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Exploring the Association between Information and Communication Technologies (ICTs) and Quality of Life: A Panel Data Analysis

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Abstract

This study examines the relationship between Information and Communication Technologies (ICTs) and quality of life using panel data from 225 countries over 2010-2019. Employing two-way fixed effects regression with country and year fixed effects, we analyze associations between five ICT indicators—mobile cellular subscriptions, fixed telephone subscriptions, internet users, ICT goods exports, and ICT goods imports—and eight quality of life measures spanning living conditions, health, and educational outcomes. Our methodology addresses a key limitation of prior cross-sectional research by controlling for time-invariant country characteristics that may confound observed relationships. Results reveal that internet usage is robustly and positively associated with quality of life across multiple dimensions, with associations strongest in low-income countries where marginal benefits of digital connectivity appear greatest. Notably, ICT goods exports show consistent negative associations with quality of life, a pattern consistent with the view that export-oriented ICT manufacturing may not translate to domestic welfare improvements, though we caution that the ICT trade variables are share-of-trade composition proxies rather than direct measures of domestic ICT production or absorption. Mobile cellular and fixed telephone subscriptions, while strongly correlated with quality of life cross-sectionally, show limited significance in fixed effects models, indicating that previous findings may reflect confounding by unobserved country characteristics. These core findings survive robustness checks including lagged specifications and income group heterogeneity analysis. The study contributes methodologically rigorous evidence with important implications for digital development policy.

Keywords

Information and Communication Technologies, ICT, Quality of Life, Panel

Data Analysis, Fixed Effects Regression, Digital Development, Living Conditions, Health Outcomes, Educational Outcomes, Digital Divide

1. Introduction

The rapid proliferation of Information and Communication Technologies (ICTs) over the past three decades has fundamentally transformed human society, reshaping how individuals communicate, access information, conduct economic activities, and engage with public services [1]. From mobile phones connecting rural communities to previously inaccessible markets and services, to internet platforms enabling global commerce and instantaneous information sharing, ICTs have emerged as potentially powerful tools for improving human welfare across multiple dimensions. The transformative potential of these technologies has captured the attention of policymakers, development practitioners, and scholars worldwide, prompting substantial investments in digital infrastructure and connectivity initiatives across both developed and developing nations.

The digital revolution has accelerated dramatically since the turn of the millennium. Global internet penetration rose from approximately 6% in 2000 to over 60% by 2019, representing one of the most rapid technology diffusion processes in human history [2] [3]. Mobile cellular subscriptions have expanded even more rapidly, exceeding 100 subscriptions per 100 people in many countries and approaching near-universal coverage in some regions. This unprecedented technological diffusion has prompted substantial scholarly and policy interest in understanding whether and how ICT adoption translates into tangible improvements in quality of life for populations worldwide.

Quality of life encompasses multiple dimensions of human wellbeing, extending beyond mere economic prosperity to include access to basic services such as clean water and sanitation, health outcomes including life expectancy and child mortality, educational attainment and opportunities, and environmental conditions affecting daily life. The relationship between ICT development and these diverse welfare dimensions represents a critical question for researchers and policymakers alike, particularly as nations invest substantial public and private resources in digital infrastructure and connectivity initiatives with the expectation that such investments will yield broad-based improvements in population welfare.

The relationship between ICT development and human welfare has been explored through various theoretical and empirical lenses. The World Bank's World Development Report 2016, titled Digital Dividends, highlighted digital technologies' potential to promote inclusion, efficiency, and innovation across economic and social domains [4]. However, the report also cautioned that technology alone proves insufficient without complementary investments in human capital, institutions, and infrastructure—the analog complements necessary to realize digital dividends. This nuanced perspective underscores the complexity of ICT-development relationships and the need for rigorous empirical investigation that can disentangle genuine technology effects from confounding factors.

Despite substantial scholarly attention to ICTs and their societal impacts, empirical research comprehensively examining the association between various ICT dimensions and multiple quality of life indicators across diverse national contexts remains limited [5]. Several critical gaps warrant attention and motivate the present study. First, methodological limitations constrain existing research. Many studies employ cross-sectional designs that cannot distinguish between-country correlations from within-country causal effects [6]. Countries with high ICT adoption typically also possess favorable institutions, geographic advantages, and historical development trajectories that independently promote quality of life, creating potential confounding that cross-sectional analysis cannot adequately address.

Second, most existing studies focus on individual ICT measures or specific quality of life dimensions, limiting understanding of differential impacts across ICT types and welfare domains. Mobile phones, fixed telephones, and internet connectivity may operate through different mechanisms and yield different welfare effects, yet few studies examine these technologies simultaneously within a unified analytical framework. Third, the distinction between ICT production for export and ICT consumption for domestic use receives insufficient attention in existing literature, despite potentially important implications for development strategy. Countries may engage with the global ICT sector as manufacturers producing for export markets or as consumers adopting technologies for domestic use, and these different modes of engagement may carry different welfare implications.

To address these limitations in the existing literature, this study poses the following research questions. First, what is the nature and magnitude of associations between ICT indicators and quality of life measures when controlling for time-invariant country characteristics through fixed effects estimation? Second, do different ICT dimensions—including mobile telephony, fixed telephony, internet connectivity, and ICT trade—show differential associations with quality of life outcomes? Third, does the distinction between ICT production for export and domestic technology adoption matter for population welfare?

The study addresses these research gaps by conducting a large-scale panel data analysis examining associations between five ICT indicators and eight quality of life measures across 225 countries over ten years from 2010 to 2019. We employ two-way fixed effects regression, controlling for both country-specific and time-specific unobserved heterogeneity. This approach isolates within-country variation, asking whether changes in ICT adoption associate with changes in quality of life within the same country over time, rather than merely whether countries with more ICT also happen to have better quality of life outcomes.

This research makes several contributions to the literature on ICTs and development. First, we provide methodologically rigorous empirical assessment using panel econometric methods that address confounding concerns inherent in cross-sectional analysis. The Hausman specification test confirms the appropriateness of fixed effects estimation, and we conduct robustness analyses including lagged ICT specifications and income-group stratification to assess sensitivity of the within-country associations. Second, we examine multiple ICT dimensions simultaneously within a unified framework, enabling systematic comparison of relative effects across technology types. Third, we explicitly distinguish between ICT production for export and domestic consumption, revealing important asymmetries with policy implications. Fourth, we analyze heterogeneous effects across income groups, demonstrating that ICT benefits vary systematically with development level.

Our findings reveal that internet usage demonstrates the most robust positive associations with quality of life across both living conditions and health and educational outcomes. These effects are strongest in low-income countries, suggesting diminishing marginal returns to ICT adoption and supporting digital leapfrogging hypotheses [7] [8]. Notably, ICT goods exports show consistent negative associations with quality of life indicators—a finding that survives multiple robustness checks and carries important implications for export-oriented development strategies. Mobile cellular and fixed telephone subscriptions, while strongly correlated with quality of life in cross-sectional analysis, show limited significant effects in fixed effects specifications, suggesting that previous findings may reflect confounding rather than causal relationships.

The remainder of this paper proceeds as follows. Section 2 establishes the theoretical foundation for examining ICT-quality of life relationships, drawing on the Capabilities Approach, Diffusion of Innovations Theory, and the Technology-Organization-Environment Framework. Section 3 reviews relevant empirical literature on ICTs and various welfare dimensions. Section 4 describes variables and develops testable hypotheses. Section 5 details our panel data methodology including fixed effects specification, model selection, and robustness procedures. Section 6 presents empirical results. Section 7 discusses findings and their theoretical and policy implications. Section 8 addresses scope and limitations, and Section 9 concludes with summary observations and directions for future research.

2. Theoretical Foundation

The relationship between Information and Communication Technologies and quality of life can be understood through multiple theoretical lenses that illuminate different mechanisms and conditions under which technology adoption may influence human welfare. This section presents three complementary theoretical frameworks—the Capabilities Approach, Diffusion of Innovations Theory, and the Technology-Organization-Environment Framework—and develops an integrated perspective that guides our empirical investigation.

