation	Japan
Korea, Dem. People's Rep.	El Salvador	
Rwanda	Serbia	
Sudan	Thailand	
Sierra Leone	Türkiye	
Somalia	South Africa	
South Sudan		
Syrian Arab Republic		
Chad		
Togo		
Uganda		
Yemen, Rep.		

Note: These countries are categorized based on the World Bank classification, 2021. We have combined low-lower middle income and upper middle-income into one group named middle-income countries.

Table 2. Variables description.

Variable	**Symbol**	**Description**	**Sources**
Dependent variable			
Economic growth	GDP_growth	GDP growth rate	World Development Indicators (WDI)
Independents variables			
Key variables			
ICT skills	ICT	The proportion of youth and adults with ICT skills.	Global SDG Database; The World Telecommunication/ICT Indicators Database; UIS Statistics-UNESCO
Quality of education	EDU	A composite index assigns scores to four variables: National Education Policies (NEP), Curricula (CURR), Teacher Education (TE), and Student Assessment (SA). The index ranges from 0 to 4.	Self-building index

Table 2. (*Continued*).

Variable	Symbol	Description	Sources
Quality of education factors			
National education policies	NEP	Index that quantifies integrating global citizenship education and education for sustainable development into national education policies (we consider explicit mention, dedicated programs, and alignment with broader education goals.)	National Education Ministers
Curricula	CURR	Alignment of curricula with global citizenship education and sustainable development goals (we consider the inclusion of relevant topics, themes, and learning objectives within subject-specific curricula.)	National Education Ministers
Teacher education	TE	Measure the number of teachers who have undergone specific training related to global citizenship education and sustainable development.	National Education Ministers
Student assessment	SA	Analyzing exam questions, projects, or performance assessments to see if they reflect an understanding of the integration of global citizenship and sustainable development themes.	National Education Ministers
Determinants of GDP growth			
Government consumption	CONS	Ratio of government consumption to GDP	WDI
Rule of law	RULE	Index measuring adherence to the rule of law	WDI
International openness	IO	Ratio of exports plus imports to GDP	WDI
Inflation rate	INF	Changes in consumer price indexes	WDI
Fertility rate	FERT		WDI
Global investment	INV	Investment-to-GDP ratio	WDI
Terms of trade	TRADE	Ratio of export prices to import prices; Index (2010 = 100)	WDI

Table 3. Summary statistics.

Variable	Mean	Std. Dev.	Min	Max
GDP_growth	1.7362	0.1180	−6.58	7.2452
ICT	0.6384	0.8090	0	1
EDU	3.249	0.0135	0	4
NEP	0.7804	0.2711	0	1
CURR	0.5492	0.1833	0	1
TE	0.4962	0.3330	0	1
SA	0.3211	0.1653	0	1
CONS	5.5202	0.3364	−1.2535	28.7530
RULE	0.6521	0.2348	0	1
IO	7.0015	2.3270	3.2658	21.6542
INF	4.6135	1.3768	1.135	42.7152
FERT	7.1863	5.5226	2.8261	29.3654
INV	6.0812	2.1358	1.6233	56.4254
TRADE	120	15	80	130
ICTxEDU	3.0562	0.0846	0	3.6945

Source : Author's calculations.

Table 4. Unit-root test.

Variable	ADF Test Statistic	*p*-value	ADF Critical Values
GDP_growtht-1	−2.132	0.024	−3.431
ICT	−1.865	0.067	−2.987
CONS	−1.942	0.053	−3.008
RULE	−2.304	0.015	−3.420
IO	−1.731	0.092	−2.989
INF	−2.004	0.043	−3.016
FERT	−2.210	0.028	−3.430
INV	−1.867	0.066	−2.988
TRADE	−2.032	0.039	−3.008
EDU	−2.145	0.022	−3.433
ICTxEDU	−2.064	0.036	−3.009

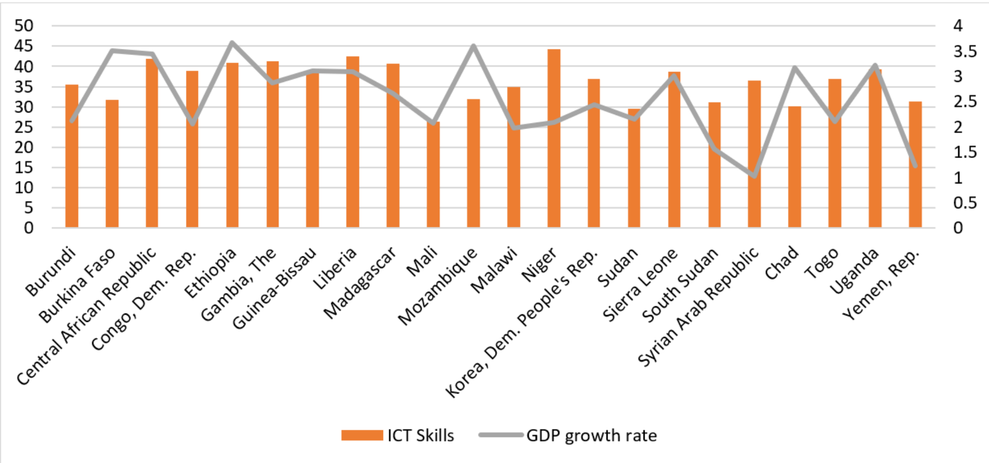

Figure 2. ICT skills and economic growth in low-income countries (average 2010–2021).

Source: authors' presentation.

