Leapfrogging Digital Development: A Quantile Regression Analysis of Quality of Life and Digitalization

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ARTICLE DETAILS	ABSTRACT
History: Accepted: 09-09-2025 Available Online: 10-12-2025 *Keywords:* *Quality of Life* *Digitalization* *Leapfrogging development* *Quantile Regression* **JEL Codes:** *I 31* *O15* *O 33*	**Objective:** This study investigates the relationship between digitalization and quality of life (QOL) for a global sample of 185 countries from 1990 to 2023. The main objective of the study is to test the validity of the leapfrogging proposition in the context of digitalization and QOL. **Research Gap:** The existing literature generally overlooks the examination of the leapfrogging hypothesis while focusing on the relationship between digitalization and QOL. **Design/Methodology/Approach:** The study employs a fixed effects model, the system generalized method of moments, and panel quantile regression approaches. **Main Findings:** The empirical findings show that digitalization has a positive and significant influence on QOL while controlling for income, age dependency, urbanization, and pollution using alternative estimation techniques. The findings also show that all dimensions of digitalization positively influence QOL in high-income and middle-income countries, suggesting that digitalization complements already established old infrastructure and technologies. However, in the case of low-income countries, mobile phone (modern technology) significantly enhances QOL while fixed telephone (old technology) is either insignificant or negatively associated with QOL, suggesting some relevance of the leapfrogging pattern. It follows that poor countries can leapfrog traditional capital-intensive technology and can focus on the latest technologies for improvement in QOL and well-being (SDG-3). **Theoretical / Practical Implications of the Findings:** This study concludes that digitalization is imperative to enhance QOL; however, its influence on QOL may vary across different forms of digitalization and stages of development. Hence, policymakers need to be careful while designing policies for human and digital development.

1. Introduction

Digitalization is an integral part of development strategies of developed as well as developing countries. Digital technologies ease access to information and communications, enhance productivity, and improve efficiency (Ryzhanovskij et al., 2021; Muralidharan et al., 2022). Therefore, countries around the world

prioritize the adoption of information and communications technologies (ICTs) to stay competitive. However, there is a concern that digitalization has negative consequences, such as addiction, anxiety, social isolation, and job displacement, which negatively influence quality of life (QOL) (Turel et al., 2021). Likewise, digitalization may deepen economic inequalities as access to digital tools and skills is unevenly distributed across income levels and, therefore, may negatively influence individuals' well-being and QOL in low-income countries (Litvintseva & Karelin, 2022). However, it is suggested that QOL can be enhanced in low-income countries if leapfrogging digital development is focused (Adeleye et al., 2022). Nevertheless, empirical studies generally overlook the examination of the leapfrogging development.

Leapfrogging digital development refers to a development strategy when a nation bypasses traditional stages of digital development and directly adopts the latest technologies (Adeleye et al., 2022). Hence, it is important to investigate the relationship between digitalization and QOL across income levels and test the validity of the leapfrogging hypothesis to fully understand the issue, and then polices can be designed accordingly.

Although the human development theories identify income, education, and health as the main elements that enable people to meet their basic human needs and contribute to their well-being and QOL (Barro, 1996; Romer, 1986; Ranis et al., 2000). However, it is argued that digital technologies may also influence QOL. ICT increases information availability for individuals, allows social interactions, grants access to education and healthcare facilities, and creates new business solutions, and therefore, it influences QOL (De La Hoz-Rosales et al., 2019; Majeed & Khan, 2018).

Primarily, ICT serves as a catalyst that expands choices and opportunities (ryzhanovskij et al., 2021). Sen (2010) highlights its importance by arguing that digital technologies function to increase human choices and efficiency in different spheres. Digitalization influences human life by saving time through the implementation of artificial intelligence (AI), automation, and big data technologies. These factors increase productivity, empower people, create social capital, and improve transparency and efficiency (Muralidharan et al., 2022). Hence, ICT remains an essential tool that helps humans, organizations, and economies to communicate smoothly and perform efficiently. Accordingly, the adoption of ICT is emphasized in all development plans.

However, it is observed that digital technologies may create negative effects and influence individuals' QOL (Dienlin & Johannes, 2020). The negative effects of digitalization on QOL are multifaceted, affecting health, education, privacy, social interactions, and economic stability. Digitalization may negatively influence QOL as excessive use of digital technologies often leads to addiction, isolation, and heightened stress levels (Turel et al., 2021; Badri et al., 2023). Additionally, automation and digitalization can cause job displacement and higher unemployment rates in certain sectors, contributing to economic instability and reducing QOL for those affected (Litvintseva & Karelin, 2021). Moreover, the digital divide exacerbates economic inequalities, as access to digital tools and skills is unevenly distributed across income levels, leading to varying outcomes of QOL (Litvintseva & Karelin, 2022).

Notably, the Sustainable Development Goal-3 (SDG-3) ensures healthy lives and focuses on well-being for all. While countries around the world prioritize the adoption of ICTs, it is argued that digital technologies have both positive and negative influences on QOL and well-being. Even though the contribution of ICT is generally appreciated at a larger scale in global and regional development, the role of ICT is usually excluded at a smaller scale, i.e., human development or well-being. Thus, it is important to investigate the relationship between digitalization and well-being (QOL) in detail to fully understand the issue.

Hence, the main objective of the present study is to investigate how digitalization influences QOL. The primary variable of interest is QOL measured with the Human Development Index (HDI), a key measure of human development that includes life expectancy, education, and income, frequently utilized in both theoretical and empirical literature. While digital technology is measured with four alternative indicators and one index, it is the focus variable of our analysis.

This study contributes to digitalization-QOL literature in the following ways: firstly, the present research provides a global perspective of digitization and QOL, using a sample of 185 countries. Secondly, this study extends the analysis for different income levels of sampled economies to test the validity of the leapfrogging development proposition. Thirdly, our study includes quantile regression analysis for digitalization and QOL.

