



Digital Connectivity and Health-System Performance: A 24-Year Panel Analysis of Global Economies, 2000–2023

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Abstract

This study examined the relationship between digital connectivity, health-system performance, and population health using World Development Indicators data for 2000–2023. Internet use and mobile cellular subscriptions were analyzed separately as measures of digital connectivity, while the Universal Health Coverage (UHC) Service Coverage Index and life expectancy served as principal health outcomes. The core analytical sample comprised 4,221 country-year observations from 186 countries and economies, with a 130-country balanced panel used for robustness analysis. Descriptive and correlational analyses showed strong positive cross-country relationships between connectivity, UHC, and life expectancy. However, two-way fixed-effects models revealed a more differentiated pattern. Internet penetration did not retain its positive association after country and year effects were controlled and became negative in the fully adjusted specifications, indicating that its favorable raw relationship largely reflected broader between-country development and common global trends. Mobile subscriptions showed a smaller but more consistent positive within-country association with UHC and life expectancy, including lagged associations with longevity. UHC remained strongly associated with life expectancy after adjustment for connectivity, income, health expenditure, urbanization, country effects, and year effects. Nonlinear models further indicated diminishing returns to mobile connectivity around universal subscription density. The findings suggest that digital connectivity is best understood as enabling infrastructure whose health value depends on integration with service coverage, institutional capacity, and broader socioeconomic development rather than as an independent determinant of health improvement.

Keywords: *digital connectivity; universal health coverage; life expectancy; Internet penetration; mobile subscriptions; panel data*

1. Introduction

Digital connectivity has become an increasingly important component of the infrastructure through which contemporary health systems operate. Internet access, mobile communications, electronic health records, telemedicine, mobile health applications, health-information platforms, remote monitoring, and digital decision-support systems have altered how health information is generated, transmitted, and used. At the policy level, this transformation has become closely connected with efforts to strengthen health systems and advance universal health coverage (UHC). The World Health Organization (WHO) explicitly recognizes digital technologies as potential enablers of sustainable health systems and UHC, while emphasizing that their benefits depend on integration with broader institutional, organizational, financial, and human-resource capacities. Reflecting the continuing importance of this agenda, the World Health Assembly extended the Global Strategy on Digital Health through 2027 and initiated preparations for a subsequent global strategy covering 2028–2033 (World Health Organization, 2025).

The scale of global digital expansion provides a compelling basis for examining whether improvements in connectivity have been accompanied by improvements in population health and health-system performance. In 2025, approximately 6 billion people, representing 74% of the global population, were estimated to be using the Internet, compared with 60% in 2020. Nevertheless, approximately 2.2 billion people remained offline. Connectivity also continues to exhibit substantial developmental disparities: Internet use has approached 94% in high-income

countries but remains approximately 23% in low-income countries. Although mobile broadband coverage has become nearly universal in geographical terms, important differences persist in network quality, affordability, device availability, digital skills, and effective use (International Telecommunication Union, 2025). These disparities suggest that connectivity should not be treated simply as a technological phenomenon. It may also represent an enabling infrastructure through which differences in economic development, information access, institutional capacity, and health-service delivery are expressed.

The expansion of digital connectivity has occurred alongside continuing efforts to achieve UHC, defined broadly as ensuring access to needed health services without financial hardship. Global progress has been substantial but insufficient. According to the 2025 WHO–World Bank Global Monitoring Report, the global UHC Service Coverage Index increased from 54 in 2000 to 71 in 2023, and 97% of countries recorded improvements in service coverage over that period. Nevertheless, progress has slowed, and an estimated 4.6 billion people still lacked full coverage of essential health services in 2023. Current trajectories therefore remain inadequate for achieving the 2030 UHC target. Moreover, progress differs across health domains. Improvements in infectious-disease services have accounted for a substantial share of the gains in UHC, whereas noncommunicable-disease services remain comparatively weak despite the growing global burden of chronic disease (World Health Organization & World Bank, 2025).

These parallel trends—the rapid diffusion of digital connectivity and the gradual improvement of health-service coverage—raise an important empirical question: to what extent are changes in digital connectivity associated with improvements in health-system performance and population health? Several mechanisms make such a relationship plausible. Internet connectivity can reduce information costs, improve access to health knowledge, facilitate remote consultations, support continuity of care, connect providers across geographical distances, and strengthen health-information systems. Mobile networks can similarly support appointment reminders, disease surveillance, clinical communication, patient education, emergency referrals, community health work, and remote care. In settings where conventional health infrastructure is constrained, mobile technologies may be particularly valuable because they can extend selected services without requiring the immediate development of equivalent physical infrastructure.

Research on digital health generally supports this potential, although the magnitude and consistency of effects vary considerably across settings and interventions. Reviews of mobile health applications in low- and middle-income countries have identified opportunities to improve communication, adherence, clinical management, and access to otherwise difficult-to-reach populations (McCool et al., 2022). More recent evidence indicates that digital health interventions in low- and middle-income countries have evolved from relatively simple short-message and telephone systems toward more comprehensive applications supporting patient education, self-care, remote consultation, disease monitoring, and health-system functions (Sylla et al., 2025). Digital technologies have also been applied in primary care and pharmaceutical services, although their effectiveness is conditioned by infrastructure, workforce capabilities, governance, interoperability, implementation quality, and the institutional environment within which technologies are deployed.

The available literature, however, also cautions against assuming that greater connectivity automatically translates into better health outcomes. An umbrella review covering 88 reviews of digital health interventions in low- and lower-middle-income countries found encouraging evidence for telemedicine and provider communication but concluded that evidence concerning long-term health outcomes, cost-effectiveness, scalability, and sustainability remained uneven. Digital interventions were frequently short-lived, limited in scale, or constrained by inadequate infrastructure and health-system capacity (Craig et al., 2025). This distinction is important because general digital connectivity is not synonymous with digital-health implementation. A country may have extensive Internet penetration or large numbers of mobile subscriptions without possessing interoperable health-information systems, effective telemedicine programs, adequate digital-health governance, digitally trained health workers, or equitable access to digitally enabled services.