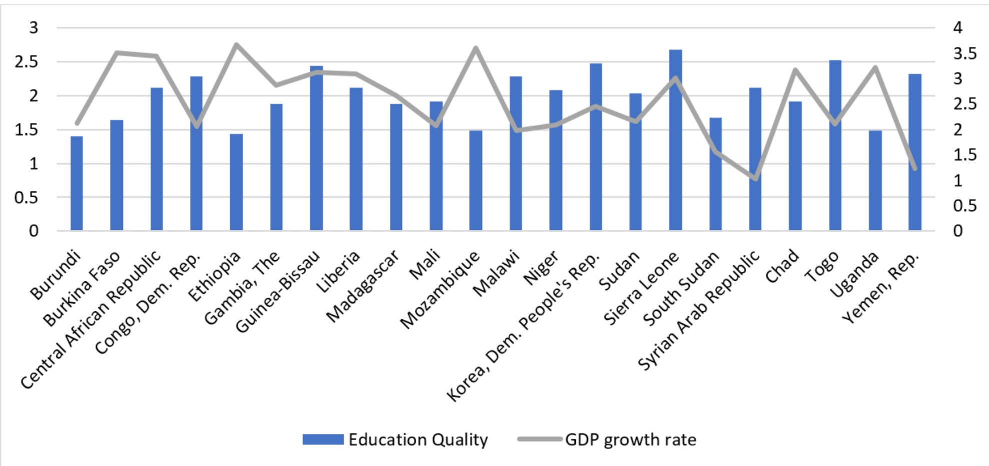

Figure 3. Education quality and economic growth in low-income countries (Average 2010–2021).

Source: authors' presentation.

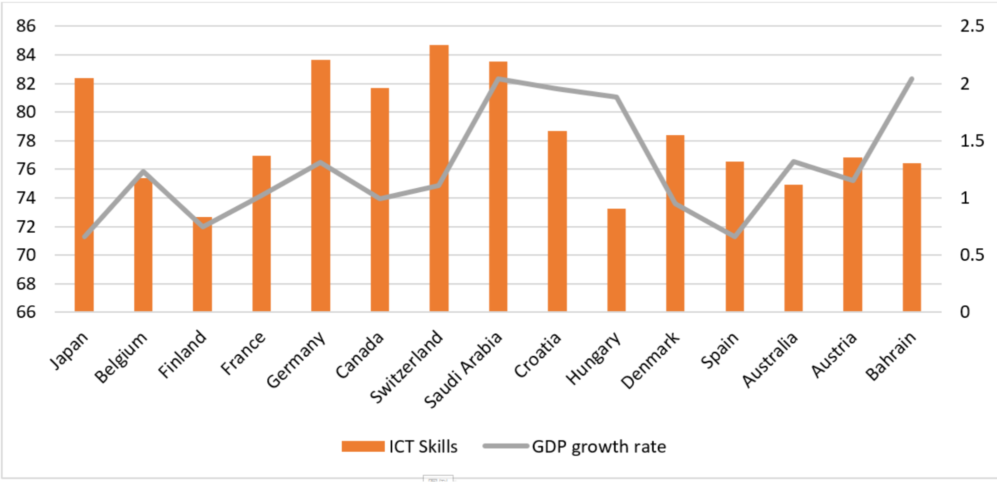

Figure 4. ICT skills and economic growth in selected high-income countries (Average 2010–2021).

Source: authors' presentation.

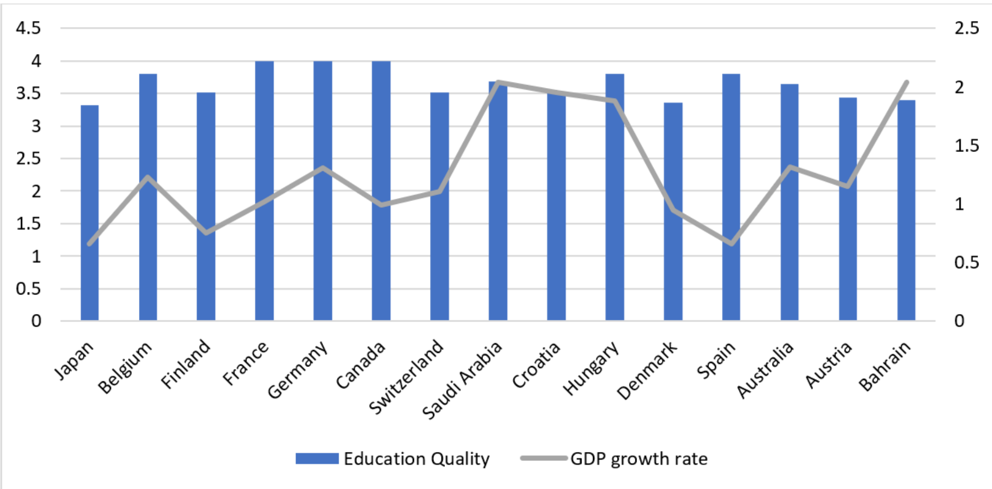

Figure 5. Education quality and economic growth in high-income countries (Average 2010–2021).

Source: authors' presentation.

Figures 2 and **4** illustrate that high-income economies demonstrate a superior proficiency in ICT skills compared to their low-income counterparts.

Conversely, low-income countries show stronger economic growth rates. The lowest ratio of ICT skills in high-income countries is observed in Hungary (73%), a figure higher than the highest ratio observed in low-income countries (Niger, 44%). This finding underscores the significant disparity between the two groups of countries. The observed phenomenon of low-income countries exhibiting lower levels of ICT skills while simultaneously experiencing higher economic growth rates may be attributed to their significant potential for improving and enhancing ICT skills. This capacity enables them to leverage ICT advancements more effectively to drive economic growth compared to high-income countries.

Figures 3 and **5** depict changes in education quality alongside economic growth. Sierra Leone boasts the highest value in our education quality index (2.68). Nevertheless, among high-income countries, all have surpassed the threshold of 3.6, with three countries—France, Germany, and Canada—attaining the maximum value of this index: 4. The direct link between the quality of education and the GDP growth rate is more noticeable in low-income economies compared to high-income ones. This positive association is evident in only three high-income economies—Saudi Arabia, Croatia, and Hungary. Interestingly, despite having a higher education quality index, most high-income countries have experienced declining economic growth. As inferred from the figures on ICT skills, we anticipate that low-income countries possess greater potential to enhance their education quality, leading to higher growth rates.