2.1. The Capabilities Approach

Developed by economist Amartya Sen and philosopher Martha Nussbaum, the Capabilities Approach provides a normative framework for evaluating individual and societal wellbeing based on what people are able to do and be, rather than merely what resources they possess [9] [10]. Central to this approach is the distinction between functionings and capabilities. Functionings represent actual achievements—states of being and doing such as being healthy, being educated, or participating in community life. Capabilities, in contrast, represent the real freedoms or opportunities to achieve those functionings. Wellbeing, from this perspective, should be evaluated in terms of the capabilities available to individuals rather than simply the resources at their disposal.

The Capabilities Approach recognizes that individuals differ in their ability to convert resources into valuable functionings due to personal, social, and environmental conversion factors. A bicycle, for example, provides different mobility capabilities to an able-bodied adult versus a person with physical disabilities, or to someone living on paved roads versus unpaved terrain. This emphasis on conversion factors highlights the importance of contextual conditions in determining whether resources translate into genuine capability expansion.

ICTs can be understood as conversion factors that enhance individuals' capabilities by expanding access to information, communication, and services that enable achievement of valued functionings. Mobile phones, for example, may enhance capability for economic participation by enabling market information access, mobile banking, and coordination with trading partners [11]. Internet connectivity may expand educational capabilities by providing access to learning resources regardless of geographic location [12]. Telemedicine applications may enhance health capabilities by enabling remote consultations and health information access [13].

The Capabilities Approach helps explain why ICTs might associate with improved quality of life across multiple dimensions. Access to digital technologies potentially expands the range of achievable functionings by reducing information asymmetries that limit opportunity awareness, enabling access to services previously unavailable due to geographic or economic barriers, facilitating economic opportunities through digital marketplaces and remote work, and supporting social connections that enhance wellbeing. The approach suggests that ICT impacts on quality of life should be evaluated not merely in terms of technology access but in terms of the expanded capabilities that technology enables.

However, the Capabilities Approach also emphasizes that technology access alone proves insufficient for capability expansion. Individuals must possess the skills, resources, and social conditions necessary to convert access into actual capability gains. Digital literacy, complementary infrastructure, supportive institutions, and social networks all serve as conversion factors that mediate the relationship between ICT access and capability expansion [14]. This perspective suggests that ICT effects on quality of life may vary across contexts depending on the presence of complementary conditions.

2.2. Diffusion of Innovations Theory

Rogers' Diffusion of Innovations Theory explains how, why, and at what rate new technologies spread through populations and societies [15]. The theory identifies five characteristics of innovations that influence adoption rates: relative advantage over existing alternatives, compatibility with existing values and practices, complexity of use, trialability allowing experimentation before full commitment, and observability of results to potential adopters. Innovations perceived as offering greater relative advantage, higher compatibility, lower complexity, greater trialability, and more observable benefits diffuse more rapidly.

The theory also characterizes adopters along a continuum from innovators and early adopters to early majority, late majority, and laggards. Different adopter categories exhibit different characteristics, motivations, and responses to innovation. Critically, the theory identifies the importance of critical mass—the point at which enough individuals have adopted an innovation that its further diffusion becomes self-sustaining. Network technologies like telephones and internet exhibit particularly strong critical mass dynamics, as the value of adoption increases with the number of other adopters.

At the national level, Diffusion of Innovations Theory helps explain variation in ICT adoption rates and, consequently, differential impacts on quality of life across countries. Countries adopting ICTs earlier and more extensively may experience greater quality of life improvements due to longer exposure and more developed complementary infrastructure. Early adoption enables accumulation of digital skills, development of locally relevant applications, and establishment of institutional frameworks supporting technology use.

However, the theory also suggests potential for leapfrogging—late adopters may benefit from mature technologies and lessons learned by early adopters, potentially achieving rapid improvements without traversing the full developmental path of pioneers. Developing countries adopting mobile phones, for example, could skip the fixed-line telephony stage entirely, potentially realizing benefits more rapidly than the historical experience of developed countries would suggest [7].

The diffusion perspective illuminates temporal dynamics in ICT-quality of life relationships. Early adopters may experience limited benefits due to small network sizes and underdeveloped applications, while critical mass adoption triggers network effects and ecosystem development that amplify benefits. This suggests potential non-linearities and threshold effects in ICT-welfare relationships, with benefits accelerating once adoption reaches levels sufficient to support robust networks and application ecosystems.

2.3. Technology-Organization-Environment Framework

Originally developed to explain technology adoption in organizational contexts, the Technology-Organization-Environment (TOE) Framework can be adapted to national-level analysis [16]. The framework emphasizes that technology impacts depend on three contextual dimensions: technological characteristics including availability, complexity, and compatibility; organizational (here, national) factors including capacity, resources, and readiness; and environmental factors including regulatory frameworks, competitive dynamics, and infrastructure conditions.

This framework suggests that ICT impacts on quality of life depend not merely on technology availability but on the broader ecosystem within which technologies are deployed. Countries with stronger institutions, higher human capital, and better complementary infrastructure may extract greater welfare benefits from equivalent ICT investments. Conversely, technology adoption without adequate supporting conditions may yield limited improvements or even negative consequences if resources are diverted from more productive uses.

The TOE Framework also illuminates why certain ICT indicators might show unexpected associations with quality of life. For instance, high ICT goods exports may indicate manufacturing specialization that prioritizes industrial production over domestic technology deployment and welfare investment. Countries deeply integrated into global electronics supply chains as manufacturers may allocate resources toward export production rather than domestic service provision, potentially explaining negative associations between exports and quality of life indicators.

The framework further suggests that ICT impacts may vary across quality of life dimensions depending on the specific mechanisms through which technology operates. Internet connectivity may most directly affect outcomes related to information access and service delivery, while mobile telephony may most strongly influence outcomes related to communication and coordination. Understanding these mechanism-specific pathways helps explain why different ICT indicators might show different patterns of association with different quality of life measures.

2.4. Integrated Theoretical Perspective

These three theoretical frameworks offer complementary insights into ICT-quality of life relationships. The Capabilities Approach provides normative grounding for why ICTs should matter for welfare—they expand human capabilities and enable achievement of valued functionings across multiple life domains. Diffusion of Innovations Theory explains variation in adoption patterns and suggests temporal dynamics including network effects and potential for leapfrogging. The TOE Framework emphasizes contextual factors moderating technology impacts and helps explain why similar technologies may yield different outcomes in different settings.

This integrated theoretical foundation generates several expectations that guide our empirical investigation. First, ICT adoption should generally associate positively with quality of life improvements, as technologies expand capabilities and enable achievement of valued functionings. Second, effects may vary across ICT types reflecting different mechanisms of influence—internet connectivity enabling information access and service delivery, mobile telephony enabling communication and coordination, and so forth. Third, effects may vary across national contexts depending on complementary conditions including human capital, institutions, and infrastructure. Fourth, ICT production for export may operate through different mechanisms than domestic adoption, potentially with different welfare implications reflecting resource allocation priorities and value chain positioning.

3. Literature Review

The relationship between Information and Communication Technologies and quality of life has attracted substantial scholarly attention across multiple disciplines including economics, information systems, public health, and development studies. This section reviews relevant empirical literature organized by quality of life dimension, examines research on ICT production versus consumption, and identifies gaps addressed by the present study.

3.1. ICTs and Living Conditions

A substantial body of research examines how ICT access relates to basic living conditions and infrastructure. Scholars have investigated connections between telecommunications infrastructure and access to electricity, clean water, sanitation, and cooking fuels. Several studies demonstrate positive associations between ICT adoption and improved access to basic services. Dewan and Riggins [17] found that information technology investment associated with development outcomes across countries, though they emphasized the importance of addressing the digital divide to ensure equitable benefits.