Panel quantile regression analysis provides a thorough understanding of the relationship's heterogeneity and identifies differential effects that mean-based methods may have overlooked. Therefore, the findings of this study are expected to provide a better understanding of the digitalization and QOL relationship.

The study is structured as follows: Section 2 is a review of the literature, and the methodology is given in Section 3. Section 4 describes the data and variables, while the results are discussed in Section 5. Lastly, the study is concluded in Section 6, and some policies for the enhancement of QOL are also suggested in this section.

2. Literature Review

Digitalization shapes the global economy by transforming traditional processes through the use of innovations and automation. It is submitted that information and communication technologies (ICTs) improve efficiency and catalyze the development of a society (Ryzhanovskij et al., 2021; Muralidharan et al., 2022). Likewise, it is suggested that digital technologies significantly impact self-esteem, collective actions, and social behaviors and play an important role in influencing human development and QOL (Floridi, 2015).

QOL is a complex concept that often encompasses the degree of choices the individuals have. QOL is determined by one's ability to achieve certain personal goals, receive quality education along with health services, and build social capital. Digitalization and related technologies have extensive potential for enhancing QOL because they can significantly expand development opportunities for humans (Choi & Yi, 2009; Jorgenson & Vu, 2005). Additionally, digital technologies provide access to health-related information, medical services, and education for all (Ganju et al., 2016). Moreover, digitalization contributes to the development of social capital and the attainment of social equality. Thus, digitalization has emerged as a crucial determinant of QOL, influencing both objective indicators and the subjective perception of QOL (Kim & Lee et al., 2011).

Sen (1999) argues that the public's ability to perform certain tasks and the tools available to them influence their QOL. Therefore, resources like ICT can help individuals be more efficient in their work, and their use can enhance their capabilities (Sen, 2010). Likewise, Badri et al. (2023) highlight that there are rich benefits of digitalization, including improved accessibility to services and information. Moreover, access to digital tools positively contributes to the subjective well-being (Osipova & Naumova, 2020). It is suggested that the digital economy brings connectivity, accelerates productivity, ensures transparency, improves efficiency, and enhances decision-making (Linkov et al., 2018). Remarkably, digitalization and related technologies have shifted their status from being merely an instrument to a mechanism that has been transforming social and economic life in every domain.

Figure 1 illustrates the channels through which digitalization can positively influence well-being and QOL.

The digital technologies have positive impacts on QOL through multiple channels, as shown in Figure 1. For example, digital technology in healthcare enhances QOL by improving healthcare delivery and patient self-management (Lockl et al., 2022). Likewise, assistive technologies for people with dementia support their daily activities, leading to self-sufficiency (Schneider et al., 2024), and help them equally participate in society (Smith et al., 2024). Hence, digitalization improves communication, health and education facilities, social networking, and offers more employment opportunities (Kryzhanovskij et al., 2021).

**Figure 1: Digitalization and Quality of Life (positive association)**
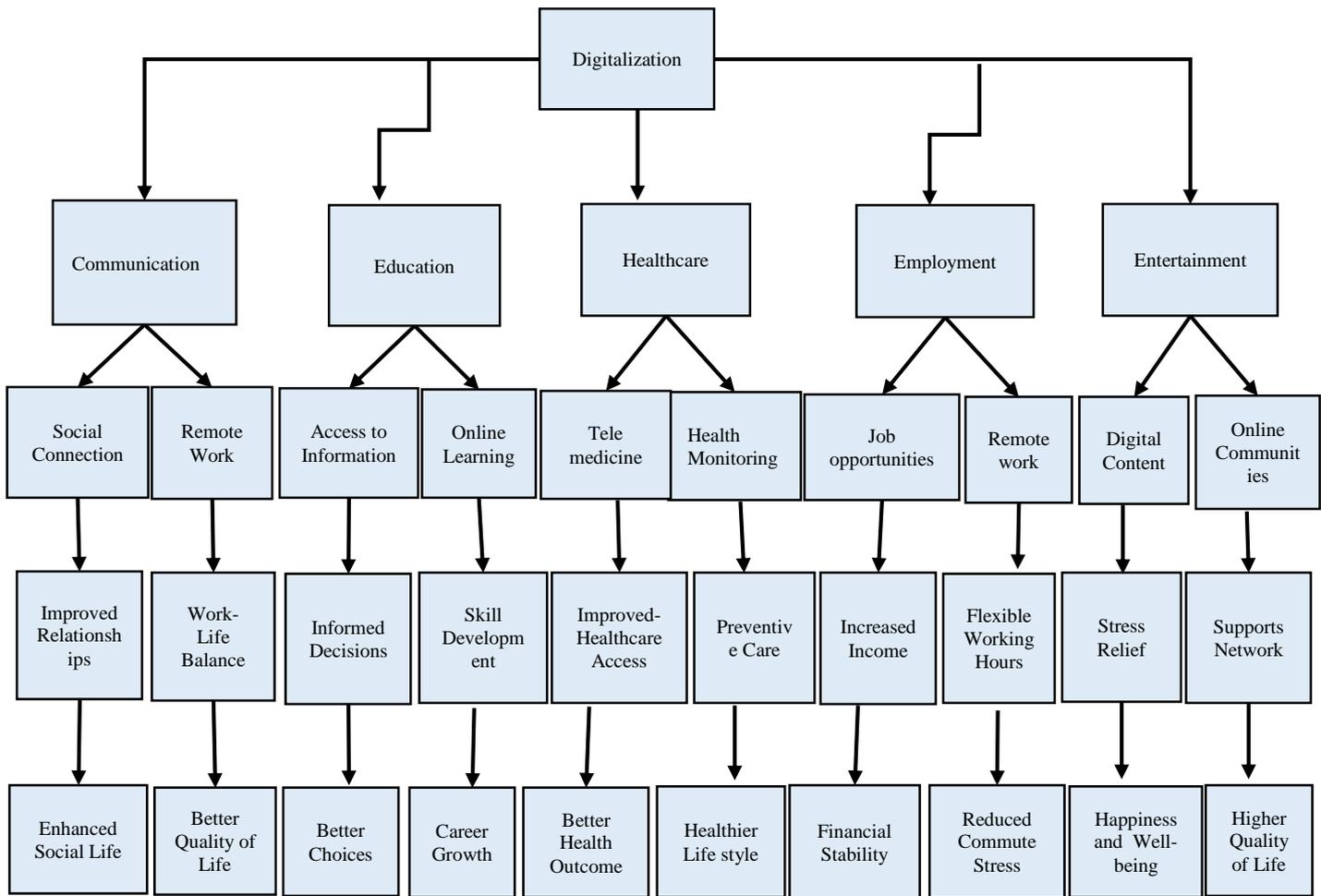
Source: Author's construction