4. Empirical methodology

Our empirical analysis draws upon the established literature on economic growth Romer (1990), Barro and Sala-i-Martin (1991), and Aghion and Howitt (1992). In particular, we align our approach with Barro (2001) who extended an endogeneous growth model within the neoclassical framework. To succinctly capture the essence of this model, Barro (2001) presents a simplified equation:

$$Dy = F(y, y^*) \quad (1)$$

where Dy represents the per capita output's growth rate, "y" denotes the output per capita level, and y^* signifies the long-term or desired output per capita. In a framework that takes into account technological advancements and human capital, the output per capita variable expands its definition to include both human and physical capital, along with alternative factors utilized in the manufacturing process. A simplified version of an endogenous growth model of Barro (2001) is defined as follows:

$$Y_t = A_t \times K_t^{\alpha} \cdot (H_t \times L_t)^{(1-\alpha)} \quad (2)$$

where:

Y_t represents real GDP (gross domestic product) at time t.

A_t denotes total factor productivity (TFP) or technological progress at time t.

K_t represents physical capital stock at time t.

H_t represents human capital stock at time t.

L_t represents labor force or population at time t.

α is the output elasticity of physical capital, representing the share of output attributed to physical capital in production.

This model posits that economic growth (measured by Y_t) is determined by the combined effect of physical capital (K_t), human capital (H_t), labor force (L_t), and total factor productivity (A_t). The production function assumes constant returns to scale and exhibits endogenous growth, meaning that the rate of technological progress and the accumulation of human capital contribute to sustained economic growth over time. Our extension of Barro's (2001) model incorporates two key variables: the quality of education and ICT skills, serving as proxies for the accumulation of human capital. Initially, we consider these variables independently. Recent advancements in education, specifically the acquisition of advanced ICT skills by both students and teachers (Das, 2019), may directly correlate with the quality of education. Hawkes and Ugur (2012) advocate prioritizing the emphasis on growth effects by including interaction variables in regression analyses. Notably, there is a scarcity of studies incorporating these terms, which presents challenges in comprehending the pathways through which investments in education and skills influence economic growth.

Acknowledging this gap, we move to the second stage, exploring the interaction between ICT skills and education quality. This exploration aims to assess their combined impact on economic growth. The extended form of the model presented in Equation (3) is as follows:

$$\text{GDP\_growth}_{i,t} = \alpha_0 + \beta_1 GDP\_growth_{i,t-1} + \beta_2 EDU_{i,t} + \beta_3 ICT_{i,t} + \beta_4 EDU_{i,t} \times ICT_{i,t} + X_{i,t} + \delta_i + \varepsilon_{i,t} \quad (3)$$

where $\text{GDP\_growth}_{i,t-1}$ describes the short-term autoregressive patterns exhibited by the dependent variable ($\text{GDP\_growth}_{i,t}$). EDU is a proxy for education quality, while ICT refers to ICT skills acquisition. X comprises standard explanatory variables commonly found in economic growth theory, encapsulating the influences of physical capital, human capital, labor force, and total factor productivity, including CONS, RULE, IO, INF, FERT, INV, and TRADE. Including variables such as inflation rate, government consumption, and fertility in a growth model of Barro is essential for capturing the complex dynamics that shape long-term economic development (Chang et al., 2013). These variables have significant impacts on various aspects of the economy, ranging from resource allocation and productivity to demographic trends and policy effectiveness. δ represents a country-specific effect. The term ε_{it} denotes the error term.

The challenge in estimating models like Equation (3) lies in the potential endogeneity of explanatory variables, such as education quality, potentially affected by the dependent variable (GDP growth rate). Failure to address endogeneity can result in biased upward estimates due to reverse causality. Within growth regressions incorporating human capital, the endogeneity problem is characterized as follows: the positive influence of education or skills on growth and, conversely, the positive impact of higher growth rates on education or skills. Extended periods of heightened growth contribute to an increase in per-capita income, thereby fostering investment in human capital. This cyclical process leads to what is commonly referred to as a "virtuous circle". If this scenario holds true, it may introduce an upward bias in the reported estimate of the growth impact associated with education and skills.

GMM approach tackles the endogeneity problem by utilizing standardized instrumental variables closely correlated with human capital but unrelated to the regression's residuals (error terms). These standardized instrumental variables incorporate previous (lagged) values of endogenous predictors, specifically human capital determinants, as Arellano and Bond (1991) recommended and are widely applied within the literature on economic growth. Effectively utilizing the model's linear moment restrictions, GMM estimation is an effective instrumentation method, especially when data are scarce for endogenous variables. Our study aligns with previous research by employing the GMM estimator to address the endogeneity problem (Hauk and Wacziarg, 2009; Leon-Gonzalez and Montolio, 2015; Siddiqui and Ahmed, 2013).

5. Results and interpretation

Table 5 shows results obtained from GMM estimator for all countries (61 countries), where we initially regress Equation (3) solely on the ICT skills variable (column 1). Subsequently, we introduce the education quality variable in the second step (column 2), and finally, we incorporate the interaction term between ICT skills and the education variable in the last step (columns 3, 4, and 5).

Table 5. Quality education, ICT skills, and economic growth, baseline model.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
GDP_growth_{t-1}	0.035*** (0.001)	0.021** (0.010)	0.032** (0.016)	0.019*** (0.001)	0.022*** (0.000)
ICT	0.015** (0.007)	0.017* (0.008)	0.008* (0.004)	0.011* (0.005)	0.076** (0.038)
CONS	0.010* (0.005)	0.063** (0.031)	0.021* (0.010)	0.044** (0.022)	0.052** (0.026)
RULE	0.416* (0.212)	0.211*** (0.101)	0.401** (0.200)	0.587** (0.293)	0.321** (0.160)
IO	0.052* (0.026)	0.014* (0.007)	0.032* (0.017)	0.337 (0.511)	−0.141 (0.073)
INF	−0.024* (0.012)	0.009** (0.004)	−0.032 (0.411)	−0.051 (0.110)	0.027** (0.013)
FERT	0.042** (0.021)	0.018* (0.009)	0.014 (0.207)	0.021* (0.010)	0.017 (0.098)
INV	0.193* (0.098)	0.128* (0.065)	0.148** (0.074)	0.087** (0.043)	0.074** (0.037)
TRADE	0.054* (0.027)	0.025 (0.307)	0.103 (0.577)	0.094* (0.047)	0.031* (0.015)
EDU		0.026** (0.013)	0.025** (0.012)	0.018* (0.009)	0.042** (0.021)
ICTxEDU			0.039*** (0.010)	0.038** (0.019)	0.061** (0.030)
R-squared (within)	0.35	0.29	0.42	0.37	0.31
F-test	2.86***	2.17***	3.24***	3.55***	2.38***
# of countries	61	61	61	61	61
# of observations	552	548	537	542	539
Breusch-Pagan Test	0.312	0.259	0.189	0.248	0.206
White Test	0159	0.357	0.168	0.201	0.397

Note: **Table 5** presents estimates for equation (3), where GDP_growth is the dependent variable. Column (1) reports results using the GMM estimator without including the education quality variable and the interaction term. Column (2) incorporates the education variable, while column (3) presents results for the overall model, including the interaction term. Column (4) presents estimates for the period 2010–2015. Column (5) shows results for the periods 2016–2021. Significance levels are denoted by ***, **, and *, representing significance at the 1%, 5%, and 10%, respectively.