Research on mobile technology specifically highlights its role in improving service delivery in resource-constrained settings. Jensen [18] demonstrated that mobile phone adoption among Indian fishermen reduced price dispersion and improved market efficiency, with benefits accruing to both producers and consumers. Aker and Mbiti [11] reviewed evidence on mobile phones and economic development in Africa, finding positive effects on agricultural and labor market efficiency, though they noted limited evidence on broader welfare outcomes.

The literature on internet access and living conditions emphasizes information asymmetry reduction and service accessibility. Chinn and Fairlie [19] examined determinants of the global digital divide, finding that income, human capital, and infrastructure significantly predicted internet penetration. Billon, Marco, and Lera-Lopez [20] analyzed disparities in ICT adoption using a multidimensional approach, identifying economic, educational, and infrastructure factors shaping cross-country differences.

However, research also identifies challenges and limitations in ICT-living conditions relationships. Piccoli and Pigni [21] noted that technology access without complementary capabilities may not translate to welfare improvements. Warschauer [22] argued that addressing the digital divide requires attention to physical resources, digital resources, human resources, and social resources—technology access alone proves insufficient for meaningful inclusion.

3.2. ICTs and Health Outcomes

The relationship between ICTs and population health has garnered substantial attention, particularly regarding telemedicine, health information access, and health system strengthening. Studies examining mobile health (mHealth) interventions demonstrate potential for improving health outcomes through enhanced communication, health education, and service delivery coordination. Mechael [13] made the case for mHealth in developing countries, arguing that mobile phones could address healthcare access challenges in resource-limited settings.

Free and colleagues [23] conducted a systematic review of mobile health technologies for health behavior change, finding evidence of effectiveness for smoking cessation and some chronic disease management applications, though they noted variable quality of evidence across domains. Noordam and colleagues [24] reviewed mobile phone use for improving maternal health services, identifying potential benefits for appointment reminders, health education, and emergency communication.

Internet access enables health information seeking that may influence health behaviors and outcomes. Cline and Haynes [25] reviewed consumer health information seeking on the internet, noting both opportunities for patient empowerment and challenges including information quality concerns. Fox and Duggan [26] documented substantial health information seeking online among American adults, with internet users reporting that online information affected their health decisions.

Recent population-level studies offer additional evidence on ICT-health relationships beyond specific intervention trials. Van Parys and Brown [27] found that broadband internet expansion influenced both patient and provider responses in the United States Medicare setting, with measurable effects on healthcare utilization and outcomes. Han *et al.* [28] used Chinese microdata to show that expansion of digital infrastructure was associated with reductions in residents' out-of-pocket healthcare expenditures, consistent with efficiency gains from digitally enabled service delivery. Kunz *et al.* [29] provided evidence from Indonesia that digital access shaped the spread of infectious disease, underscoring the role of information flows in population health outcomes.

Research on ICTs and mortality specifically suggests that improved communication infrastructure enables more effective emergency response and health service coordination. However, most studies focus on specific interventions rather than population-level relationships, limiting understanding of aggregate associations between national ICT adoption and health outcomes.

3.3. ICTs and Educational Outcomes

Literature on ICTs and education examines both educational access and learning outcomes. Digital technologies potentially democratize educational opportunities by transcending geographic constraints and providing access to learning resources regardless of location. Research demonstrates that internet access associates with educational participation and attainment, though mechanisms and effect sizes vary across contexts.

Fairlie [30] examined the relationship between race and the digital divide in educational contexts, finding that home computer access associated with educational outcomes among American students. Fuchs and Woessmann [31] analyzed international data on computers and student learning, finding that the relationship between computer availability and student performance was more complex than simple access effects might suggest.

Broader policy-oriented assessments reinforce that technology in education is not a standalone lever. UNESCO [32] concluded that realizing the promise of educational technology requires coordinated attention to equity, pedagogy, and governance rather than device provision alone, and cautioned against assuming automatic learning gains from connectivity expansion. Dastyari and Jose [33] argued that digital inclusion is a prerequisite for achieving inclusive and equitable quality education for all, particularly for learners in marginalized and remote settings whose access to digital resources shapes both enrolment opportunities and continuity of learning.

Studies examining ICT impacts in developing countries emphasize potential for leapfrogging traditional educational infrastructure constraints. Trucano [12] discussed ICT use in education across developing countries, identifying both opportunities and implementation challenges. Motlik [34] explored mobile learning potential in developing nations, arguing that mobile technologies could expand educational access where fixed infrastructure remains limited.

Critical perspectives emphasize that technology access alone cannot overcome fundamental educational challenges. Warschauer [22] argued that effective technology integration in education requires attention to social contexts and pedagogical approaches, not merely device provision. Selwyn [35] called for critical examination of educational technology assumptions, questioning whether technology-focused interventions address underlying educational inequities.

3.4. ICT Production versus Consumption

An underexplored area in existing literature concerns differential impacts of ICT production (exports) versus consumption (imports and domestic use). Nations engaged in ICT manufacturing for export operate within global value chains where benefits may concentrate among multinational corporations and skilled workers rather than diffusing broadly to populations. This distinction carries important implications for development strategy but receives limited empirical attention.

Dedrick, Kraemer, and Linden [36] examined value capture in the global electronics industry, analyzing the distribution of value in iPod and notebook PC production. They found that design and marketing activities generate higher returns than manufacturing, with component suppliers and assemblers capturing relatively small shares of product value. This pattern suggests that countries specializing in ICT assembly for export may not capture substantial development benefits from their manufacturing activities.

Kraemer and Dedrick [37] discussed strategic use of internet and e-commerce, emphasizing that technology deployment strategies matter for outcomes. Countries importing ICT goods for domestic use may realize different benefits than those exporting ICT products, as domestic deployment enables technology-enhanced service delivery while export production primarily generates employment and foreign exchange.

This literature suggests that ICT goods exports might associate differently with quality of life than ICT adoption measures, a distinction this study explicitly examines through separate analysis of exports and imports as ICT indicators.

3.5. Research Gaps

Despite substantial scholarly attention, several research gaps remain that motivate the present study. First, most studies employ cross-sectional designs that cannot distinguish correlation from within-country effects. Countries with high ICT adoption typically possess favorable institutions, geography, and development histories that independently promote quality of life. Cross-sectional correlations between ICT and welfare may reflect these confounding factors rather than genuine technology effects.

Second, few studies examine multiple ICT indicators and quality of life dimensions simultaneously within a unified analytical framework. This limits understanding of differential effects across technology types and welfare domains. Third, the ICT production-consumption distinction receives limited attention despite its potential importance for development strategy. Fourth, methodological approaches rarely address temporal dynamics including lagged effects and reverse causality concerns.

This study addresses these gaps by employing panel data methods with two-way fixed effects to control for time-invariant confounding, examining five ICT indicators and eight quality of life measures within a unified framework, explicitly distinguishing ICT exports from domestic adoption, and conducting robustness analyses including lagged specifications and income group heterogeneity.

4. Variables and Hypotheses Development

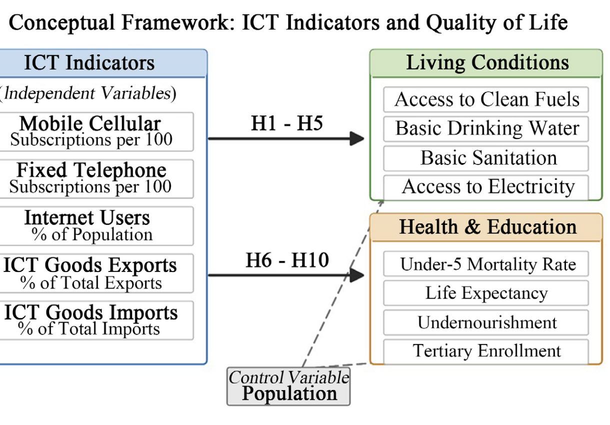

Figure 1. Conceptual framework: ICT indicators and quality of life relationships.