Although the current research on the interrelations between digitalization and QOL usually suggests that increased access to ICTs positively impacts QOL. Nevertheless, the positive effects of digitalization are accompanied by social, economic, and psychological threats to individuals, societies, states, and the global community. These threats include the rise of cyber threats, privacy insecurity, digital inequality, and the encouragement of sedentary lifestyles, among others (Maiti & Awasthi, 2020). Figure 2 illustrates the channels through which digitalization can negatively influence well-being and QOL.

The automation of information processing and service delivery can disrupt traditional sectors, cause structural and economic changes, and result in unemployment and wage inequality, all of which impact overall well-being (Frey & Osborne, 2017; Acemoglu, 2002). Moreover, the emergence of a new digital segment in the shadow economy amplifies the risks of personal data theft, financial resource theft, database breaches, and other cyber threats (Ohrimenko et al., 2019). ICT can adversely affect social life by causing high-tech pressure (Salanova, Marisa, and Ventura, 2014), anxiety, unease (Kessler and Ustun, 2008), and internet obsession (Porter and Kakabadse, 2006; Douglas et al., 2008). Accordingly, ICT may also critically disturb QOL.

Figure 2: Digitalization and Quality of life (Negative association)
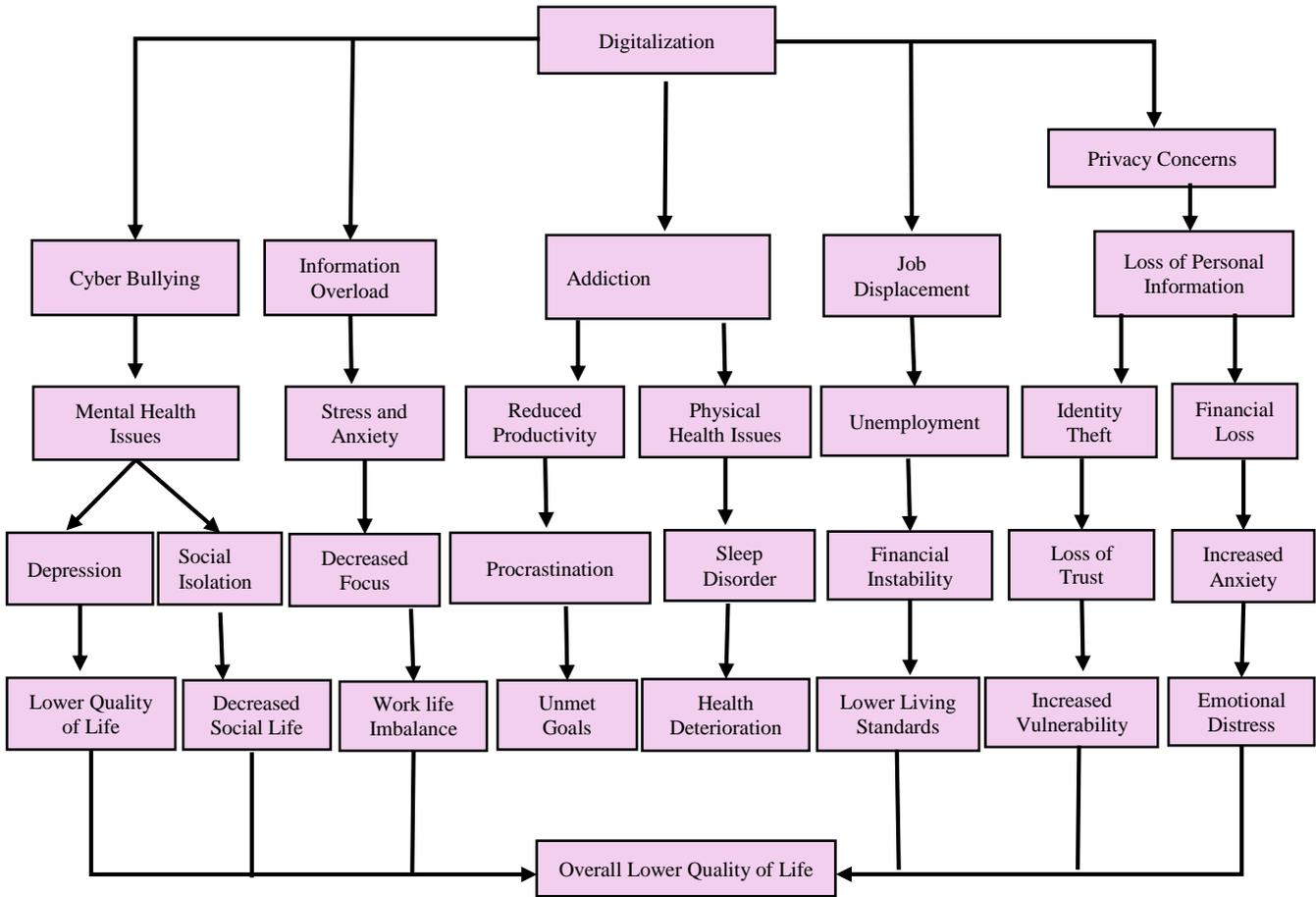
Source: Author's construction

Digitalization has introduced new challenges for societal development, raising questions about its impacts on QOL. However, the negative aspects of digitalization on QOL can be mitigated through the use of appropriate technologies.