The results demonstrate a statistically significant and positive impact of ICT skills and education quality on economic growth. These findings underscore the favorable influence of both ICT skills and high-quality education in fostering economic growth across all categories of countries. Notably, the impact of ICT skills alone, without accounting for education quality, is lower compared to the introduction of education quality. Additionally, the results indicate that education quality exerts a more pronounced favorable impact than ICT skills; a stronger coefficient is observed for “EDU” compared to “ICT” (column 2).

One of the key findings of this study is emphasized by our primary variable of interest, the interaction term “ICTxEDU,” revealing a more robust favorable impact on economic growth (column 3). The estimates suggest that a one standard deviation increase in the interaction term results in a 39 basis point rise in GDP growth rate[3]. This result affirms that the development of ICT skills is directed towards facilitating the adoption of new methodologies and techniques in education, consequently enhancing the favorable impact of education quality on economic growth.

When dividing our analysis into two sub-periods, 2010–2015 (column 4) and 2016–2021 (column 5), we observe a more pronounced impact of ICT skills and education quality on economic growth during the second period than the first. This heightened influence may be attributed to the substantial progress witnessed in recent years in ICT. This progress has facilitated improvements in the quality of education, ultimately contributing to enhanced economic growth outcomes.

Most determinants of economic growth align with the existing empirical literature on economic growth, albeit with variations observed across diverse model specifications[4]. Notably, the lagged dependent variable exhibits a statistically significant and positive coefficient. This finding implies a considerable persistence effect, signifying that past values of the dependent variable exert a notable influence on its current values.

In the next phase of our analysis, our objective is to evaluate the impact of our main variables, considering the income levels of the countries in our sample. The regression results for Equation (3) are subsequently presented in **Table 6**. Our sample countries are categorized into three groups: low-income countries (column 1), middle-income countries (column 2), and high-income countries (column 3). We conducted both the Breusch-Pagan and White tests to scrutinize the presence of heteroscedasticity or serial correlation in the standard errors of our model specifications. The results of these tests are presented at the bottom of **Table 5**. Across all model specifications, the obtained *p*-values exceed the conventional significance level of 0.05, indicating that we fail to reject the null hypothesis of no heteroscedasticity or autocorrelation. Therefore, these results suggest that the standard errors are not heteroscedastic and not autocorrelated for all model specifications, bolstering the robustness of our regression analyses. Despite the results of the Breusch-Pagan and White tests indicating the absence of heteroscedasticity or autocorrelation in the standard errors of our model, we opted to use the Newey-West method to estimate standard errors. This decision was made to ensure a better fit of our model by accounting for any potential issues related to heteroscedasticity and serial correlation that might not have been detected by the aforementioned tests. The estimations reveal that a one-standard-deviation increase in the interaction term results in a 51, 27, and 13 basis points increase in the GDP growth rate for low, middle, and high-income economies, respectively. These findings align with the results presented in **Table 5**. The estimates reveal stronger coefficients for ICT skills, the quality of education, and the interaction term in low-income countries than their counterparts in middle and high-income countries. This result might appear counterintuitive, given that low-income economies are typically less developed in ICT and education quality than high-income countries. Nevertheless, this result can be attributed to the considerable potential for progress in low-income countries, allowing them to exert a more substantial impact on economic growth by improving both ICT and the quality of education. Our findings on low-income countries diverge from specific studies reviewed by Hawkes and Ugur (2012), wherein human capital investment was found to have a modest positive impact on economic growth. However, the authors recognized the likelihood that the minor effects observed could be ascribed to proxies used to gauge the extent of human capital. They acknowledged that employing more suitable measures of education and skills might reveal larger effects, aligning with economic theory and consistent with our results.

Table 6. Quality education, ICT skills, and economic growth-income category countries.

	(1)	**(2)**	**(3)**
GDP_growth_{t-1}	0.041*** (0.008)	0.013** (0.006)	0.024** (0.012)
ICT	0.052** (0.026)	0.026* (0.013)	0.031** (0.015)
CONS	0.024* (0.012)	0.040** (0.020)	0.052** (0.026)
RULE	0.051 (0.360)	0.097* (0.049)	0.081** (0.040)
IO	0.030* (0.015)	−0.237 (0.511)	−0.141 (0.373)
INF	−0.022* (0.011)	−0.051 (0.098)	−0.027* (0.013)
FERT	0.021* (0.011)	0.015* (0.007)	0.057 (0.398)
INV	0.068** (0.034)	0.087* (0.043)	0.032** (0.016)
TRADE	0.087 (0.127)	0.094 (0.347)	0.041* (0.021)
EDU	0.045** (0.022)	0.018* (0.009)	0.012** (0.006)
ICTxEDU	0.061** (0.030)	0.032* (0.016)	0.016** (0.008)
R-squared (within)	0.31	0.23	0.24
F-test	1.38***	2.55**	3.08**
# of countries	26	20	15
# of observations	275	208	129

Note: **Table 6** presents Equation (3) estimates, where GDP_growth is the dependent variable. Column (1) presents results for low-income countries, (2) for middle-income countries, and (3) for high-income countries. Significance levels are denoted by ***, **, and *, representing significance at the 1%, 5%, and 10%, respectively.