This study examines relationships between Information and Communication Technologies and quality of life through a comprehensive framework encompassing five ICT indicators and eight quality of life measures. This section describes variable measurement, presents the conceptual framework, and develops testable hypotheses grounded in theoretical foundations and literature review insights. Figure 1 illustrates the conceptual framework guiding this investigation.

4.1. Independent Variables: ICT Indicators

We employ five distinct measures to capture different aspects of national ICT infrastructure and engagement. These indicators span communication technologies (mobile and fixed telephony, internet) and ICT trade (exports and imports), enabling examination of both technology adoption and modes of engagement with the global ICT sector. Table 1 presents detailed measurement information for all independent variables.

Table 1. Independent variables: ICT indicators.

Variable	Definition	Source
Mobile Cellular Subscriptions	Mobile cellular telephone subscriptions per 100 people	World Bank WDI
Fixed Telephone Subscriptions	Fixed telephone subscriptions per 100 people	World Bank WDI
Individuals Using Internet	Percentage of population using the internet	World Bank WDI
ICT Goods Exports	ICT goods exports as percentage of total goods exports	World Bank WDI
ICT Goods Imports	ICT goods imports as percentage of total goods imports	World Bank WDI

Notes: All variables normalized to 0 - 1 scale. WDI = World Development Indicators.

Mobile Cellular Subscriptions per 100 people represents the prevalence of mobile phone access within a population. This metric captures what has become the most ubiquitous ICT globally, with mobile phones enabling voice communication, text messaging, and increasingly sophisticated digital services including mobile banking and internet access. Mobile technology has been particularly transformative in developing countries where it often represents the primary or only form of telecommunications access.

Fixed Telephone Subscriptions per 100 people measures traditional landline telecommunications infrastructure. While declining in many developed countries as mobile and internet telephony substitute for fixed lines, fixed telephone infrastructure remains relevant as an indicator of established telecommunications networks and may indicate broader infrastructure development patterns.

Individuals Using the Internet as a percentage of population captures the proportion of people accessing the internet regardless of access mode—whether through fixed broadband, mobile data, or public access points. This measure indicates participation in the digital information economy and access to the wide range of services, information, and opportunities available online.

ICT Goods Exports as a percentage of total goods exports indicates the extent to which a nation's economy engages in ICT production and manufacturing for international markets. High values indicate specialization in electronics manufacturing for export, reflecting integration into global ICT supply chains as a producer.

ICT Goods Imports as a percentage of total goods imports represents national demand for ICT products and technologies from international sources. This measure suggests domestic technology adoption and modernization, as countries import devices and equipment for use by businesses, government, and consumers.

Two interpretive caveats apply to the ICT trade indicators. First, both variables are trade-composition proxies rather than direct measures of domestic ICT production or domestic ICT adoption: they capture the share of ICT goods within total merchandise trade rather than the absolute volume of ICT activity, the value added retained domestically, or the diffusion of ICT capital into local firms and households. Second, because shares depend on a denominator, observed changes can arise from movements in non-ICT trade as well as from movements in ICT trade itself—a country whose commodity exports collapse will see its ICT export share rise even if ICT exports are flat. We therefore read the ICT exports and ICT imports coefficients as associations between trade-composition shifts and quality of life, and we are cautious about strong welfare interpretations that would require a cleaner measure of domestic ICT production or absorption.

4.2. Dependent Variables: Quality of Life Indicators

Quality of life represents a multidimensional construct encompassing various aspects of human wellbeing. Following established development frameworks including the United Nations Human Development Index and Sustainable Development Goals [38], we examine eight indicators organized into two dimensions: living conditions capturing access to basic infrastructure and services, and health and educational conditions capturing outcomes related to human capital and population wellbeing. Table 2 presents detailed measurement information for all dependent variables.

Table 2. Dependent variables: quality of life indicators.

Dimension	Variable	Definition	Source
Living Conditions	Access to Clean Fuels	% of population with access to clean cooking fuels and technologies	World Bank WDI
Living Conditions	Basic Drinking Water	% of population using at least basic drinking water services	World Bank WDI
Living Conditions	Basic Sanitation	% of population using at least basic sanitation services	World Bank WDI
Living Conditions	Access to Electricity	% of population with access to electricity	World Bank WDI
Health/Education	Under-5 Mortality Rate	Deaths per 1000 live births before age 5	World Bank WDI
Health/Education	Life Expectancy	Life expectancy at birth in years	World Bank WDI
Health/Education	Undernourishment	% of population with insufficient caloric intake	World Bank WDI
Health/Education	Tertiary Enrollment	Gross enrollment ratio in tertiary education	World Bank WDI

Notes: All variables normalized to 0 - 1 scale. For mortality and undernourishment, higher normalized values indicate worse outcomes.

The living conditions dimension encompasses four indicators reflecting access to basic infrastructure and services essential for human dignity and wellbeing. Access to Clean Fuels and Technologies for Cooking measures the proportion of people using clean cooking solutions rather than traditional biomass fuels that contribute to household air pollution and associated health burdens. People Using at Least Basic Drinking Water Services indicates access to improved water sources that provide safe water for drinking and domestic use. People Using at Least Basic Sanitation Services captures access to improved sanitation facilities that safely separate human waste from human contact. Access to Electricity measures the proportion of people with electrical power access enabling lighting, communication, refrigeration, and productive activities.

The health and educational conditions dimension encompasses four indicators capturing outcomes related to human capital development and population wellbeing. Mortality Rate Under-5 measures the probability of death between birth and age five years, serving as a sensitive indicator of overall health system performance and living conditions affecting child survival. Life Expectancy at Birth captures average expected lifespan, reflecting cumulative influences of healthcare quality, nutrition, sanitation, and environmental conditions. Prevalence of Undernourishment indicates the proportion of people whose food intake is insufficient to meet dietary energy requirements. School Enrollment Tertiary measures participation in higher education relative to the relevant age population, indicating educational opportunity and human capital development.

4.3. Control Variable

Population serves as the primary control variable, representing the total number of people residing in each country. Population size may influence both ICT adoption patterns and quality of life outcomes through multiple mechanisms including economies of scale in infrastructure provision, market size effects on technology deployment, and resource distribution challenges in highly populous nations. Including population as a control helps isolate ICT effects from scale-related confounding. We deliberately keep the set of time-varying controls parsimonious for two reasons. First, the two-way fixed effects design already absorbs all time-invariant country characteristics (geography, institutions, colonial history, baseline development) and all common annual shocks (global growth cycles, technology diffusion waves, common policy events), so the most pervasive sources of confounding are differenced out before any covariate is added. Second, candidate time-varying covariates such as GDP per capita, urbanization, and government health or education spending are themselves plausibly affected by ICT diffusion—internet expansion can raise productivity and GDP, accelerate rural-to-urban migration, and reshape public budgets. Including them as controls would absorb part of the very channels through which ICT is hypothesized to operate, attenuating the ICT coefficients and obscuring rather than clarifying the relationships of interest [39]. For these reasons we report a parsimonious specification with country and year fixed effects plus population, and we acknowledge in Section 8 that the resulting coefficients should be read as ICT-quality of life associations net of scale, common shocks, and time-invariant country traits, rather than as estimates that have been purged of every conceivable concurrent development trend.

4.4. Hypothesis Development

Building on theoretical foundations and literature review insights, we develop ten hypotheses examining associations between ICT indicators and quality of life dimensions. These hypotheses are organized by ICT indicator and quality of life dimension, with expected directions of association grounded in theoretical mechanisms. Table 3 summarizes all hypotheses.

Table 3. Summary of research hypotheses.