While the literature provides substantial support for the potential association between digitalization and QOL yet this literature holds some potential research gaps. First, the existing literature does not portray a clear picture of the relationship between digitalization and QOL. In effect, the literature suggests both positive and negative influences of digitalization on QOL. A clear direction of the relationship can be settled by conducting an empirical analysis for a global sample with alternative dimensions of digitalization. Second, the empirical literature generally overlooks the examination of the leapfrogging hypothesis in the context of digitalization and QOL. Therefore, it is important to investigate the relationship between QOL and digitalization to understand the relationship in a border context.

3. Methodology

In the present world, digital technologies influence all dimensions of human life. It is suggested that information and communication technologies significantly impact self-esteem, collective actions, social behaviors, and QOL (Floridi, 2015). The following model is used for our empirical analysis, which is consistent with the existing studies.

$$QOL_{it} = \beta_1 + \beta_2 DIG_{it} + \beta_3 X_{it} + A_{it} + \varepsilon_{it} \tag{1}$$
$$(i = 1, \ldots \ldots N; t = 1, \ldots \ldots T)$$

Here, the outcome variable is QOL, and the input variable DIG represents digitalization. The term

X is a row vector of control variables. The term A represents unobserved country-specific effects, which have zero correlation with the independent variable and are fixed over time. The term ε_{it} is the residual term while 'i' indicates the country and 't' indicates time.

Historically, income per person is considered an important measure of well-being (Sapkota, 2011), and the research has largely shown its favorable influence on different dimensions of human life. However, social and psychological factors are also important and cannot be solely captured with income. It is submitted that literacy rate and health status also need to be considered, instead of just focusing on income per person to reflect population well-being (World Development Report, 2001). Accordingly, the Human Development Index (HDI) represents a comprehensive picture of QOL (UNDP, 1990; 2024). Thus, HDI assesses social well-being by evaluating human freedom, choices, and capacity to achieve a high QOL (United Nations, 2005). HDI comprises indicators such as life expectancy, literacy, and per capita income, and serves as an indicator to demonstrate the full potential of humans and their leading role in living productive lives.

Our focus variable digitalization is measured with four dimensions and one index, which is constructed through a Principal Component Analysis (PCA). The PCA is a multivariate statistical method that reduces the dimensionality of a data set and improves its interpretability with minimum information loss (Khan, 2025). The effects of these measures are estimated independently, as these measures are highly correlated with each other.

$$QOL_{it} = \beta_1 + \beta_2 Net_{it} + \beta_3 X_{it} + A_{it} + \varepsilon_{it} \qquad (1.1)$$
$$QOL_{it} = \propto_1 + \propto_2 FB_{it} + \propto_3 X_{it} + A_{it} + \varepsilon_{it} \qquad (1.2)$$
$$QOL_{it} = \emptyset_1 + \emptyset_2 MCS_{it} + \emptyset_3 X_{it} + A_{it} + \varepsilon_{it} \qquad (1.3)$$
$$QOL_{it} = \gamma_1 + \gamma_2 FT_{it} + \gamma_3 X_{it} + A_{it} + \varepsilon_{it} \qquad (1.4)$$
$$QOL_{it} = \delta_1 + \delta_2 Index_{it} + \delta_3 X_{it} + A_{it} + \varepsilon_{it} \qquad (1.5)$$

The term Net in equation 1.1 represents internet users, while FB shows fixed broadband subscriptions in equation 1.2, MCS represents mobile cellular subscriptions in equation 1.3 and FT shows fixed telephone subscriptions in equation 1.4. Finally, an index of digitalization is shown in equation 1.5.

3.1 Estimation Techniques

The Pooled Ordinary Least Squares (POLS) method is the most frequently used panel data technique but the estimates of POLS become efficient only when the error terms are homoscedastic and unobserved heterogeneity does not exist in the data used. To tackle this issue, a fixed effects model (FEM) or random effects model (REM) is usually suggested. The results of the Hausman test suggest that FEM is preferred to REM in our analysis. Therefore, the study has estimated the model using FEM. The FEM allows variation of country-related fixed effects. The advantage of this model is that it controls unobserved heterogeneity that can create biased estimates. Moreover, it provides consistent estimates even when individual effects are correlated with independent variables. However, this model consumes a considerable degree of freedom.

In our models, the issue of endogeneity can undermine the strengths of the results. To tackle the issue of endogeneity and heterogeneity, we use system GMM that employs instruments from the internal structure of the data. It tackles endogeneity by employing lagged variables as instruments. Finally, the panel quantile regression approach is used for the following reasons (Adeleye et al., 2022). First, in the presence of heteroscedasticity in the data, it provides heterogeneous slopes at different points. Second, this approach also helps to tackle the issue of outliers in the data, which is a common issue in panel data sets.

4. Data Description

This study investigates the relationship between digitalization and QOL for a panel of 185 countries from 1990 to 2023. The variable QOL is measured by HDI, and its data is extracted from UNDP (2024), while the data for the remaining indicators is retrieved from World Development Indicators (2024).

The key focused variable of the study, digitalization, is measured using "internet users (Net), fixed broadband (FB) subscriptions, mobile cellular subscriptions (MCS), and fixed telephone subscriptions (FTS)".

This study employs four measures of digitalization. A single measure can produce biased results; therefore, we use alternative measures. Besides, we also conduct a principal component analysis of these measures, and the resulting index is used to find the overall impact of digitalization on QOL (Sana et al., 2022).