The results of our empirical examination suggest significant policy implications for fostering economic growth. Investments in ICT skills and education quality are crucial. Policymakers should focus on strategies that integrate the development of ICT skills with improvements in education quality, recognizing their synergistic effect. The study emphasizes temporal considerations, indicating a more pronounced impact in recent years, highlighting the need for adaptive policies in response to technological advancements.

Surprisingly, low-income countries show stronger coefficients for ICT skills and education quality, indicating a higher potential for growth through improvements.

Policymakers should acknowledge this counterintuitive finding and consider targeted policies to bridge the digital and educational divide in these countries. Global collaboration and assistance may be essential in supporting low-income countries, with developed nations and international organizations playing a role in knowledge transfer and technology adoption.

The study underscores the cumulative impact of ICT and education quality, emphasizing the need for long-term planning. Policymakers should adopt a sustained approach to human capital development, recognizing the ongoing evolution of technology and its role in education.

In a further development, we examine the repercussions of shocks on education quality and ICT skills indicators, which is essential for comprehending the intricacies of economic growth in low-income and high-income countries. The quality of education directly influences the skill set of the workforce, impacting productivity and innovation. Additionally, in an era where technology plays a pivotal role, assessing ICT skills becomes crucial for a nation's competitiveness. Understanding how external shocks affect these aspects provides valuable insights into the resilience and adaptability of a country's human capital, shedding light on the pathways through which economic growth may be sustained or hindered in diverse economic landscapes. We can analyze these factors' interdependencies and causal relationships by employing a PVAR (Panel Vector Autoregression) model incorporating key sustainable development variables and the GDP growth rate. Extracting impulse response functions allows us to quantify and visualize education quality and ICT skills shocks' effects on economic growth. This modeling approach provides valuable insights for policymakers, enabling them to formulate targeted strategies that foster inclusive development and sustainable economic growth.

Our PVAR model integrates our previous key variables, EDU indicator as a proxy for education quality, and ICT indicator to represent ICT skills. Additionally, we introduce the dependent variable '$GDP\_growth_{i,t}$' to measure the effects of shocks on the dynamics of economic growth within our model. The ensuing VAR models vividly portray the impulse response of '$GDP\_growth_{i,t}$' in both low- and high-income countries. **Figure 6** visually examines the effects of a 10% increase in the EDU indicator, reflecting an enhancement in education quality. Additionally, a parallel analysis is performed for the ICT indicator, investigating the consequences of a comparable 10% increase in this indicator. The horizontal axis represents quarters, and the vertical axis indicates changes in economic growth rates. The solid blue line depicts the response of the economic growth rate to different shocks.

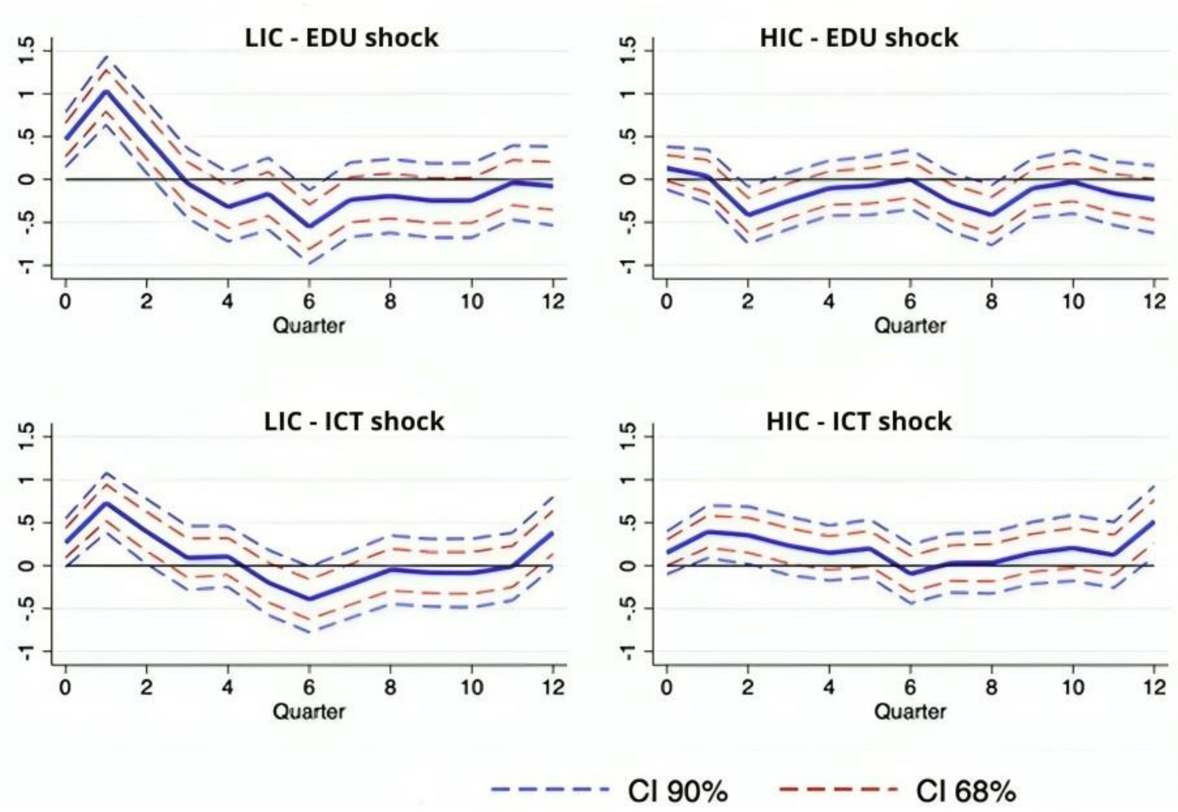

Figure 6. Impulse response analysis, shocks on EDU, and ICT indicators.

Source: authors' presentation.

Note: LIC and HIC denote low and high-income countries, respectively. CI refers to the confidence interval set at 90% and 68%.

The impulse response graphs reveal distinct patterns in the economic dynamics of low-income and high-income countries following shocks. In low-income countries, an immediate surge in economic growth for one quarter indicates a rapid initial response, followed by a subsequent decline, suggesting potential challenges in sustaining the momentum. Notably, the impact on education quality surpasses that on ICT skills, emphasizing the pivotal role of education in driving short-term economic improvements.