Hypothesis	ICT Variable	QoL Dimension	Expected Direction	Theoretical Rationale
H1	Mobile Cellular	Living Conditions	+	Information access, service coordination
H2	Fixed Telephone	Living Conditions	+	Infrastructure development indicator
H3	Internet Users	Living Conditions	+	Information access, e-services
H4	ICT Exports	Living Conditions	−	Resource diversion, manufacturing focus
H5	ICT Imports	Living Conditions	+	Technology adoption, modernization
H6	Mobile Cellular	Health/Education	+	mHealth, emergency communication
H7	Fixed Telephone	Health/Education	+	Healthcare coordination
H8	Internet Users	Health/Education	+	Health information, e-learning
H9	ICT Exports	Health/Education	−	Resource diversion from social services
H10	ICT Imports	Health/Education	+	Medical technology, educational equipment

Notes: + indicates expected positive association; − indicates expected negative association.

Hypotheses H1 through H3 predict positive associations between ICT adoption indicators (mobile, fixed telephone, internet) and living conditions. These predictions derive from the Capabilities Approach suggesting that ICTs expand capabilities for accessing services and information, and from empirical literature demonstrating ICT contributions to service delivery improvement. Mobile phones enable coordination for infrastructure maintenance and service requests. Internet access enables information seeking about available services and online service delivery platforms.

Hypothesis H4 predicts negative association between ICT exports and living conditions, while H5 predicts positive association for ICT imports. This asymmetry derives from the TOE Framework insight that export-oriented manufacturing may divert resources from domestic welfare investment, while imports indicate domestic technology adoption for population benefit. Countries specializing in ICT assembly for export may prioritize industrial production over infrastructure and service provision, while countries importing ICT goods deploy these technologies to enhance domestic service delivery.

Hypotheses H6 through H10 parallel H1 through H5 for health and educational outcomes. Mobile phones enable mHealth interventions, emergency communication, and educational messaging. Internet access enables health information seeking, telemedicine, and online learning. Fixed telephones support healthcare system coordination and educational institution connectivity. ICT exports may indicate resource diversion from health and education investment, while ICT imports suggest adoption of medical technologies and educational equipment.

5. Methodology

This section describes the research design, data collection procedures, variable measurement, and analytical approach employed to test the hypothesized associations between ICT indicators and quality of life measures. We detail the panel data specification, model selection procedures, and robustness analyses conducted to strengthen causal inference.

5.1. Research Design

This study employs a panel data research design examining country-level relationships between ICT indicators and quality of life measures over time. Panel data combines cross-sectional and time-series dimensions, enabling analysis that accounts for both between-country differences and within-country changes over time. This design offers substantial advantages over purely cross-sectional analysis by enabling control for time-invariant unobserved heterogeneity through fixed effects estimation.

5.2. Data Collection and Sample

The dataset comprises country-level observations from 225 countries and regions spanning the period 2010-2019, yielding a maximum of 2250 potential observations. Data were compiled from the World Bank's World Development Indicators database, which provides standardized international definitions ensuring cross-national comparability. The 2010-2019 period captures a decade of substantial ICT diffusion including smartphone proliferation and mobile broadband expansion, while avoiding potential disruptions from the COVID-19 pandemic beginning in 2020.

All variables were normalized to 0 - 1 scale using min-max normalization within the sample. This transformation preserves relative differences among observations while standardizing scales across measures with different original units, facilitating comparison of coefficient magnitudes across variables. The analysis sample size varies across models depending on data availability for specific variable combinations, ranging from approximately 1580 to 1900 complete observations. The discrepancy between the 225 countries and regions present in the raw World Development Indicators panel and the 213 - 215 units that appear in most regression tables reflects two factors. First, several units in the WDI universe are very small territories or non-sovereign reporting entities (for example, certain dependent territories and small island reporters) for which no values are recorded for the ICT or quality of life indicators across any year of the 2010-2019 window; these units are dropped automatically because the within-country fixed effects estimator requires at least one observation per country on every variable in the model. Second, the count of countries varies modestly across outcomes (e.g., 215 for life expectancy and electricity access, 213 for drinking water, 203 for undernourishment, 186 for tertiary enrollment) because outcome-specific reporting coverage differs across the WDI series. Within each outcome, missing observations are handled by listwise deletion at the country-year level, so a country contributes an unbalanced sequence of years rather than being dropped entirely whenever a single year is missing. We do not impute missing values, and we do not require a balanced panel. Country and observation counts for every model are reported in the regression tables in Section 6, and the underlying data are available from the corresponding author on request.

5.3. Analytical Approach

5.3.1. Panel Data Specification

Given the panel structure of our data with countries observed over multiple years, we employ fixed effects regression to control for unobserved country-level heterogeneity that may confound ICT-quality of life relationships. The general specification is as follows, where QoL represents a quality of life indicator for country i in year t, alpha represents country fixed effects, gamma represents year fixed effects, ICT is a vector of five ICT indicators, Controls includes population, and epsilon is the idiosyncratic error term.

Country fixed effects absorb all time-invariant characteristics of countries that may influence both ICT adoption and quality of life outcomes. These characteristics include geographic factors such as climate and natural resource endowments, historical factors including colonial experience and institutional legacies, cultural factors affecting technology adoption and social organization, and persistent institutional features that change slowly over time. By controlling for these factors, fixed effects estimation isolates within-country variation, identifying associations between changes in ICT adoption and changes in quality of life within the same country over time.

Year fixed effects absorb common temporal shocks affecting all countries simultaneously. These include global economic conditions, technology diffusion waves, measurement methodology changes, and other time-specific factors. Two-way fixed effects combining country and year effects provides robust control for unobserved heterogeneity along both cross-sectional and temporal dimensions.

Standard errors are clustered at the country level to account for serial correlation in the error term within countries over time. Clustering acknowledges that observations from the same country across different years are not independent, providing heteroskedasticity-robust inference appropriate for panel data with persistent country-specific shocks.

5.3.2. Model Selection: Hausman Specification Test

The choice between fixed effects and random effects estimation depends on whether country-specific effects are correlated with the regressors. Under the null hypothesis that such correlation is absent, both fixed effects and random effects estimators are consistent, but random effects is more efficient. Under the alternative hypothesis that country effects are correlated with regressors, only fixed effects provides consistent estimates.

The Hausman [40] specification test evaluates this assumption by testing whether fixed effects and random effects estimates differ systematically. For our primary specification examining life expectancy as the dependent variable, the Hausman test statistic is chi-squared with 5 degrees of freedom equal to 60.53, with p-value less than 0.001. This strongly rejects the null hypothesis, indicating that country-specific effects are correlated with ICT variables and that fixed effects estimation is appropriate. We report life expectancy as a representative case; the Hausman test was conducted for each of the eight quality of life outcomes, and in every model the null of no correlation between country effects and regressors was rejected at conventional significance levels ($p < 0.05$). The fixed effects specification was therefore retained across all outcome models, and the full set of test statistics is available from the authors on request. This correlation is theoretically expected: institutional quality, development history, and other time-invariant factors likely influence both ICT adoption and quality of life outcomes. We therefore employ fixed effects estimation for all models.

5.3.3. Robustness Checks

To strengthen inference and assess sensitivity of results to alternative specifications, we conduct two sets of robustness analyses addressing potential threats to valid inference.

First, we estimate models with lagged ICT variables to address reverse causality concerns. Contemporaneous associations might reflect reverse causation—countries with higher quality of life may have greater resources to invest in ICT infrastructure, or quality of life improvements might drive ICT demand. By using ICT indicators measured one and two years prior to quality of life outcomes, we establish temporal precedence: past ICT levels predicting future outcomes cannot reflect reverse causation from those outcomes to past ICT. Stable effects across lag specifications are consistent with a causal interpretation, though they do not constitute formal causal identification, which would require an exogenous source of variation in ICT adoption.

Second, we conduct heterogeneity analysis by income group to examine whether ICT effects differ across development levels. Theory suggests potential for both diminishing marginal returns in high-income countries where infrastructure is already developed, and differential absorptive capacity affecting how effectively countries can translate ICT adoption into welfare gains. We stratify the sample into terciles based on mean GDP per capita over the study period and estimate separate models for low-income, middle-income, and high-income country groups.