Empirical studies examining information and communication technology and population health have likewise produced results that depend on geographical scope, model specification, and outcome selection. A recent cross-country study covering 182 countries from 1990 to 2020 reported a generally positive relationship between Internet use and life expectancy, but also found considerable spatial and temporal heterogeneity in the magnitude of the association (Pu et al., 2025). Research focused on emerging-market economies has similarly identified relationships between Internet use, mobile subscriptions, and life expectancy, although the direction of causality and the strength of relationships differed across countries and types of technological change (Bayar et al., 2024). A panel study of the

Group of Seven economies for 1997–2021 also reported favorable associations of Internet use and mobile subscriptions with life expectancy, illustrating how digital infrastructure may complement income and health expenditure in explaining population-health differences (Kaya et al., 2025).

However, much of this literature faces an important analytical problem. Cross-sectional comparisons and pooled longitudinal models may confound the effect of connectivity with the broader developmental characteristics of countries. Economies with high Internet penetration are also generally wealthier, more urbanized, better educated, institutionally stronger, and more capable of financing comprehensive health services. Consequently, a positive relationship between Internet use and life expectancy across countries does not necessarily demonstrate that increasing Internet use within a particular country will independently produce an equivalent improvement in health. Similarly, both digital connectivity and health indicators have exhibited strong global upward trends over the past two decades. Without accounting for common temporal changes, statistical associations may partly represent simultaneous modernization rather than a distinct relationship between digital connectivity and health performance.

Recent evidence illustrates the significance of this distinction. Lu and Tang (2026), using a multi-country panel with country and year fixed effects, found that higher general connectivity did not consistently correspond to short-term improvement in the UHC Service Coverage Index after broader country-level and temporal factors were taken into account. They argued that connectivity should be viewed as enabling infrastructure rather than as evidence of effective digital-health integration, since health-system benefits depend on complementary factors including financing, governance, organizational capacity, workforce readiness, interoperability, and equitable uptake. This finding is particularly important because it challenges a technologically deterministic interpretation in which expanding Internet and telecommunications infrastructure is assumed to generate health-system improvement by itself.

Several gaps nevertheless remain. First, much of the empirical literature analyzes either life expectancy or UHC rather than examining health-system coverage and population-health outcomes within the same analytical framework. Second, Internet use and mobile connectivity are frequently combined into general information-and-communication-technology or digital-connectivity indices, potentially obscuring differences between the two forms of connectivity. Internet penetration and mobile subscriptions may operate through different pathways and may exhibit different saturation effects. Third, conventional panel analyses often do not explicitly distinguish between-country relationships—whether more digitally connected countries have better health systems—from within-country relationships—whether increases in connectivity within the same country correspond to subsequent health improvement. Fourth, aggregate UHC measures can conceal considerable variation among reproductive, maternal, newborn and child health services, infectious-disease services, noncommunicable-disease services, and service capacity and access. Finally, nonlinear relationships remain underexplored. This issue may be especially relevant for mobile subscriptions because subscription rates exceeding 100 per 100 people frequently reflect multiple subscriptions or multiple subscriber identity modules rather than proportional increases in unique population access.

The present study addresses these issues using World Development Indicators country-year data covering 2000–2023. It examines Internet use and mobile cellular subscriptions as distinct measures of general digital connectivity; the UHC Service Coverage Index as the principal measure of health-system coverage; and life expectancy at birth as a broad population-health outcome. Economic development, current health expenditure, and urbanization are incorporated as major covariates. The analysis further distinguishes within-country from between-country relationships, evaluates lagged associations, examines potential nonlinearities in mobile connectivity, and considers the major component domains of UHC. By combining health-system and population-health outcomes within a 24-year multinational panel, the study seeks to determine not merely whether digitally connected countries tend to have better health outcomes, but whether the relationship persists when countries are compared with their own historical trajectories and when common global changes are taken into account.

Accordingly, the study addresses the following objectives: (1) to describe the longitudinal development of Internet use, mobile connectivity, UHC service coverage, and population health from 2000 to 2023; (2) to determine the association of Internet penetration and mobile cellular subscriptions with UHC service coverage after accounting for economic, health-financing, urbanization, country-specific, and period effects; (3) to examine the relationship between digital connectivity and life expectancy and determine whether UHC coverage contributes additional explanatory value; (4) to distinguish within-country relationships from persistent between-country differences in digital connectivity and health performance; (5) to evaluate whether the associations persist under lagged and balanced-panel specifications; and (6) to examine whether relationships differ across UHC service domains and whether mobile connectivity exhibits nonlinear or diminishing associations at high subscription levels.

By making these distinctions, the study treats digital connectivity neither as an automatic determinant of better health nor as merely a background technological indicator. Instead, it evaluates connectivity as an enabling component of a wider socioeconomic and health-system environment. Such an approach is relevant at a time when digital infrastructure is expanding rapidly but progress toward UHC remains uneven. Understanding whether connectivity itself accompanies measurable health-system improvement—and under what analytical conditions that relationship appears or disappears—is therefore important for determining the role that digital development can realistically play in strengthening health systems and improving population health.

2. Review of Related Literature

2.1 Digital Connectivity and Health-System Performance

Digital connectivity has become an increasingly important component of contemporary health systems because it supports communication, information exchange, service coordination, remote care, and administrative efficiency. Across different healthcare environments, digital infrastructure enables providers to communicate more rapidly, patients to interact with health systems without necessarily being physically present, and health institutions to integrate information across multiple levels of care. The literature generally indicates that stronger digital capacity is associated with better health-system performance, although the magnitude of these benefits depends substantially on institutional readiness and the quality of supporting infrastructure.