In high-income countries, attention turns to the EDU shock, revealing a minor impact on economic growth and suggesting a resilient or less responsive economic system to changes in education quality. However, a contrasting trend emerges with the shock of ICT skills, which exhibits a prolonged effect for up to six quarters. This underscores the enduring influence of technological skills on economic dynamics in high-income countries. The observed variations in the duration and nature of shocks between low and high-income countries may signify underlying differences in economic structures, policy responses, or workforce adaptability to changes in education and technology. Recognizing and understanding these distinctions is imperative for formulating targeted and effective economic policies tailored to countries' specific needs and challenges at different income levels.

6. Robustness check

Striving for a more robust model, we conduct various checks, exploring alternative measures for the dependent variable, education quality, and ICT skills. Besides, we employ different estimation approaches. We conducted a robustness check of our empirical results by considering the overall sample of countries without dividing the sample into the three income categories.

Initially, in assessing the economic growth metric, we refer to the study by Hawkes and Ugur (2012), which highlights that prominent empirical research typically uses three main indicators: GDP growth, per capita GDP growth, and TFP growth. Our primary focus is on GDP growth per capita, chosen as the cornerstone for our baseline model. Additionally, we explore per capita GDP growth as an alternative measure for our dependent variable (column 1).

Moving on to the second aspect, we delve into educational quality, considering diverse metrics such as teacher-to-pupil ratios and teacher qualifications. To measure educational quality differently, we incorporate the teacher qualifications measure (column 2), assessing the percentage of teaching staff with valid teaching certificates or licenses. This approach aligns with previous research by Darling-Hammond et al. (2005) and Kusumawardhani (2017).

Addressing the challenge of limited data on ICT skills, particularly precise measurements of ICT skills acquisition, we propose government expenditure on ICT as an alternative metric for assessing ICT skills acquisition (column 3). Our study suggests that increased government expenditure in this area could significantly enhance the acquisition of ICT skills, especially among teachers and students (Agustina and Pramana, 2019; Sul, 2017).

Building on these alternative measures, we assess the impact of introducing alternative variables on our model. The robustness check estimates are presented in **Table 7**. Despite the consistent positive impact of education quality and ICT skills on economic growth, the coefficients are weaker than in the initial baseline model. Furthermore, the interaction term between ICT skills and education quality maintains a favorable impact but with diminished coefficients. Our initial findings persist in transitioning from the GMM approach to Maximum Likelihood Estimation (column 4) and the Anderson-Hsiao estimator (column 5). However, the significance of most coefficients diminishes in these alternative approaches. This decrease in significance may lead us to favor the GMM estimation, which, as we note, addresses the endogeneity problem more effectively.

Table 7. Robustness checks.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
GDP_growth_{t-1}	0.027** (0.023)	0.019** (0.009)	0.032* (0.016)	0.010** (0.005)	0.013** (0.006)
ICT	0.012** (0.006)	0.013* (0.007)	0.019* (0.010)	0.011* (0.005)	0.010* (0.005)
CONS	0.011** (0.005)	0.013** (0.006)	0.017 (0.019)	0.013* (0.006)	0.009* (0.004)
RULE	0.026* (0.013)	0.031** (0.015)	0.021** (0.010)	0.017 (0.093)	0.011* (0.005)
IO	0.022* (0.011)	0.011* (0.005)	0.032 (0.087)	0.337 (0.511)	−0.141 (0.973)

Table 7. (*Continued*).

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
INF	−0.031* (0.016)	0.010** (0.005)	−0.062 (0.411)	−0.051 (0.310)	0.027* (0.013)
FERT	0.035** (0.017)	0.012* (0.006)	0.014 (0.367)	0.021* (0.080)	0.017 (0.598)
INV	0.073* (0.036)	0.058* (0.029)	0.038* (0.019)	0.027* (0.013)	0.024* (0.012)
TRADE	0.024* (0.012)	0.035 (0.307)	0.123 (0.577)	0.094* (0.047)	0.011* (0.005)
EDU	0.021** (0.010)	0.018** (0.009)	0.025** (0.012)	0.021* (0.010)	0.022** (0.011)
ICTxEDU	0.028* (0.014)	0.035** (0.017)	0.019** (0.009)	0.018* (0.009)	−0.011 (0.755)
R-squared (within)	0.20	0.23	0.19	0.29	0.30
F-test	1.86**	3.01**	2.84***	3.05**	3.38**
# of countries	61	61	61	61	61
# of observations	549	563	541	532	528

Note: Column (1) employs a distinct measure for the dependent variable—per-capita GDP growth. In column (2), a different measure of education quality, focusing on teacher qualifications, is utilized. For column (3), the analysis incorporates an alternative gauge for ICT skills, represented by information and communication technology expenditure as a percentage of GDP. Columns 4 and 5 utilize diverse estimators, specifically Maximum Likelihood Estimation and the Anderson-Hsiao estimator, respectively.

7. Case study findings: Saudi Arabia

Dynamic panel data has yielded compelling insights into the effect of education quality and ICT skills on economic development, revealing patterns and relationships across various countries. However, the inherent limitation of inadequate data on these crucial variables prompted us to seek further clarity through an in-depth exploration employing a one-country case study. In opting for this approach, we aim to delve deeper into the intricate dynamics between education quality and ICT skills within the unique context of a single country. By focusing on a specific nation, we anticipate a more nuanced analysis that allows for a detailed examination of the interplay between these factors, potentially uncovering intricacies that might be overshadowed in broader cross-country analyses. This strategic choice aims to enhance the precision and depth of our understanding regarding the effect of education quality and ICT skills in shaping economic development within a specific national context.

Our study focuses on Saudi Arabia as a case analysis, holding particular significance due to the concerted efforts of this nation to bolster ICT skills and education quality, aiming to propel economic growth. Saudi Arabia, through its Vision 2030 initiative, has committed to an ambitious reform agenda that spans across multiple sectors. The forefront of these efforts is the education system, which plays a pivotal role in the country's endeavor to diversify its economy. The key focus lies in cultivating human capital, recognizing its significance in transitioning toward a more balanced and sustainable economy, reducing reliance on non-renewable energy sources, and minimizing dependence on government employment.