The first dimension of digitalization is the internet, which is measured as individuals using the internet (percentage of population) in the last 3 months. Likewise, other dimensions of digitalization are measured as individuals using mobile cellular subscriptions (per 100 people), fixed broadband subscriptions (per 100 people), and fixed telephone subscriptions (per 100 people). The indicator of income is measured with gross domestic product (GDP) per capita (constant 2015 US$). Urbanization refers to the urban population, which "refers to people living in urban areas as defined by national statistical offices. The data is measured as a percentage of the total population of the respective country. The control variable age dependency is measured as the proportion of dependents per 100 working-age population. Lastly, carbon dioxide emissions (CO_2) are measured in metric tons per capita.

5. Results and Discussion

The study reports estimation results with SGMM in Table 1. The empirical results indicate that the influence of different digitalization measures on QOL is consistently positive and significant. According to Ganju et al. (2016), digital technologies and their usage contribute to improvement in the country's well-being, social capital development, and attainment of social equality. It also helps in providing access to information related to health and medical services, access to education for the poor population and supports trade. Moreover, the digital revolution increases the value of time by reducing time spent on routine tasks, providing opportunities for creativity and self-development, and providing new, often "free" goods (Coyle, 2014). Sen (2010) also highlights the importance of digital technologies in enhancing efficiency and human choices. Hence, it can be suggested that digitalization appears to be an important determinant of human development, influencing both objective indicators and the subjective perception of QOL.

The parameter estimate on income is positive and significant, suggesting that an increase in income improves QOL. The human development theory identifies income as one of the elements that enable people to meet their human needs. Therefore, an increase in income improves QOL. This finding is in line with existing studies (Anand & Ravallion, 1993; Ranis et al., 2000; Tsai, 2007; Samli, 2008).

The effect of age dependency shows a negative effect on QOL. With the increasing age dependency ratio, the proportion of the population available for work declines. As a consequence, the savings of individuals are reduced, and resources required for better living conditions, such as education, housing, clean water and sanitation, quality food, and health facilities are squeezed. In this respect, Yenilmez (2015) suggests that aging populations create a wide range of implications for society and the labor market, lowering QOL.

The next control variable is urbanization, which shows a positive association with QOL. It is argued that more educational, health, and sanitation facilities, along with employment opportunities, are available in urban areas, which positively influences QOL (Todaro & Smith, 2020). Moreover, it offers community engagement and provides access to amenities that positively influence mental well-being (Nussbaum & Sen, 1993). Furthermore, urban areas mostly have better access to digital resources, which enhances the productivity of the labor force. All these factors contribute to improved standards of living and lead to a better QOL in urban areas (Kryzhanovskij et al., 2021).

The last control variable is CO_2 emissions, which negatively affect QOL in our analysis. Majeed and Khan (2018) found that carbon dioxide emissions have an adverse and significant effect on life expectancy. Moreover, the study highlighted that carbon dioxide emission threatens the well-being and health of current and upcoming generations.

Table 1: Digitalization and QOL: System-GMM Results

Variables	(1) QOL	(2) QOL	(3) QOL	(4) QOL	(5) QOL
GDP per capita	0.129***	0.144***	0.128***	0.129***	0.156***
	(0.00447)	(0.00572)	(0.00367)	(0.00452)	(0.00625)
CO_2 Emissions	-0.204***	-0.209***	-0.236***	-0.260***	-0.208***
	(0.0159)	(0.0173)	(0.0143)	(0.0135)	(0.0157)
Urbanization	0.0126	0.00534	0.0340***	0.0267**	0.00262
	(0.0112)	(0.0172)	(0.0130)	(0.0117)	(0.0182)
Age Dependency	-0.511***	-0.286***	-0.563***	-0.518***	-0.253***
	(0.0171)	(0.0179)	(0.0197)	(0.0180)	(0.0219)
Internet	0.0218***				
	(0.00210)				
Fixed Broadband		0.0598***			
		(0.00415)			
Mobile Phones			0.00739***		
			(0.00204)		
Fixed Telephones				0.0422***	
				(0.00673)	
Digitalization					0.0469***
					(0.00364)
Constant	0.989***	-0.0967	1.253***	1.046***	-0.336**
	(0.107)	(0.118)	(0.120)	(0.104)	(0.136)
Instruments	124	95	124	124	95
Groups	185	185	185	185	185
Ar2	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05
Over ID	P=0.17	P=0.10	P=0.06	P=0.06	P=0.10
Hansen	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05
Observations	5,033	3,184	5,133	5,112	3,096
Number of id	185	185	185	185	184

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

There are different channels through which CO_2 emissions adversely influence QOL. For example, higher CO_2 emissions are linked with higher levels of air pollution, which causes certain respiratory problems and adversely influences overall well-being and QOL (Majeed & Khan, 2018). Moreover, it has been established that CO_2 emissions are the main cause of global warming, while global warming leads to heat stress, unpredictable water supplies, food insecurity, higher coastal erosion, and a rise in the frequency of severe climatic events. In extreme cases, global warming causes migration and displacement, which negatively influences economic and mental well-being and QOL (Sharif & Khan, 2024). Hence, the finding of the negative influence of CO2 emissions on QOL is consistent with the literature.

The study has investigated the relationship between digitalization and QOL with alternative techniques, and it can be concluded that digitalization positively influences QOL in our global sample of 185 countries. It is also evident from Table 1 that consistent findings are available for the digitalization index, where the digitalization index positively influences QOL.

The impact of digitalization on QOL can vary depending on the level of development of the countries under investigation. Theory suggests that developing countries may gain less from investment in digitalization because they lack complementary inputs for digitalization due to lower absorptive capacity, and a lack of investment in human capital and research and development, as suggested by Absorptive Capacity Theory (Cohen & Levinthal, 1990).