Cross-country evidence suggests a particularly strong relationship between digital maturity and primary healthcare performance. Kan et al. (2025), examining 109 countries, reported a strong positive association between digital-health maturity and measures of primary healthcare performance and universal coverage. Similarly, Hrytsenko et al. (2026) found that digital government development was associated with improved health-system outcomes across a large international panel. These findings suggest that digitalization may strengthen health systems not simply through individual technologies but by improving the broader architecture through which information, services, and resources are coordinated. Panel evidence from ASEAN and China likewise treats routine immunization performance as an indicator of primary healthcare delivery capacity, reporting a delayed association between immunization and lower tuberculosis incidence in fixed-effects panel models in which Internet use and electricity access were also associated with lower incidence (Quinto et al., 2026).

Digital technologies can also improve operational processes within health systems. Advanced digital platforms, artificial intelligence, and data-driven decision systems can assist in patient-flow management, resource allocation, clinical coordination, and supply-chain management (Aerts & Bogdan-Martin, 2021; Elkefi & Asan, 2022; Periañez et al., 2024). Such applications may improve efficiency by reducing information delays, improving forecasting, and enabling health institutions to allocate scarce resources more systematically.

A second major pathway concerns healthcare accessibility. Digital connectivity enables telemedicine, asynchronous consultation, remote monitoring, and digital follow-up, thereby reducing some of the geographic and financial barriers associated with conventional facility-based healthcare (Awad et al., 2021; Hameed et al., 2024; MacAskill et al., 2026). These benefits may be especially important in rural and geographically isolated areas where specialist services are limited. Digital platforms can therefore function as an extension of conventional health infrastructure rather than merely as an administrative supplement.

However, evidence also shows that digitalization does not produce uniform benefits. Infrastructure instability, limited electricity, weak broadband coverage, lack of devices, and insufficient digital literacy may prevent health systems from translating connectivity into effective service delivery (Jabin & Nyatuka, 2026). Curtis et al. (2021), for example, documented substantial digital-access disparities between rural and metropolitan households. Other studies similarly emphasize that digital health can reproduce or deepen existing inequalities when vulnerable populations lack access to the technologies required to use digitally mediated services (Shaw et al., 2024; Yao et al., 2021).

The literature therefore supports a generally positive relationship between digital connectivity and health-system performance, but it also indicates that connectivity is best regarded as an enabling condition rather than a sufficient condition for better health-system outcomes. The effectiveness of digital infrastructure depends on whether health institutions possess the organizational, financial, technical, and human capabilities needed to convert connectivity into improved service delivery.

2.2 Internet Penetration and Population Health Outcomes

Internet penetration represents one of the most widely used indicators of digital development and has increasingly been examined as a potential determinant of population health. The underlying argument is that greater Internet access may improve health by reducing information asymmetry, expanding health knowledge, facilitating communication with providers, supporting preventive behavior, and increasing access to digitally mediated services.

A growing body of cross-national evidence identifies a positive association between Internet use and population health. Pu et al. (2025), using data from 182 countries between 1990 and 2020, found that Internet use was positively associated with life expectancy, although the strength of the relationship varied across geographical locations and time periods. Comparable findings have been reported in Sub-Saharan Africa, emerging-market economies, BRICS countries, low-income economies, and advanced economies (Bayar et al., 2024; Byaro et al., 2023; Jiang et al., 2022; Kaya et al., 2025; Wang et al., 2024).

Several studies specifically associate increasing Internet penetration with longer life expectancy. Byaro et al. (2023) found positive associations across most segments of the life-expectancy distribution in Sub-Saharan Africa. More recent evidence similarly suggests that increasing Internet use is associated with improvements in longevity across African economies (Byanyima et al., 2026). Studies of countries with high longevity have also identified digital access as one among several socioeconomic and technological characteristics associated with longer life expectancy (Zhang et al., 2025).

Beyond longevity, Internet access has been linked to other dimensions of health. J.-P. Zhang et al. (2022) found evidence that information and communication technology diffusion contributed to lower mortality partly through health expenditure and health-literacy pathways. At the household or individual level, Internet use has also been associated with lower illness incidence, improved self-reported health, enhanced mental well-being, and better access to health information (Liao & Luo, 2024; Luo et al., 2024; Zhang et al., 2026). Gawai and Deller (2024) likewise reported relationships between broadband access and improved health indicators at the local level.

Nevertheless, the relationship between Internet penetration and health should be interpreted cautiously. Countries with high levels of Internet use also tend to differ systematically in income, education, urbanization, healthcare capacity, infrastructure, and institutional development. Consequently, a positive cross-sectional association does not necessarily demonstrate that increased Internet penetration alone produces improvements in population health. The relationship may partially reflect broader processes of socioeconomic development occurring simultaneously with digitalization.

This issue is particularly important for longitudinal research. Internet penetration has risen sharply worldwide during the same period in which life expectancy and many health indicators have also improved. Analyses that do not adequately control for common time trends may therefore attribute to Internet diffusion improvements that partly arise from other global developments. Two-way fixed-effects evidence from ASEAN-5 illustrates that Internet access can be associated with some macro-level outcomes but not others: lagged Internet access was positively associated with equity-market capitalization but did not significantly predict household consumption growth (Lantin-Magana & Atento, 2026). This creates a need to distinguish between-country differences from within-country changes over time, an issue directly relevant to the present study.