Saudi Arabia has committed substantial financial resources for numerous decades to enhance its education sector. In 2021, the country allocated 9.1% of its gross domestic product (GDP) to education, surpassing the average expenditure of 5.2% among OECD countries (World Bank, 2022). This significant investment has played a pivotal role in successfully increasing educational accessibility, with near-universal enrollment rates in both primary and secondary schooling (UNESCO Institute for Statistics, 2022).

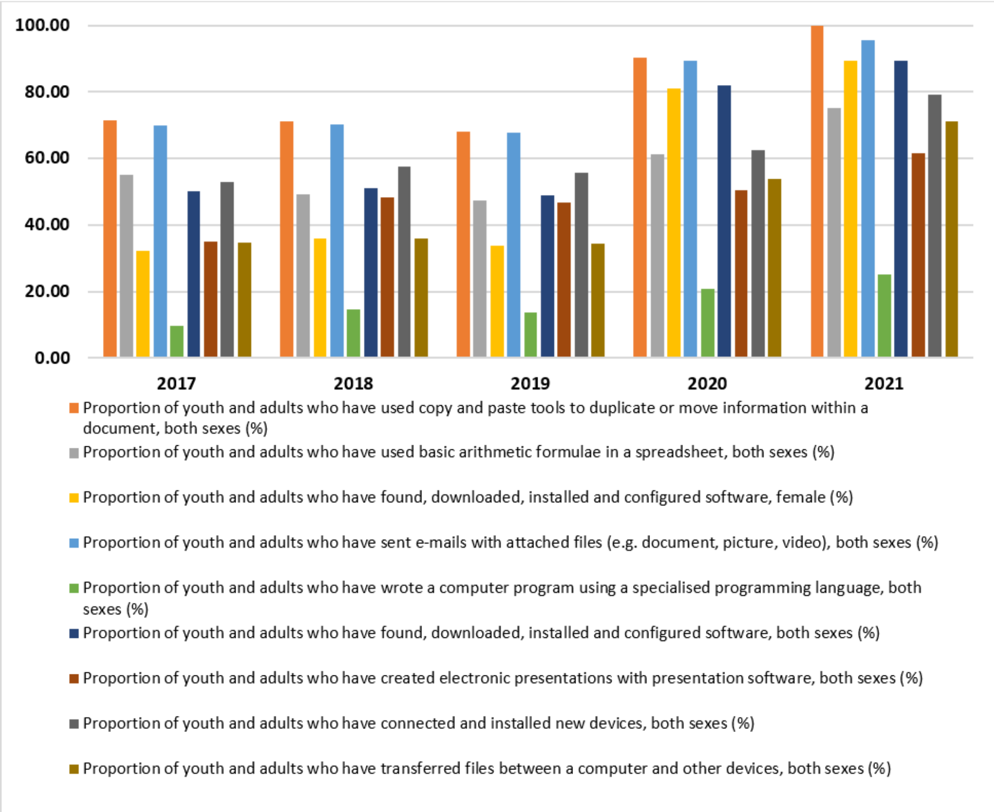

Figure 7. Ratios selected from indicator 4.4.1 (ICT skills) of the UN SDG 4.
Source: authors' presentation.

Figure 7 illustrates the specific ratios constituting Indicator 4.4.1 of the United Nations Sustainable Development Goal 4, focusing on "Education Quality" in Saudi Arabia from 2017 to 2021. **Figure 7** illustrates significant progress across various skills, with noticeable differences. Specifically, high ratios are evident in certain ICT practices, such as "using copy and paste tools" and "sending emails with attached files", reaching values of up to 70%. Conversely, lower ratios are observed in more complex tasks like "writing computer programs," which may pose challenges for individuals with limited computer skills. Notably, proficiency in this skill increased from 10% in 2017 to 25% in 2021, indicating a positive trend over the specified period.

In the subsequent analysis, we have illustrated the relationship between the aggregated ratio of ICT skills (depicted on the left axis) and the GDP growth rate (represented on the right axis) in Saudi Arabia from 2017 to 2021 (**Figure 8**). Our examination reveals significant advancements in ICT skills, displaying a positive correlation with the GDP growth rate throughout the specified period, except for 2020. This graphical representation substantiates Saudi Arabia's commitment to enhancing

ICT skills and corroborates our empirical findings from the panel analysis. Our empirical study identifies a positive impact of ICT skills on economic growth. It is important to note that the decline observed in economic growth in 2020 can be primarily attributed to the global impact of the coronavirus pandemic and is unrelated to the level of ICT skills.

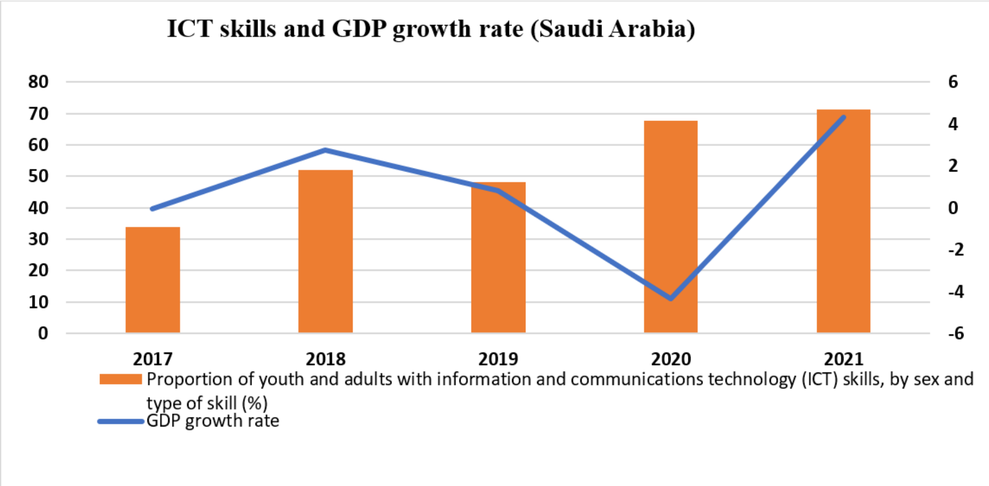

Figure 8. ICT skills and GDP growth in Saudi Arabia.