However, recently the discussion of leapfrogging has been added to the literature in the context of sustainable development, which suggests that developing countries can accelerate development by leapfrogging inferior, less efficient, more expensive, or more polluting technologies and industries and moving directly to more advanced technologies and industries. Steinmueller (2001) proposes the theory that developing economies can leapfrog the conventional methods of productivity. The extra benefits arising from improved productivity can be induced by "ICT-related spillovers or network effects" because ICT reduces the costs of transactions and shortens the time required to develop new knowledge (Stiroh, 2002). When firms use similar levels or types of ICT, then network effects become more noticeable (Chen et al., 2004). Conversely, Fong (2009) mentions that improving the conditions in developing countries to support the application, diffusion, and innovation of leapfrog technologies is challenging due to weak or inadequate infrastructure. Moreover, it can sometimes create negative impacts, such as creating a digital divide among individuals with and without technological skills (Mansell, 1999). This digital divide may further negatively influence QOL in low-income countries.

Following this discussion, it is important to assess the impact of digitalization on QOL across different income levels, such as high-income, upper-middle-income, lower-middle-income, and low-income countries. Hence, in the second step of analysis, the study has analyzed the relationship between QOL and digitalization across income levels, and the results are reported in Tables 2, 3, 4, and 5, respectively.

The relationship between digitalization and QOL is presented in Table 2 for high-income countries (HICs). Across all models, all dimensions of digitalization positively and significantly influence QOL.

Table 2: Digitalization and QOL (HICs)

Variables	(1) QOL	(2) QOL	(3) QOL	(4) QOL	(5) QOL
GDP per capita	0.0764***	0.0599***	0.0864***	0.0987***	0.0539***
	(0.00204)	(0.00226)	(0.00212)	(0.00293)	(0.00217)
CO2 Emissions	-0.0526***	-0.0115**	-0.0634***	-0.0952***	-0.0169***
	(0.00509)	(0.00554)	(0.00543)	(0.00659)	(0.00509)
Urbanization	0.0579***	0.0389***	0.0554***	0.0406***	0.0526***
	(0.00466)	(0.00454)	(0.00499)	(0.00608)	(0.00430)
Age Dependency	0.00470	0.0290***	0.00118	-0.0661***	0.0553***
	(0.00625)	(0.00582)	(0.00680)	(0.00787)	(0.00556)
Internet	0.0462***				
	(0.00140)				
Fixed Broadband		0.0528***			
		(0.00232)			
Mobile Phones			0.0360***		
			(0.00132)		
Fixed Telephones				0.0385***	
				(0.00454)	
Digitalization					0.0997***
					(0.00387)
Constant	-1.237***	-1.179***	-1.260***	-0.965***	-1.505***
	(0.0350)	(0.0333)	(0.0384)	(0.0451)	(0.0346)
Observations	1,638	1,114	1,649	1,650	1,105
R-squared	0.790	0.749	0.759	0.661	0.774

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Likewise, our control variables have a positive influence on QOL as discussed earlier, except for the effect of the age dependency variable, which varies across models. CO_2 emissions have a significant negative

impact on QOL; however, it is consistent with the theory.

Notably, the digitalization index has the strongest influence on QOL, highlighting the importance of digitalization in enhancing well-being and QOL in HICs. Programs such as the European Union's Digital Agenda, which seeks to ensure fast and ultra-speed internet access, and Germany's Digital Strategy 2025, which focuses on increasing digital infrastructure and services, demonstrate the region's commitment to leveraging digitalization to improve QOL.

How digitalization influences QOL in upper-middle-income countries (UMICs) is shown in Table 3. It is evident from Table 3 that there is a strong positive association between digitalization and QOL. These findings imply that digital development plays a fundamental role in enhancing well-being in UMICs.

Table 3: Digitalization and QOL (UMICs)

Variables	(1) QOL	(2) QOL	(3) QOL	(4) QOL	(5) QOL
GDP per capita	0.0576***	0.0469***	0.0688***	0.0827***	0.0476***
	(0.00397)	(0.00486)	(0.00396)	(0.00350)	(0.00534)
CO2 Emissions	-0.0317***	0.0148	0.00608	-0.0362***	0.00596
	(0.00989)	(0.0110)	(0.00986)	(0.00948)	(0.0119)
Urbanization	0.0300***	0.0249***	0.0322***	0.0305***	0.0210***
	(0.00591)	(0.00690)	(0.00613)	(0.00596)	(0.00734)
Age Dependency	-0.180***	-0.138***	-0.217***	-0.203***	-0.160***
	(0.00922)	(0.0111)	(0.00889)	(0.00862)	(0.0117)
Internet	0.0478***				
	(0.00279)				
Fixed Broadband		0.0879***			
		(0.00518)			
Mobile Phones			0.0234***		
			(0.00194)		
Fixed Telephones				0.0799***	
				(0.00510)	
Digitalization					0.0689***
					(0.00496)
Constant	-0.487***	-0.563***	-0.313***	-0.531***	-0.462***
	(0.0534)	(0.0645)	(0.0530)	(0.0556)	(0.0675)
Observations	1,335	882	1,377	1,372	850
R-squared	0.715	0.608	0.692	0.711	0.576

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

All dimensions of digitalization positively influence QOL, signifying the importance of basic (fixed telephone lines) as well as advanced digital technologies (mobile phones) in enhancing QOL in UMICs.

Our next income classification is meant for lower-middle-income countries (LMICs), and estimation results for digitization and QOL for LMICs are reported in Table 4. It is shown in Table 4 that digitalization has a positive and significant impact on QOL in LMICs.