An earlier draft of this section also described an Anderson-Hsiao [41] dynamic panel specification using second-order lags as instruments for the first-differenced lagged dependent variable. We have removed that procedure from the present study. Preliminary diagnostics suggested weak-instrument concerns and unstable coefficients across alternative lag depths, so we judged that the dynamic panel results would not provide reliable additional inference at this stage. We retain the lagged-ICT and income-group robustness checks reported below as the basis for our sensitivity analysis, and leave dynamic panel estimation with stronger instruments to future work.

6. Results and Analysis

This section presents empirical findings from fixed effects regression analysis and robustness checks. We first examine associations between ICT indicators and living conditions, then health and educational outcomes, followed by robustness analyses and hypothesis testing summary.

6.1. Descriptive Overview

The analysis sample comprises approximately 1900 country-year observations across 215 countries after accounting for missing data on specific variable combinations. ICT indicators show substantial variation both across countries and within countries over time. Internet usage exhibited the largest within-country changes during the study period, increasing on average by approximately 25 percentage points across countries between 2010 and 2019. Mobile cellular subscriptions showed more modest within-country growth as many countries approached saturation levels. Quality of life indicators generally improved over the period, with life expectancy increasing and child mortality declining in most countries.

6.2. Fixed Effects Regression: Living Conditions

Table 4 presents fixed effects regression results for the four living condition outcomes: access to clean cooking fuels, basic drinking water services, basic sanitation services, and electricity access. Each column reports coefficients from a separate regression with the indicated outcome as the dependent variable. All models include country and year fixed effects with standard errors clustered at the country level.

Internet users demonstrates consistent positive associations across all four living condition measures, with coefficients ranging from 0.088 for sanitation to 0.172 for electricity access. All internet coefficients achieve statistical significance at the 0.05 level or better. These results indicate that within countries over time, increases in internet penetration associate with improvements in access to clean cooking fuels, drinking water, sanitation, and electricity, controlling for time-invariant country characteristics and common temporal trends.

ICT goods exports shows consistent negative associations across all four living condition measures, with coefficients ranging from −0.070 for clean fuels to −0.156 for electricity access. All export coefficients achieve statistical significance at the 0.05 level or better. These findings indicate that within countries over time, increases in ICT export intensity associate with relative declines in living condition indicators. This pattern supports H4 predicting negative export effects and suggests that export-oriented ICT manufacturing may divert resources from domestic infrastructure and service provision.

Table 4. Fixed effects regression results: living conditions.

Variable	Clean Fuels	Drinking Water	Sanitation	Electricity
Mobile Cellular	0.074*	0.020	0.053	0.031
	(0.031)	(0.033)	(0.032)	(0.044)
Fixed Telephone	0.066**	−0.002	0.048	−0.056
	(0.024)	(0.032)	(0.026)	(0.044)
Internet Users	0.132***	0.100**	0.088**	0.172***
	(0.026)	(0.032)	(0.033)	(0.037)
ICT Exports	−0.070**	−0.107**	−0.095***	−0.156**
	(0.022)	(0.034)	(0.028)	(0.050)
ICT Imports	0.065	0.049	0.110***	0.077
	(0.034)	(0.036)	(0.032)	(0.052)
Observations	1884	1881	1883	1897
Countries	214	213	214	215
Within R-squared	0.460	0.144	0.411	0.043
Country Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes

Notes: Clustered standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Population control included but not shown.

Mobile cellular subscriptions shows a significant positive association only with clean cooking fuels access, with non-significant coefficients for other outcomes. Fixed telephone subscriptions shows a significant positive association only with clean fuels access. ICT imports shows a significant positive association only with sanitation access. These mixed patterns provide limited support for hypotheses predicting positive effects of these indicators across living conditions.

6.3. Fixed Effects Regression: Health and Educational Conditions

Table 5 presents fixed effects regression results for the four health and educational outcomes: under-5 mortality rate, life expectancy, undernourishment prevalence, and tertiary enrollment. Note that for mortality and undernourishment, negative coefficients indicate beneficial associations (lower mortality, less undernourishment).

Table 5. Fixed effects regression results: health and educational conditions.

Variable	Child Mortality	Life Expectancy	Undernourishment	Tertiary Enrollment
Mobile Cellular	0.012	−0.028	0.003	−0.183
	(0.037)	(0.029)	(0.031)	(0.099)
Fixed Telephone	0.069*	−0.030	−0.071	0.150***
	(0.029)	(0.022)	(0.048)	(0.044)
Internet Users	−0.124***	0.062***	−0.062	−0.028
	(0.022)	(0.015)	(0.040)	(0.038)
ICT Exports	0.121***	−0.070***	−0.049	0.051*
	(0.034)	(0.020)	(0.036)	(0.026)
ICT Imports	−0.020	0.007	−0.088	0.018
	(0.035)	(0.031)	(0.047)	(0.048)
Observations	1897	1897	1755	1580
Countries	215	215	203	186
Within R-squared	−0.068	−0.078	−0.015	0.248
Country Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes

Notes: Clustered standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1. Population control included. Negative within R-squared indicates model fit is worse than country means alone, expected when between-country variance dominates.

Internet users shows significant beneficial associations with child mortality (coefficient −0.124, indicating lower mortality) and life expectancy (coefficient 0.062, indicating higher life expectancy). Both coefficients achieve significance at the 0.01 level. These findings indicate that within countries over time, increases in internet penetration associate with reductions in child mortality and improvements in life expectancy, supporting H8 predicting positive internet effects on health outcomes.

ICT goods exports shows significant adverse associations with child mortality (coefficient 0.121, indicating higher mortality) and life expectancy (coefficient -0.070, indicating lower life expectancy). Both coefficients achieve significance at the 0.01 level. These findings indicate that within countries over time, increases in ICT export intensity associate with relative increases in child mortality and decreases in life expectancy, providing partial support for H9 predicting negative export effects on health outcomes.

Fixed telephone subscriptions show an unexpected positive association with child mortality (coefficient 0.069) but a significant positive association with tertiary enrollment (coefficient 0.150). The mortality finding is counterintuitive and may reflect compositional effects or measurement timing issues discussed in Section 7. Mobile cellular subscriptions and ICT imports show no significant associations with health and educational outcomes.

6.4. Robustness: Lagged ICT Variables

Table 6 presents results using lagged ICT variables to address reverse causality concerns. We report coefficients for internet users and ICT exports, the two indicators showing consistent significant effects in contemporaneous specifications, across contemporaneous, one-year lag, and two-year lag specifications with life expectancy as the outcome.

Table 6. Robustness check: lagged ICT variables (Life expectancy outcome).

Variable	Contemporaneous	1-Year Lag	2-Year Lag
Internet Users	0.062***	0.065***	0.070***
	(0.015)	(0.014)	(0.016)
ICT Exports	−0.070***	−0.075***	−0.093***
	(0.020)	(0.019)	(0.023)
Observations	1897	1713	1530
Countries	215	214	213

Notes: All models include country and year fixed effects with clustered standard errors. Mobile, fixed telephone, and ICT imports omitted as not significant.

Internet users coefficients remain highly significant and stable across lag specifications, ranging from 0.062 in the contemporaneous model to 0.070 in the two-year lag specification. The slight increase in coefficient magnitude with longer lags suggests that internet effects may build over time rather than reflecting reverse causation. ICT exports coefficients similarly remain significant and stable, with the coefficient magnitude increasing from −0.070 contemporaneously to −0.093 at two-year lags. This pattern indicates that past ICT export intensity is associated with subsequent life expectancy declines, a result that is consistent with a causal reading but does not, on its own, rule out time-varying omitted factors that move together with ICT trade composition.

6.5. Robustness: Income Group Heterogeneity

Table 7 presents results stratified by income group, examining whether ICT effects differ across development levels. Countries are classified into low, middle, and high income terciles based on mean GDP per capita over the study period.