Source: authors' presentation.

Regarding data from indicator 4.7.1 about SDG 4, only two values for 2001 about the variables NEP and SA are available. Specifically, Saudi Arabia has attained the maximum value 'one' for the variable SA, representing the "Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in student assessment". For the second variable, Saudi Arabia has a value of (0.75) for the variable NEP "Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in national education policies".

To gain deeper insights into the enhancement of educational quality, Saudi Arabia engages in various global assessments, including the Progress in International Reading Literacy Study (PIRLS), Trends in International Mathematics and Science Study (TIMSS), and lately, the OECD Programme for International Student Assessment (PISA). Findings from these assessments indicate a generally diminished educational investment yield concerning learning achievements.

Consistently, there was a lower performance in reading, mathematics, and science among students in Saudi Arabia compared to OECD countries, with their scores in mathematics and science also ranking lower than those of other participating countries in the Middle East and North Africa region in the PISA 2018 findings. More than half of Saudi Arabian students failed to attain the baseline level of reading proficiency essential for full societal participation, in stark contrast to the less than a quarter observed throughout nations in the OECD (OECD, 2019). These findings underscore the pressing need for urgent improvements in student learning outcomes if Saudi Arabia is to realize the economic objectives outlined in Vision 2030.

In an era where knowledge and innovation are fundamental drivers of economic success, the deficiency in learning outcomes jeopardizes the nation's ability to meet the demands of a rapidly evolving global economy. The urgent need for improvements in education is underscored, emphasizing that addressing low learning outcomes is not merely an educational concern but a crucial prerequisite for achieving sustainable economic growth.

8. Conclusion

The main results of this study show a synergistic relationship, where developing ICT skills enhances the overall quality of education and ultimately promotes economic growth. This collaborative effect is more pronounced in low-income countries, challenging conventional expectations and emphasizing their potential for substantial progress.

The empirical literature exhibits several gaps, with a significant one being identifying a suitable measure for quality education and skills. Our study addresses this gap by introducing a novel approach that utilizes indicators outlined in SDG 4 of the United Nations. These indicators have the advantage of aligning with international standards, thus providing more accurate measures of education quality and ICT skills. Nevertheless, the education quality index is constructed solely based on scores and self-evaluations, presenting a potential drawback to the overall assessment.

This study makes several significant contributions to the literature. It emphasizes the importance of education quality over quantity, leveraging SDG 4 as a standardized measure. Additionally, it focuses on the specific role of ICT skills, exploring their interaction with education quality in influencing economic growth, which is a novel approach. Methodologically, the study addresses previous concerns by employing robust estimation methods and analyzing different income groups. Finally, by using Saudi Arabia as a case study, it offers unique insights into the regional dynamics of human capital development and economic growth, contributing to a deeper understanding of these relationships.

In light of the study’s findings, it is evident that policymakers should strategically prioritize investments to bolster education and technology. Specifically, targeted initiatives in educational infrastructure, teacher training, and technology are crucial to enhancing education quality and ICT skills. Simultaneously, establishing a standardized numerical database for education and skills quality necessitates collaborative efforts with international organizations and experts. This collaborative approach ensures the development of accurate and comparable metrics applicable across diverse contexts. Regular assessments and updates become imperative to effectively track progress, providing a foundation for evidence-based policy decisions. Together, these interconnected strategies form a comprehensive framework for advancing education quality and ICT skills to foster sustainable economic growth.

While our study offers valuable insights into the relationship between education quality, ICT skills, and economic growth, several limitations should be noted. These include reliance on secondary data sources, challenges in measuring education quality and ICT skills across diverse contexts, and potential limitations in generalizing findings beyond the specific case of Saudi Arabia. Additionally, despite efforts to address endogeneity, the possibility of omitted variable bias or reverse causality remains. These limitations underscore the need for future research to employ more comprehensive data collection methods, conduct cross-country comparative analyses, and delve deeper into causal mechanisms. Addressing these limitations would enhance the academic implications of our study by providing a more robust understanding of the complex dynamics between human capital development and economic prosperity.

Besides, future research in this domain could delve deeper into the causal mechanisms that drive the positive impact of ICT skills and education quality on economic growth. A more extensive longitudinal analysis spanning a broader timeframe may offer insights into evolving trends and the sustainability of observed effects. Additionally, conducting a sector-specific analysis could help discern variations in the impact across different industries. Exploring how improvements in ICT skills and education quality directly contribute to economic growth and potential mediating factors would contribute to a more comprehensive understanding of the dynamics at play.

Author contributions: Conceptualization, CZ and IZ; methodology, CZ; software, AK; validation, CZ, HS and IZ; formal analysis, AK; investigation, CZ and MEAB; resources, AK; data curation, IZ; writing—original draft preparation, HS; writing—review and editing, CZ; visualization, AK and MEAB; supervision, CZ; project administration, IZ; funding acquisition, CZ. All authors have read and agreed to the published version of the manuscript.

Funding: This project is sponsored by Prince Sattam Bin Abdulaziz University (PSAU) as part of funding for its SDG Roadmap Research Funding Programme project number PSAU-2023-SDG-05.

Conflict of interest: The authors declare no conflict of interest.

Notes

1. Most empirical studies focus on estimating the direct effect on growth. This direct effect is visually represented by the broad arrow in **Figure 1**.
2. We employed a comprehensive approach involving self-evaluation and scoring on a scale from 0 to 1 for the progress of each country across four key components of the index: National Education Policy (NEP), Curriculum (CURR), Teacher Education (TE), and Student Assessment (SA). Through this detailed assessment process, individual scores for each component were derived. Subsequently, the authors aggregated these scores, resulting in the calculation of the overarching Education Quality Index, which spans a range from 0 to 4, providing a holistic measure of the overall education quality in each country.
3. To calculate this value, multiply the interaction term coefficient (0.039 from to **Table 5**) by its standard deviation (0.0846 according to **Table 3**).
4. The interpretation of these coefficients is not extensively elaborated upon in this study, as it is not the primary focus of the analysis and to avoid overloading the paper with content.

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