Table 4: Digitalization and QOL (LMICs)

Variables	(1) QOL	(2) QOL	(3) QOL	(4) QOL	(5) QOL
GDP per capita	0.118***	0.107***	0.117***	0.122***	0.0907***
	(0.00615)	(0.00704)	(0.00574)	(0.00568)	(0.00712)
CO_2 Emissions	-0.218***	-0.163***	-0.256***	-0.0159	-0.239***
	(0.0343)	(0.0399)	(0.0340)	(0.0368)	(0.0388)
Urbanization	0.00547	-0.0108	0.00221	0.0165**	-0.0116
	(0.00720)	(0.00783)	(0.00707)	(0.00699)	(0.00790)
Age Dependency	-0.310***	-0.253***	-0.296***	-0.321***	-0.235***
	(0.0171)	(0.0180)	(0.0164)	(0.0158)	(0.0175)
Internet	0.0427***				
	(0.00580)				
Fixed Broadband		0.105***			
		(0.0205)			
Mobile Phones			0.0326***		
			(0.00328)		
Fixed Telephones				0.133***	
				(0.0153)	
Digitalization					0.0640***
					(0.00702)
Constant	-0.814***	-0.880***	-0.928***	-0.492***	-0.976***
	(0.131)	(0.146)	(0.127)	(0.117)	(0.141)
Observations	1,463	871	1,496	1,489	847
R-squared	0.710	0.690	0.715	0.714	0.711

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

These findings suggest that LMICs are benefiting from both traditional and newer digital technologies, partially supporting a leapfrogging effect where mobile and internet-based modern technologies complement rather than completely replace legacy infrastructure.

Lastly, the study has estimated our digitalization-QOL models for low-income countries (LICs), and the findings are reported in Table 5. Nonetheless, in low-income nations, the advantages of fixed broadband and fixed telephones are not promising. These effects are insignificant in low-income nations, most likely due to insufficient infrastructure and a greater dependence on mobile technology. Notably, the findings support the leapfrogging hypothesis, suggesting that LICs can enhance QOL by focusing latest digital technologies (Adeleye et al., 2022).

For example, in nations such as Ethiopia and Malawi, mobile phone usage has outperformed the development of fixed broadband and telephone services, highlighting mobile technology's vital role in enhancing QOL in these regions. Likewise, in Kenya, the extensive use of mobile technology, as seen by the success of mobile money services such as M-Pesa, has transformed financial inclusion and economic participation. Additionally, initiatives like Rwanda's Vision 2020, which aspires to transform the country into a knowledge-based economy, and Ghana's Digital Financial Services policy, demonstrate how low-income countries are prioritizing digitalization to promote growth and improve QOL. It follows from the findings that there is limited relevance of old technologies (such as fixed telephones) in improving QOL in LIC. However, internet usage and the digitalization index have a strong positive influence on QOL, suggesting that leapfrogging traditional infrastructure in favor of digital technologies may be an effective strategy for LICs to achieve the SDGs, and particularly relevant for enhancement in well-being and QOL (SDG-3).

Table 5: Digitalization and QOL (LICs)

Variables	(1) QOL	(2) QOL	(3) QOL	(4) QOL	(5) QOL
GDP per capita	0.117***	0.0384**	0.0887***	0.153***	0.0417**
	(0.0162)	(0.0165)	(0.0134)	(0.0160)	(0.0172)
CO2 Emissions	-0.900***	-0.813***	-1.369***	-0.749***	-0.725***
	(0.155)	(0.180)	(0.138)	(0.261)	(0.170)
Urbanization	0.0257*	0.0375**	0.0114	0.0398**	-0.0170
	(0.0145)	(0.0152)	(0.0128)	(0.0156)	(0.0153)
Age Dependency	-0.379***	-0.529***	-0.329***	-0.686***	-0.529***
	(0.0699)	(0.0644)	(0.0576)	(0.0693)	(0.0618)
Internet	0.194***				
	(0.0180)				
Fixed Broadband		-0.0123			
		(0.0901)			
Mobile Phones			0.118***		
			(0.00671)		
Fixed Telephones				-0.0105	
				(0.0647)	
Digitalization					0.128***
					(0.0173)
Constant	-2.628***	-0.668	-3.591***	-0.632	-0.725
	(0.529)	(0.583)	(0.451)	(0.578)	(0.547)
Observations	597	317	611	601	294
R-squared	0.583	0.514	0.666	0.506	0.612

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The insignificant effects of fixed broadband and fixed telephone services in low-income nations have substantial policy implications. These findings indicate that governments in low-income nations should prioritize the deployment of mobile internet services above traditional fixed-line technology. Given the widespread availability and affordability of mobile internet, it is more likely to be an effective tool to bridge the digital divide and improve QOL in these regions.

How digitalization influences QOL across development or income levels, the findings can be summarized as follows. The findings reveal the relevance of both traditional development patterns and leapfrogging potentials. In high-income and upper-middle-income countries, all dimensions of digitalization positively influence QOL, signifying that digitalization complements already established old infrastructure and technologies. QOL patterns are observed for lower-middle-income countries, where both modern and old technologies positively influence QOL, indicating a transitional stage where leapfrogging is observed but partial reliance on old technology is also noted. However, just the opposite pattern is observed for poor countries, where mobile phones significantly enhance QOL while fixed telephones are either insignificant or negatively associated, suggesting the leapfrogging pattern. It follows that poor countries can bypass traditional capital-intensive technology and can focus latest technologies for improvement in QOL.

To consider the heterogeneity of estimated slopes, a panel quantile regression analysis is conducted, and the findings are reported in Table 6. Table 6 summarizes the results of a quantile regression analysis focusing on the relationship between digitalization and QOL (Adeleye et al., 2022). Instead of focusing only on the average effects, quantile regression shows how the relationship between digitalization and QOL varies across different levels of QOL.