2.3 Mobile Connectivity and Healthcare Access

Mobile connectivity represents a related but distinct dimension of digital development. Unlike general Internet penetration, mobile telecommunications can reach populations even where fixed broadband infrastructure remains limited. Mobile phones have therefore played a particularly prominent role in health systems in low- and middle-income countries, where they are used for communication, appointment reminders, patient education, disease surveillance, remote consultation, and community-based care.

Evidence consistently indicates that mobile technologies can improve access to healthcare by reducing geographic and informational barriers. McCool et al. (2022) documented the growing use of mobile health technologies in low- and middle-income countries, emphasizing their capacity to extend services to populations that might otherwise have limited contact with formal healthcare systems. Haenssger et al. (2021) similarly showed how mobile phones and social networks can facilitate healthcare access among marginalized rural populations.

Mobile connectivity can also support remote and mobile service delivery. Connected clinics, mobile medical units, and telehealth platforms have been used to extend healthcare into geographically isolated areas (Chen et al., 2024; Iacoella et al., 2024). Newer telecommunications technologies, including 5G networks, further expand the

technical possibilities for remote monitoring, connected medical devices, and real-time clinical interaction (Peralta-Ochoa et al., 2023).

Evidence also suggests that mobile technologies can improve selected health outcomes. Mobile interventions have demonstrated benefits in chronic disease management, patient adherence, blood-pressure control, and diabetes management. Sun et al. (2024), synthesizing evidence from multiple meta-analyses, found significant improvements in several chronic-disease outcomes associated with mobile-phone interventions. Wang and Chen (2024) similarly reported that mobile Internet use among middle-aged and older adults was associated with improved health indicators.

However, mobile access remains unequal. Device ownership, network quality, affordability, age, socioeconomic position, and digital literacy strongly influence whether populations can actually benefit from mobile health systems (Blake et al., 2023; Khoong et al., 2021). Research on digital financial inclusion in Asia similarly indicates that mobile and Internet connectivity alone does not explain divergent outcomes across subregions; digital literacy, trust, and the regulatory and institutional environment shape whether connectivity is converted into active and equitable use (Atento, Atento, et al., 2026). Consequently, high national subscription rates may not necessarily indicate equivalent access among all individuals. Mobile-subscription statistics may also exceed 100 subscriptions per 100 people because users maintain multiple SIM cards or devices, making national subscription density an imperfect measure of unique-user access.

These limitations suggest that mobile connectivity should be examined separately from Internet penetration. Although both indicators represent digital access, they may capture different infrastructures and mechanisms. Mobile connectivity may be particularly relevant to basic communication and service reach, while Internet penetration may more strongly reflect broader socioeconomic and digital-development conditions.

2.4 Digital Connectivity and Universal Health Coverage

Universal Health Coverage represents one of the most important health-system outcomes potentially influenced by digital development. UHC requires that populations obtain necessary health services without experiencing excessive financial hardship. Digital technologies may contribute to this objective by expanding service access, improving health-system coordination, strengthening financing mechanisms, and reducing administrative barriers.

The literature generally supports a positive relationship between digital capability and progress toward UHC. Wilson et al. (2021) emphasized that digital health can support UHC through improvements in service availability, quality, and system efficiency. More recent studies similarly suggest that digital infrastructure and digital-health applications can expand access to essential services, particularly in geographically underserved or resource-constrained settings (Ahmed et al., 2025; Erku et al., 2023). In the Philippine context, universal healthcare reforms and digital disruption have likewise posed new strategic challenges for private-sector actors central to healthcare access, such as national pharmacy retail chains (Atento & Atento, 2025).

Digital platforms have also been used to extend specialist care and primary healthcare coverage. Large-scale telemedicine systems demonstrate the potential of digital infrastructure to connect rural populations with services that would otherwise be geographically inaccessible. At the administrative level, electronic health records, digital insurance systems, and integrated digital platforms can improve patient identification, enrollment, information management, and coordination between service providers and payers (Kodali & Das, 2021; Okuzu et al., 2022).

Digital financial technologies may also contribute to the financial-protection dimension of UHC. Evidence from Kenya and Rwanda indicates that mobile-money and digital payment systems can support health-insurance enrollment and premium collection, thereby reducing some of the transaction barriers encountered by low-income households (Wilson et al., 2023). Such applications illustrate how telecommunications infrastructure can affect UHC not only through clinical care but also through health financing.

Nevertheless, the literature consistently emphasizes that digital connectivity does not automatically produce universal coverage. Infrastructure deficiencies, inadequate digital literacy, weak governance, fragmented systems, and unequal access can restrict the benefits of digital technologies (Craig et al., 2023; Memmel & Kerschbaumer, 2026). Evidence from selected local government units in the CALABARZON region of the Philippines similarly suggests that integrating community health workers with digital health tools is socially acceptable and operationally feasible, although confidence in data confidentiality was comparatively low and financial barriers to access persisted (Morcilla & Quinto, 2026). In some circumstances, digitalization can create new forms of exclusion by shifting access procedures toward platforms that vulnerable populations are less equipped to navigate.

The available evidence therefore supports digital connectivity as an important facilitator of UHC rather than as an independent guarantee of improved coverage. This distinction provides a central rationale for examining whether national measures of Internet and mobile connectivity remain associated with UHC after controlling for differences in economic development, health expenditure, urbanization, and persistent country characteristics.

2.5 Socioeconomic Conditions and the Limits of Digital Health Effects

The benefits associated with digital connectivity are not distributed uniformly across countries or populations. A major theme in the literature concerns the role of socioeconomic conditions in determining whether digital access can be converted into health benefits. Income, education, digital literacy, geographical location, infrastructure quality, and institutional capacity all influence the effective use of digital technologies.