Table 7. Heterogeneity by income group (Life expectancy outcome).

Variable	Low Income (n = 69)	Middle Income (n = 79)	High Income (n = 65)
Internet Users	0.057*	0.052*	0.042
	(0.027)	(0.030)	(0.021)
ICT Exports	−0.056***	−0.043	−0.104***
	(0.032)	(0.035)	(0.028)
Observations	590	705	602

Notes: Income groups based on terciles of mean GDP per capita 2010-2019. All models include country and year fixed effects.

Internet effects show a gradient across income groups, with the coefficient largest in low-income countries (0.057) and declining through middle-income (0.052) to high-income (0.042) countries. The high-income coefficient does not achieve statistical significance. This pattern suggests diminishing marginal returns to internet expansion—countries with lower baseline connectivity realize greater marginal benefits from additional internet penetration. This finding aligns with digital leapfrogging hypotheses suggesting that ICT adoption offers greatest benefits where alternative infrastructure is weakest.

ICT export effects show a different pattern, with significant negative coefficients in both low-income (−0.056) and high-income (−0.104) countries but not in middle-income countries. The larger magnitude in high-income countries may reflect that these nations include major electronics manufacturing centers where export intensity is highest. The negative effect persisting across income levels indicates that the adverse association between export-oriented manufacturing and domestic welfare is not limited to particular development stages.

6.6. Hypothesis Testing Summary

Table 8 summarizes hypothesis testing results based on fixed effects estimation. Hypotheses are evaluated based on whether the predicted direction of association is confirmed and whether effects achieve statistical significance across relevant outcome measures.

Table 8. Summary of hypothesis testing results.

Hypothesis	ICT Variable	QoL Dimension	Predicted	Significant Outcomes	Verdict
H1	Mobile	Living Conditions	+	1 of 4	Not Supported
H2	Fixed Phone	Living Conditions	+	1 of 4	Partially Supported
H3	Internet	Living Conditions	+	4 of 4	Supported
H4	ICT Exports	Living Conditions	−	4 of 4	Supported
H5	ICT Imports	Living Conditions	+	1 of 4	Partially Supported
H6	Mobile	Health/Education	+	0 of 4	Not Supported
H7	Fixed Phone	Health/Education	+	Mixed	Not Supported
H8	Internet	Health/Education	+	2 of 4	Partially Supported
H9	ICT Exports	Health/Education	−	2 of 4	Partially Supported
H10	ICT Imports	Health/Education	+	0 of 4	Not Supported

Notes: Supported = majority of outcomes significant in predicted direction; Partially Supported = some outcomes significant; Not Supported = no or contrary significant effects.

Two hypotheses receive full support: H3 predicting positive internet effects on living conditions, with significant positive coefficients across all four outcomes; and H4 predicting negative ICT export effects on living conditions, with significant negative coefficients across all four outcomes. Four hypotheses receive partial support: H2, H5, H8, and H9, each showing significant effects in the predicted direction for some but not all outcomes. Four hypotheses are not supported: H1, H6, H7, and H10, showing no significant effects or effects contrary to predictions.

The overall pattern indicates that internet usage and ICT exports are the most consequential indicators for quality of life, with internet showing consistent positive effects and exports showing consistent negative effects. Mobile and fixed telephone subscriptions, despite strong cross-sectional correlations with quality of life, show limited within-country effects once time-invariant confounding is controlled through fixed effects. ICT imports shows limited significant effects despite theoretical expectations of positive associations.

7. Discussion

The empirical findings reveal a more nuanced picture of ICT-quality of life associations than simple cross-sectional correlations would suggest. While all ICT indicators show strong positive correlations with quality of life in bivariate analysis, fixed effects estimation controlling for time-invariant country characteristics reveals that only internet usage demonstrates robust within-country associations with quality of life improvements, and that ICT exports actually show negative associations with welfare indicators. This section discusses the substantive meaning and implications of these findings.

7.1. Internet Usage as the Primary Driver of ICT-Welfare Relationships

Internet usage emerges as the only ICT indicator with consistent positive associations across both living conditions and health outcomes in fixed effects specifications. This finding provides important nuance to the literature on ICTs and development: the relationship reflects within-country improvements over time, not merely cross-sectional correlations that may be confounded by unobserved factors. Countries that expanded internet access over the 2010-2019 period experienced improvements in quality of life indicators including clean cooking fuel access, drinking water access, sanitation, electricity access, child mortality, and life expectancy, controlling for time-invariant country characteristics and common temporal trends.

The mechanisms through which internet usage influences quality of life likely operate through multiple pathways consistent with theoretical frameworks presented in Section 2. From the Capabilities Approach perspective, internet access expands capabilities for information seeking, service access, and economic participation that enable achievement of valued functionings [9] [14]. Internet-enabled platforms allow citizens to access information about available services, apply for benefits, coordinate with service providers, and participate in economic activities that generate resources for wellbeing investments. These capability expansions translate into improved welfare outcomes across multiple dimensions.

The finding that internet effects are strongest in low-income countries and weaken at higher income levels provides additional support for this interpretation.

In low-income contexts where alternative information and service infrastructure is limited, internet access represents a transformative capability expansion. In high-income contexts where physical infrastructure and service systems are already developed, the marginal capability gains from internet access are smaller. This pattern of diminishing returns is consistent with both the Capabilities Approach emphasis on conversion factors and Diffusion of Innovations Theory predictions about leapfrogging potential [7] [15].

7.2. The ICT Exports Paradox: Manufacturing for Export versus Domestic Welfare

Perhaps the most striking finding is the consistent negative association between ICT goods exports and quality of life indicators. Countries that increased their ICT export intensity over the study period experienced relative declines in living conditions and health outcomes compared to countries with stable or declining export shares. This pattern is robust across living condition indicators (all four outcomes significant), health indicators (child mortality, life expectancy), and survives lagged variable specifications that address reverse causality concerns.

This finding complicates the assumption that participation in the global ICT sector necessarily benefits domestic populations. The theoretical framework provided by the Technology-Organization-Environment perspective helps explain this pattern [16]. Countries specializing in ICT manufacturing for export may prioritize industrial production over domestic infrastructure and service provision. Resources—including capital, labor, and policy attention—can flow toward export-oriented manufacturing rather than domestic welfare investments. Value chain positioning as assemblers and manufacturers, rather than designers and marketers, may limit value capture relative to the social costs of manufacturing operations [36]. We emphasize, however, that the ICT exports variable is a share of total goods exports rather than a direct measure of domestic ICT production or value added. Movements in this share can reflect changes in the non-ICT export base as well as changes in ICT manufacturing itself, so the negative coefficient should be read as evidence that a rising ICT share of trade is not, on average, accompanied by improvements in domestic welfare indicators—rather than as a direct estimate of how much manufacturing diverts resources from health, sanitation, or education spending.

The persistence of negative export effects across income groups indicates this is not merely a developing-country phenomenon. High-income countries with substantial electronics manufacturing sectors also show negative associations between export intensity and life expectancy. This suggests that the resource diversion mechanism operates across development levels, with manufacturing specialization potentially crowding out welfare-enhancing investments regardless of national income level.

These findings carry important implications for development strategy. Export-led growth models emphasizing ICT manufacturing may not deliver expected welfare improvements if production is oriented toward foreign markets rather than domestic needs. Policies should consider complementary investments ensuring that manufacturing sector growth translates into improved living conditions and health outcomes for domestic populations, rather than assuming automatic trickle-down benefits.

7.3. Cross-Sectional Correlations versus Within-Country Effects

The contrast between cross-sectional correlations and fixed effects estimates provides a cautionary methodological lesson. Mobile cellular subscriptions and fixed telephone subscriptions show strong positive correlations with quality of life in simple cross-sectional analysis, yet limited significant effects in fixed effects specifications. This pattern indicates that cross-sectional associations largely reflect confounding by time-invariant country characteristics rather than genuine technology effects.