Table 6: Quantile Regression Estimates for Digitalization and QOL

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	QOL	QOL	QOL	QOL	QOL	QOL	QOL	QOL	QOL
GDP per	0.116***	0.118***	0.115***	0.106***	0.0978***	0.0947***	0.0902***	0.0883***	0.0816***
Capita	(0.00622)	(0.00355)	(0.00316)	(0.00293)	(0.00217)	(0.00203)	(0.00210)	(0.00215)	(0.00286)
CO2	-0.154***	-0.140***	-0.120***	-0.0939***	-0.0665***	-0.0579***	-0.0548***	-0.0528***	-0.0353***
Emissions	(0.0234)	(0.0133)	(0.0119)	(0.0110)	(0.00815)	(0.00763)	(0.00789)	(0.00808)	(0.0108)
Urbanization	0.0820***	0.0423***	0.0439***	0.0509***	0.0543***	0.0554***	0.0578***	0.0475***	0.00460
	(0.0126)	(0.00721)	(0.00642)	(0.00595)	(0.00441)	(0.00413)	(0.00426)	(0.00437)	(0.00582)
Age	-0.156***	-0.205***	-0.210***	-0.186***	-0.200***	-0.206***	-0.205***	-0.192***	-0.131***
Dependency	(0.0209)	(0.0119)	(0.0106)	(0.00987)	(0.00731)	(0.00684)	(0.00707)	(0.00725)	(0.00964)
Digitalization	0.120***	0.0992***	0.0842***	0.0797***	0.0711***	0.0675***	0.0681***	0.0669***	0.0673***
	(0.0112)	(0.00640)	(0.00570)	(0.00529)	(0.00392)	(0.00367)	(0.00379)	(0.00388)	(0.00517)
Constant	-1.225***	-0.789***	-0.719***	-0.792***	-0.701***	-0.652***	-0.619***	-0.598***	-0.625***
	(0.133)	(0.0759)	(0.0676)	(0.0627)	(0.0464)	(0.0434)	(0.0449)	(0.0460)	(0.0612)
Observations	3,096	3,096	3,096	3,096	3,096	3,096	3,096	3,096	3,096

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0

The findings confirm the previous results with slight variations of slopes; however direction of effect and significance of the effect remain intact. Additionally, the quantile analysis suggests the complexities of the relationship between digitalization and QOL. Digitalization has a positive and statistically significant influence across all quantiles of QOL; however, its influence weakens from 0.12 in the lowest quantile to 0.067 in the highest.

This pattern implies that digitalization is largely favourable for regions at the lower end of QOL index, probably because digital technologies support education, health facilities, and other economic opportunities in poor countries. As QOL improves, the marginal gains from digitalization are likely to diminish, signifying that its role may shift from being transformative to supportive in higher-QOL regions. It is suggested that digitalization can be focused on for the improvement of well-being (SDG-3), in less-developed countries. By revealing heterogeneous effects, quantile regression provides deeper insights for policymakers aiming to ensure equitable digital transformation.

6. Conclusion

This study investigates the impact of digitalization on QOL across 185 countries from 1990 to 2023, employing a comprehensive panel dataset. The empirical results, derived from various econometric models such as fixed effects, system-GMM, and panel quantile regression analysis, consistently indicate that digitalization enhances QOL. The analysis is also conducted for four groups of economies according to their income levels: high-income, high-middle-income, low-middle-income, and low-income countries. The effect of digitalization on QOL remains the same across all income groups except low-income economies, where fixed broadband and fixed telephones do not exert any significant influence. These findings signify the importance of the leapfrogging proposition and highlight the transformative potential of digitalization in enhancing QOL globally. To assess the robustness of the results, a panel quantile regression analysis is conducted. This approach takes care of slope heterogeneity depending on the distribution of the dependent variable. The main findings remain the same in terms of sign and significance, while coefficients slightly vary across quantiles. On the basis of our findings, it is suggested that policymakers should prioritize investments in digital infrastructure to leverage these benefits, particularly focusing on expanding access to broadband and mobile networks.

There are certain limitations of our study: The study relies on data from 1990 to 2023, which may not fully capture the latest digitalization trends. Likewise, various econometric models were used in our analysis, and inherent limitations in these models could affect the results. Lastly, digitalization measures may not uniformly capture the multifaceted nature of digital transformation across countries. Future studies need to explore new variables and incorporate emerging digitalization metrics such as AI adoption, IoT deployment, and 5G coverage. Additionally, sector-specific analysis may be conducted to provide deeper insights for specific sectors such as the health or education sectors.

In conclusion, the empirical evidence strongly suggests that digitalization enhances QOL across countries. Prioritizing leapfrogging digital development can lead to substantial QOL improvements, especially in underserved regions. Given the variability in digitalization impact across income levels, policies should be tailored to specific economic contexts. Policies must ensure that digital advancements are inclusive, addressing disparities in access and usage among different demographic groups.

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Appendix

Table A1: Fixed Effects Results for Digitalization and QOL

Variables	(1) QOL	(2) QOL	(3) QOL	(4) QOL	(5) QOL
GDP per capita	0.146***	0.149***	0.117***	0.177***	0.0966***
	(0.00402)	(0.00394)	(0.00367)	(0.00327)	(0.00398)
CO2 Emissions	-0.118***	-0.109***	-0.0826***	-0.168***	-0.0745***
	(0.0131)	(0.0116)	(0.0121)	(0.0131)	(0.00997)
Urbanization	0.379***	0.346***	0.313***	0.388***	0.229***
	(0.00878)	(0.0113)	(0.00850)	(0.00878)	(0.0115)
Age Dependency	-0.0587***	-0.0883***	-0.00670	-0.0997***	-0.0158**
	(0.00731)	(0.00672)	(0.00710)	(0.00699)	(0.00668)
Internet	0.0205***				
	(0.00148)				
Fixed Broadband		0.00976***			
		(0.00179)			
Mobile Phones			0.0323***		
			(0.00112)		
Fixed Telephones				0.000874	
				(0.00431)	
Digitalization					0.0559***
					(0.00212)
Constant	-2.664***	-2.418***	-2.531***	-2.603***	-2.065***
	(0.0632)	(0.0627)	(0.0593)	(0.0646)	(0.0590)
Observations	5033	3184	5133	5112	3096
R^2	0.737	0.716	0.765	0.726	0.770
Adjusted R^2	0.727	0.699	0.756	0.715	0.755
F- Test	2718.8	1513.0	3223.8	2604.6	1947.1
Hausman Test	Chi2=430	Chi2=344.81	Chi2=49.17	Chi2=3188	Chi2=154.87
	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Disclosure statement

There is no potential conflict of interest.

Disclaimer

The views and opinions expressed in this paper are those of the authors alone and do not necessarily reflect the views of any institution.