Cai (2026) found that socioeconomic status moderated digital health-information seeking, suggesting that higher-resource populations may be better positioned to translate digital access into useful health information and services. Digital literacy similarly influences whether users can effectively engage with digital health systems (Chen & He, 2026). This produces what is often described as a second-level digital divide: differences may persist even after basic physical access has been achieved because populations differ in their capacity to use technology productively. Evidence from Philippine manufacturing firms similarly indicates that divides in digital access correspond to measurable differences in outcomes, with high-access firms reporting significantly greater digital financial inclusion and supply chain resilience than low-access firms in a cross-sectional comparison (Atento, Quinto, et al., 2026).

The relationship between digital connectivity and health inequality is therefore complex. Some studies suggest that digital access may reduce inequality by providing disadvantaged populations with information and services that were previously inaccessible (Yu & Meng, 2022; Zhen et al., 2024). Others warn that digitally mediated healthcare may widen disparities when access, literacy, and technological competence remain concentrated among relatively advantaged groups (Yao et al., 2021; D.-L. Zhang et al., 2022). The consequences of digitalization consequently depend not only on the availability of infrastructure but also on the distribution of complementary social and economic resources.

A further issue concerns whether the relationship between connectivity and health remains linear at high levels of digital penetration. Evidence increasingly suggests that the largest benefits may occur when populations move from limited connectivity to basic or moderate access. Subsequent increases may generate progressively smaller marginal benefits. Moumin et al. (2026), for example, identified threshold effects in the relationship between digital inclusion and maternal-health access. Similar nonlinear relationships have been reported for individual Internet use, where moderate engagement may be associated with favorable outcomes while excessive use may provide no additional benefit or may be associated with adverse physical or psychological consequences (Li et al., 2025; Luo et al., 2026).

This issue is especially relevant to mobile-subscription measures. At low levels of penetration, increases in subscriptions may reflect substantial expansion of population access. At very high levels, additional subscriptions increasingly represent multiple devices, secondary SIM cards, or overlapping network accounts rather than newly connected individuals. Consequently, the relationship between mobile subscriptions and health-system performance may exhibit diminishing marginal returns.

Taken together, the literature indicates that digital connectivity operates within a broader socioeconomic and institutional environment. Its health benefits depend on complementary conditions, and its marginal effects may change as connectivity becomes widespread. These considerations justify analytical approaches that account for socioeconomic controls, country-specific characteristics, temporal trends, and potential nonlinear relationships.

2.6 Synthesis of the Literature

The reviewed literature establishes a substantial body of evidence linking digital connectivity with healthcare access, health-system performance, Universal Health Coverage, and population health. Internet penetration is generally associated with higher life expectancy and better health indicators, while mobile connectivity has demonstrated particular value in extending services to geographically and socioeconomically underserved populations. Digital technologies have also contributed to UHC through telemedicine, health-information systems, insurance administration, mobile payments, remote monitoring, and improved clinical coordination.

At the same time, the literature consistently shows that these relationships are conditional rather than automatic. Connectivity operates through broader health-system and socioeconomic structures. Countries and populations with greater financial resources, stronger institutions, better infrastructure, higher digital literacy, and more effective service delivery are better positioned to convert connectivity into health gains. Evidence on digital inequality also indicates that the same technologies capable of expanding access may deepen exclusion when devices, networks, skills, or digitally mediated services are unequally distributed.

A further synthesis emerging from the literature is that Internet penetration and mobile connectivity should not necessarily be treated as equivalent indicators. Internet use frequently tracks broader national development, whereas mobile technologies may directly support communication-intensive health functions, particularly in settings where fixed infrastructure is weaker. Moreover, evidence of threshold effects and diminishing returns suggests that the health implications of expanding connectivity may differ markedly between countries moving from low to moderate penetration and those that have already achieved near-universal access.

Collectively, these studies support an analytical framework in which digital connectivity is viewed as enabling infrastructure embedded within a wider health-system environment. The appropriate empirical question is therefore not simply whether more connected countries are healthier, but whether changes in specific forms of connectivity remain associated with changes in health-service coverage and population outcomes after broader development differences and common global trends are taken into account.

2.7 Research Gaps

Despite the growing literature, several gaps remain. First, many studies focus on either population health outcomes or health-system coverage rather than examining Universal Health Coverage and life expectancy within the same empirical framework. This limits the ability to assess whether connectivity is related to both the functioning of the health system and the broader population outcome to which that system ultimately contributes.

Second, Internet penetration and mobile connectivity are frequently combined into general measures of information and communication technology. This aggregation may obscure important differences in how each form of connectivity operates. Internet penetration may represent general digital development, while mobile subscriptions may more directly capture communication reach and may also display saturation effects once access becomes widespread.

Third, a substantial portion of the existing evidence is based on cross-sectional comparisons, pooled panels, or models that do not clearly distinguish persistent differences between countries from changes occurring within the same country over time. Strong positive cross-country correlations may therefore reflect underlying differences in wealth, urbanization, institutional quality, education, and health-system capacity rather than an independent effect of increasing connectivity.

Fourth, relatively few cross-national studies simultaneously account for country fixed effects, global year effects, lagged connectivity, nonlinear relationships, and alternative UHC service domains. These methodological distinctions are important because Internet use, mobile connectivity, UHC, and life expectancy have all increased markedly over time, creating a risk that common secular trends may be mistaken for independent relationships.

The present study addresses these gaps by analyzing Internet penetration and mobile subscriptions separately within a 24-year country panel, examining both UHC and life expectancy, distinguishing within-country from between-country relationships, introducing country and year fixed effects, evaluating lagged and nonlinear specifications, and examining UHC component domains and balanced-panel robustness.

3. Methodology

3.1 Research Design

The study employed a quantitative longitudinal panel research design to examine the relationship between digital connectivity, health-system performance, and population health across countries and economies from 2000 to 2023. Panel data were used because they allow observations to be examined simultaneously across geographical units and over time. This design permits the analysis to distinguish persistent differences between countries from changes occurring within the same country over successive years.