Countries with extensive telecommunications infrastructure also tend to have favorable geography, strong institutions, advantageous historical legacies, and other characteristics that independently promote quality of life. Cross-sectional correlations capture both genuine technology effects and these confounding factors. Fixed effects estimation isolates within-country variation, asking whether changes in ICT adoption within the same country over time associate with changes in quality of life. The limited effects found suggest that cross-sectional literature may overstate technology impacts by failing to account for confounding.

This finding does not imply that mobile phones and fixed telephones provide no welfare benefits. Rather, it suggests that the variation in our sample may be insufficient to detect effects if they are small, or that benefits operate through mechanisms that are absorbed by country fixed effects or captured by other variables. The widespread adoption of mobile phones in many countries by 2010 means limited within-country variation remains to identify effects during our study period.

7.4. Interpreting Effect Magnitudes and Model Fit

Fixed effects coefficients are substantially smaller in magnitude than pooled cross-sectional estimates would suggest. This is methodologically appropriate and expected. Fixed effects isolates within-country variation, which for slowly-changing outcomes like life expectancy represents a small fraction of total variation. Approximately 98 percent of variation in life expectancy is between countries (captured by country fixed effects) rather than within countries over time. The small within R-squared values, and even negative values for some specifications, reflect this variance decomposition rather than model failure.

Despite modest coefficients, the effects are substantively meaningful. An internet coefficient of 0.062 for life expectancy indicates that moving from sample minimum to maximum internet penetration associates with a 0.062 unit increase in normalized life expectancy within the same country. Given the normalization scale, this represents approximately two years of life expectancy improvement—a substantial public health gain. The fact that this effect is identified from within-country variation, controlling for time-invariant confounding, strengthens confidence in its validity despite the modest magnitude.

7.5. Policy Implications

The findings carry several implications for digital development policy. First, among ICT indicators examined, internet connectivity shows the most robust associations with quality of life improvements. Policies should prioritize internet access expansion, particularly in low-income countries where marginal benefits appear greatest. Investment in broadband infrastructure, affordability programs, and digital literacy training can support internet-driven welfare gains.

Second, export-oriented ICT manufacturing may not deliver expected domestic welfare improvements. Countries considering electronics manufacturing as a development strategy should carefully assess whether production for export markets translates into benefits for domestic populations, or whether resources might be better directed toward domestic technology deployment and service provision. Industrial policy should consider complementary investments ensuring that manufacturing growth includes domestic welfare considerations.

Third, cross-sectional correlations between ICT and welfare may overstate genuine technology effects due to confounding. Policymakers should exercise caution in interpreting simple correlations as evidence of causal impact. Rigorous evaluation using methods that address confounding is necessary to assess whether technology investments actually deliver promised benefits.

8. Scope and Limitations

While this study provides methodologically rigorous evidence on ICT-quality of life relationships, several limitations warrant acknowledgment and suggest directions for future research.

First, fixed effects estimation addresses time-invariant confounding but cannot definitively establish causality. Time-varying omitted variables correlated with both ICT adoption and quality of life could still bias estimates. The lagged variable specifications partially address reverse causality by establishing temporal precedence, but do not constitute definitive causal identification through experimental or quasi-experimental variation. Future research employing instrumental variables, regression discontinuity, or other identification strategies could strengthen causal inference. A practical constraint also applies to the choice of control variables: candidate time-varying covariates such as GDP per capita, urbanization, and government health and education spending are themselves subject to substantial missing-data coverage in the WDI panel over 2010-2019, particularly for low-income and small-state reporters. Adding these variables would have shrunk the estimation samples and dropped precisely the countries for which ICT-welfare relationships are most policy-relevant. This data-availability consideration, together with the mechanism-absorption concern noted in Section 4.3, motivated our parsimonious specification, and we flag it here as a limitation. Future work with more complete time-varying covariate panels or with multiple-imputation strategies could profitably revisit this trade-off.

Second, country-level aggregate data obscures within-country heterogeneity. National averages may mask substantial variation across regions, socioeconomic groups, and demographic categories. ICT effects may differ for urban versus rural populations, educated versus less-educated individuals, or young versus old age groups. Individual or household-level data could reveal heterogeneous effects that national aggregates conceal.

Third, ICT measures capture access or availability rather than actual usage patterns, quality of service, or digital skills. A country with high internet penetration may nonetheless have populations with limited digital literacy, poor connection quality, or restricted access to beneficial content and services. More nuanced measures of digital engagement could better capture the mechanisms through which ICTs influence welfare.

Fourth, the 2010-2019 study period captures a specific phase of digital evolution characterized by smartphone proliferation and mobile broadband expansion. Relationships may differ in earlier periods when technologies were less mature, or in later periods as technologies continue evolving. The COVID-19 pandemic beginning in 2020 has also transformed digital engagement in ways that may alter ICT-welfare relationships going forward.

Fifth, within R-squared values are modest or negative for several models, indicating that ICT indicators explain limited within-country variation in quality of life outcomes. This reflects the reality that quality of life is influenced by many factors beyond ICT, and that outcomes like life expectancy change slowly relative to ICT adoption. The limited explained variance does not invalidate significant coefficient estimates but does indicate that ICTs represent only one factor among many influencing welfare.

9. Conclusions

This study examined associations between Information and Communication Technologies and quality of life across 225 countries from 2010 to 2019 using two-way fixed effects regression. The methodology addresses limitations of prior cross-sectional research by controlling for time-invariant country characteristics that may confound ICT-welfare relationships. The Hausman specification test confirms the appropriateness of fixed effects over random effects estimation, and extensive robustness analyses strengthen confidence in core findings.

The results reveal important patterns with implications for both academic understanding and development policy. Internet usage emerges as the ICT indicator most robustly associated with quality of life improvements, with significant positive effects on living conditions (clean cooking fuels, drinking water, sanitation, electricity access) and health outcomes (reduced child mortality, increased life expectancy). These associations are strongest in low-income countries, a pattern consistent with diminishing marginal returns and with digital leapfrogging hypotheses. The stability of internet coefficients across lagged specifications is consistent with a causal interpretation, although our design does not provide formal causal identification.

Perhaps most notably, ICT goods exports show consistent negative associations with quality of life indicators across living conditions and health outcomes. Countries that increased ICT export intensity experienced relative declines in welfare measures compared to countries with stable or declining export shares. This finding challenges assumptions that ICT sector participation automatically benefits domestic populations and suggests that export-oriented manufacturing may divert resources from domestic welfare investments.

Mobile cellular and fixed telephone subscriptions, despite showing strong positive correlations with quality of life in simple cross-sectional analysis, demonstrate limited significant effects in fixed effects models. This contrast indicates that cross-sectional associations largely reflect confounding by unobserved country characteristics rather than genuine within-country technology effects. The finding provides a cautionary lesson about interpreting correlational evidence as causal.

The study contributes to literature on ICTs and development by providing methodologically rigorous evidence from a comprehensive multi-country panel analysis. The findings suggest that how countries engage with ICTs matters as much as whether they engage. Domestic internet adoption for population use shows welfare benefits, while export-oriented manufacturing does not. Policymakers should prioritize internet connectivity expansion, particularly in underserved regions, while carefully assessing whether manufacturing-focused strategies deliver promised domestic welfare improvements.

Future research should examine causal mechanisms in greater depth, investigate conditions under which ICT production benefits domestic populations, analyze heterogeneous effects across population subgroups, and assess how emerging technologies relate to evolving welfare dimensions. As digital transformation accelerates globally, understanding the conditions under which technology advances translate into genuine improvements in human welfare remains an essential research and policy priority.

Declaration of Generative AI and AI-Assisted Technologies in the Manuscript Preparation Process

During the preparation of this work the authors used Claude in order to check references, diagram creation, and copy editing. After using this tool/service, the authors reviewed and edited the content as needed and took full responsibility for the content of the published article.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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