The study was primarily explanatory and associational. It assessed whether changes in Internet penetration and mobile cellular connectivity were associated with changes in Universal Health Coverage service coverage and life

expectancy after accounting for socioeconomic and health-system characteristics. Because the study used observational macro-level data, the estimated relationships were interpreted as associations rather than direct causal effects.

The analytical strategy progressed from descriptive and bivariate analysis to multivariable panel regression. Country fixed effects were incorporated to account for relatively stable unobserved characteristics that differ across countries, while year fixed effects were used to account for common global changes affecting all countries within a given year. Additional analyses examined within-country and between-country effects, lagged relationships, nonlinear effects, and alternative health outcomes.

3.2 Data Source

Data were obtained from the World Development Indicators (WDI) database of the World Bank (World Bank, 2026). The study used the bulk WDI dataset containing annual country-level indicators covering economic, demographic, technological, and health-related measures.

The original dataset contained 1,498 indicators and 265 country, economy, regional, income-group, and aggregate entities. Regional aggregates, income classifications, and other non-country groupings were excluded from the country-level panel analysis. After these exclusions, 216 country or economy units remained potentially available for analysis.

The study period was limited to 2000–2023. The lower boundary was determined primarily by the availability of the UHC Service Coverage Index and current health expenditure data, while 2023 represented the most recent year for which the UHC indicator was available in the uploaded WDI dataset. The resulting study period therefore covered 24 years.

No external survey or primary data collection was undertaken. All variables used in the principal analyses were obtained from the same WDI data source to maintain consistency in country definitions, observation periods, and indicator coding.

3.3 Unit of Analysis and Analytical Sample

The unit of analysis was the country-year observation. Thus, each row in the analytical panel represented one country or economy observed in one calendar year.

The core analytical sample was constructed from country-year observations containing complete information for the principal variables: Internet use, mobile cellular subscriptions, UHC service coverage, life expectancy, current health expenditure, GDP per capita, and urbanization.

The complete-case core panel contained 4,221 country-year observations, 186 countries or economies with sufficient data for at least part of the 2000–2023 period, and 130 countries or economies with complete observations across all 24 years for the core variables.

The principal models used the larger unbalanced panel because excluding countries with partial observations would unnecessarily discard usable information. A separate balanced-panel analysis involving the 130 countries with complete 24-year coverage was conducted as a robustness test.

Missing values were treated as unavailable observations and were not statistically imputed. Consequently, the number of observations could vary slightly across models depending on the variables included.

3.4 Study Variables

3.4.1 Digital Connectivity Variables

Two indicators represented digital connectivity. Internet penetration was measured using Individuals using the Internet (% of population), WDI code IT.NET.USER.ZS. The indicator represents the percentage of individuals within a country who used the Internet during the reference period and served as the principal measure of population-level Internet penetration.

Mobile connectivity was measured using Mobile cellular subscriptions (per 100 people), WDI code IT.CEL.SETS.P2. The indicator measures active mobile cellular subscriptions relative to population size. Values can exceed 100 because individuals may maintain multiple subscriptions, devices, or subscriber identity modules.

Internet use and mobile subscriptions were modeled separately rather than combined into a single digitalization index because the two indicators capture different dimensions of connectivity.

3.4.2 Health-System Performance Variable

The principal measure of health-system performance was the UHC Service Coverage Index, WDI code SH_UHC_SCI. The index summarizes national coverage of essential health services and was used as the primary dependent variable in the health-system models. Higher values indicate broader service coverage.

Additional analyses examined the major UHC service domains available in the WDI dataset, including reproductive, maternal, newborn, and child health; infectious diseases; noncommunicable diseases; and service capacity and access. These component analyses were undertaken to determine whether digital connectivity exhibited similar relationships across different dimensions of UHC.

3.4.3 Population Health Outcome

The principal population-health outcome was Life expectancy at birth, total (years), WDI code SP.DYN.LE00.IN. Life expectancy was selected because it represents a broad population-level outcome influenced by mortality conditions, healthcare access, socioeconomic circumstances, and health-system performance.

As robustness outcomes, the study also considered indicators such as infant mortality, under-five mortality, and maternal mortality where sufficient observations were available.

3.4.4 Control Variables

Three principal control variables were included in the regression models. Current health expenditure (% of GDP), WDI code SH.XPD.CHEX.GD.ZS, represented national health-resource allocation relative to the size of the economy.

GDP per capita, purchasing power parity, constant international prices, WDI code NY.GDP.PCAP.PP.KD, was included to account for differences in national economic development. Because the variable was strongly right-skewed and because proportional rather than absolute income differences are economically more interpretable, GDP per capita was transformed using the natural logarithm.

Urban population (% of total population), WDI code SP.URB.TOTL.IN.ZS, was included because population concentration can affect telecommunications infrastructure, physical healthcare accessibility, and availability of health facilities.

These controls were selected because economic capacity, healthcare spending, and settlement patterns could influence both digital connectivity and health outcomes.

3.5 Data Preparation

The uploaded WDI bulk file was transformed from its original indicator-by-country format into a country-year analytical panel. The data-preparation process involved excluding WDI regional, income-group, and other aggregate entities; identifying the required indicators using official WDI codes; extracting annual observations from 2000 through 2023; reshaping the selected indicators into country-year format; transforming GDP per capita using the natural logarithm; generating complete-case samples for each specification; identifying a balanced-panel subsample; generating lagged digital-connectivity variables; and creating a squared mobile-subscription term for nonlinear analysis.

No interpolation was used to create artificial observations between missing years. Likewise, missing country-year observations were not replaced using sample means, regional averages, or model-based imputation.

3.6 Statistical Analysis

The analysis was conducted in several stages. Descriptive statistics were calculated for all principal study variables, including the mean, standard deviation, minimum, maximum, median, and interquartile values. Annual averages were also computed to examine the long-term development of Internet penetration, mobile subscriptions, UHC service coverage, life expectancy, health expenditure, GDP per capita, and urbanization.

Pearson correlation coefficients were initially calculated to examine the bivariate relationships among digital-connectivity measures, UHC, life expectancy, and the control variables. The correlation analysis was treated as descriptive rather than causal because raw correlations combine differences between countries, changes within

countries over time, and global trends shared by multiple indicators. Consequently, the principal inferential conclusions were based on the panel regression models rather than on the correlation coefficients alone.

3.7 Panel Regression Models

3.7.1 Baseline Model

Pooled regression models were estimated as baseline specifications to describe the overall relationship between digital connectivity and the selected health outcomes. The general specification was:

$$Y_{it} = \beta_0 + \beta_1 \text{Internet}_{it} + \beta_2 \text{Mobile}_{it} + \beta_3 \ln \text{GDP}_{it} + \beta_4 \text{HealthExp}_{it} + \beta_5 \text{Urban}_{it} + \varepsilon_{it}$$

where Y_{it} represents the health outcome for country i in year t ; Internet_{it} represents Internet users as a percentage of the population; Mobile_{it} represents mobile cellular subscriptions per 100 people; $\ln \text{GDP}_{it}$ represents the natural logarithm of real PPP-adjusted GDP per capita; HealthExp_{it} represents current health expenditure as a percentage of GDP; and Urban_{it} represents the urban population percentage. Because pooled estimates may reflect stable differences between countries, they were not treated as the primary specification.

3.7.2 Country Fixed-Effects Model

Country fixed-effects models were then estimated:

$$Y_{it} = \beta_1 \text{Internet}_{it} + \beta_2 \text{Mobile}_{it} + \beta_3 \ln \text{GDP}_{it} + \beta_4 \text{HealthExp}_{it} + \beta_5 \text{Urban}_{it} + \alpha_i + \varepsilon_{it}$$

where α_i represents country-specific fixed effects. The inclusion of country fixed effects removes the influence of time-invariant characteristics specific to each country. These may include relatively stable geographical, historical, institutional, cultural, or structural characteristics that could otherwise confound the relationship between digital connectivity and health outcomes. The resulting coefficients therefore reflect associations between changes occurring within a country over time rather than simply differences between countries.

3.7.3 Two-Way Fixed-Effects Model

The principal analytical specification included both country and year fixed effects:

$$Y_{it} = \beta_1 \text{Internet}_{it} + \beta_2 \text{Mobile}_{it} + \beta_3 \ln \text{GDP}_{it} + \beta_4 \text{HealthExp}_{it} + \beta_5 \text{Urban}_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$$

where λ_t represents year fixed effects. Year effects control for global developments affecting countries simultaneously, including technological diffusion, international health initiatives, medical advances, global economic conditions, and secular improvements in population health.

The two-way fixed-effects specification was considered particularly important because Internet use, mobile connectivity, UHC, and life expectancy all exhibit substantial long-term global trends. Failure to account for these common trends could produce apparently strong relationships even when the indicators merely increase simultaneously over time. Standard errors were clustered at the country level to account for serial correlation and heteroskedasticity within countries across years.

3.8 UHC and Life-Expectancy Models

Two principal outcome families were analyzed. The first examined UHC using $\text{UHC}_{it} = f(\text{Internet}_{it}, \text{Mobile}_{it}, \text{Controls}_{it}, \text{Country}_i, \text{Year}_t)$. This model assessed whether changes in digital connectivity were associated with changes in essential health-service coverage.

The second examined life expectancy using $\text{LifeExp}_{it} = f(\text{Internet}_{it}, \text{Mobile}_{it}, \text{Controls}_{it}, \text{Country}_i, \text{Year}_t)$. A subsequent model added UHC to evaluate whether service coverage contributed additional explanatory information regarding life expectancy after digital connectivity and socioeconomic characteristics were taken into account.

Because the study was observational, changes in coefficients after adding UHC were interpreted as evidence consistent with an explanatory pathway rather than as formal proof of causal mediation.

3.9 Within-Between Decomposition

To distinguish cross-country differences from changes occurring within individual countries, a within-between or hybrid decomposition was performed. For each time-varying predictor X , two variables were generated:

$X_{it}^{\text{Within}} = X_{it} - \bar{X}_i$ and $X_{it}^{\text{Between}} = \bar{X}_i$, where $\bar{X}_i$ represents the country's mean value of the variable across the study period.

The within-country coefficient estimates whether years in which a country recorded higher-than-usual connectivity were associated with higher-than-usual health performance. The between-country coefficient estimates whether countries characterized by persistently higher average connectivity also tended to exhibit better average health outcomes.

This decomposition was particularly important for distinguishing whether a positive global association resulted primarily from more developed countries being both more connected and healthier, or whether increases in connectivity within countries were also associated with subsequent health improvement.

3.10 Lagged Models

Lagged regression models were used to examine whether changes in digital connectivity preceded rather than occurred simultaneously with changes in health outcomes. Internet penetration and mobile subscriptions were lagged by one or more years using the specification $Y_{it} = \beta_1 \text{Internet}_{i,t-k} + \beta_2 \text{Mobile}_{i,t-k} + \text{Controls}_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$, where k represents the lag period.

Lagged specifications were considered useful because improvements in communication infrastructure may require time before influencing healthcare utilization, health-system coverage, or population health. These analyses were treated as robustness tests rather than as definitive causal identification strategies.

3.11 Nonlinear Analysis

A nonlinear specification was estimated for mobile cellular subscriptions because subscription density may exhibit diminishing returns at high levels of penetration. The model incorporated both the linear and squared mobile terms: $Y_{it} = \beta_1 \text{Mobile}_{it} + \beta_2 \text{Mobile}_{it}^2 + \text{Controls}_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$.

A positive coefficient for the linear term combined with a negative coefficient for the squared term would indicate diminishing marginal associations as mobile subscriptions increase. This analysis was particularly appropriate because mobile-subscription rates can exceed 100 per 100 people. Beyond widespread population coverage, additional subscriptions increasingly represent multiple SIM ownership rather than additional individuals obtaining connectivity.

3.12 UHC Component Analysis

Supplementary models examined whether the relationship between digital connectivity and UHC differed across its major service dimensions. Separate fixed-effects models were estimated for available indicators representing reproductive, maternal, newborn, and child health; infectious diseases; noncommunicable diseases; and service capacity and access. These analyses allowed the study to determine whether any aggregate association between connectivity and UHC was broadly distributed across health services or concentrated within particular dimensions of healthcare delivery.

3.13 Robustness Analysis

Several robustness procedures were undertaken. First, the principal models were repeated using the balanced panel of 130 countries or economies with complete data throughout the 2000–2023 observation period. Second, alternative health outcomes—including infant mortality, under-five mortality, and maternal mortality—were examined where data coverage permitted. Third, lagged digital-connectivity specifications were evaluated to reduce dependence on contemporaneous relationships. Fourth, within-between decomposition was used to determine whether findings reflected persistent cross-country differences or within-country change. Fifth, the nonlinear mobile specification evaluated whether the estimated relationship depended on the assumption of constant marginal effects.

Consistency across these specifications was considered stronger evidence of a stable empirical relationship, whereas changes in coefficient direction, magnitude, or statistical significance were treated as substantive findings rather than disregarded.

3.14 Statistical Significance and Interpretation

Statistical significance was evaluated using an alpha level of $\alpha = 0.05$. Regression coefficients were reported together with clustered standard errors, 95% confidence intervals, and corresponding probability values.

Emphasis was placed not only on statistical significance but also on coefficient direction, effect magnitude, confidence intervals, consistency across model specifications, and substantive plausibility. Because the dataset consisted of observational country-level indicators, regression coefficients were not interpreted as experimental treatment effects. Terms such as associated with, related to, and corresponded with were therefore preferred over causal expressions such as caused, produced, or resulted in.

3.15 Ethical Considerations

The study relied exclusively on publicly available, aggregated, country-level secondary data. No individual-level information, personally identifiable information, clinical records, or direct human participants were included. Consequently, the analysis posed no direct risk to individual participants and did not involve informed consent, recruitment, intervention, or access to confidential health information.

The study nevertheless followed principles of responsible secondary-data research by maintaining indicator definitions, avoiding fabrication or imputation of unavailable country-year observations, documenting transformations and exclusions, and interpreting associations within the limitations of an observational ecological dataset.

3.16 Methodological Scope

The methodology was designed to answer a more specific question than whether digitally connected countries are healthier. The analytical framework distinguishes between-country association, within-country association, and temporal robustness. The first asks whether countries with greater average digital connectivity also tend to exhibit better health-system performance. The second asks whether health-system performance changes when connectivity changes within the same country. The third asks whether these relationships remain when common global year effects, socioeconomic controls, lag structures, nonlinear effects, and alternative samples are considered.

This distinction is central to the study because a strong cross-national correlation between digitalization and health does not necessarily imply that additional connectivity alone will generate corresponding improvements in health-system performance.

4. Results and Discussion

4.1 Descriptive Characteristics and Longitudinal Trends

The final core analytical sample consisted of 4,221 country-year observations from 186 countries and economies covering the period 2000–2023. Of these, 130 countries had complete observations for all core variables across the entire 24-year period and constituted the balanced-panel subsample used for robustness analysis.

Table 1 presents the descriptive statistics for the principal study variables.

Table 1. *Descriptive Statistics of the Core Analytical Sample*

Variable	N	Mean	SD	Minimum	Median	Maximum
Internet users (% of population)	4,221	38.03	31.79	0.00	31.00	100.00
Mobile subscriptions per 100 people	4,221	80.08	49.01	0.00	86.19	361.05
UHC Service Coverage Index	4,221	63.27	18.36	13.00	69.00	92.00
Life expectancy at birth (years)	4,221	70.32	8.73	14.67	71.83	85.71
Current health expenditure (% GDP)	4,221	6.16	2.72	1.22	5.65	24.46
GDP per capita, PPP constant	4,221	22,328.93	23,933.73	711.98	13,536.82	149,025.12
Urban population (%)	4,221	57.18	22.53	8.04	58.49	100.00

Substantial variation was observed across countries and years. Internet use averaged 38.03% of the population but ranged from effectively zero to universal use. Mobile subscriptions averaged 80.08 per 100 people and exceeded

100 in many observations, consistent with multiple-SIM and multiple-device ownership in highly connected economies.

The UHC Service Coverage Index averaged 63.27, while mean life expectancy was 70.32 years. The wide ranges in both variables reflected the considerable diversity of health-system development represented in the multinational sample.

Longitudinal patterns were particularly pronounced in the balanced panel of 130 countries. Mean Internet penetration increased from 9.19% in 2000 to 74.46% in 2023, while mobile cellular subscriptions increased from 18.84 to 121.23 per 100 people over the same period. UHC service coverage rose from 58.15 to 71.31, representing an increase of more than 13 index points.

Life expectancy also increased over the study period. Mean life expectancy rose from 68.11 years in 2000 to 73.84 years in 2019. A visible disruption occurred during the COVID-19 period, with the mean declining to 73.11 years in 2020 and 72.40 years in 2021. By 2023, however, mean life expectancy had recovered to 74.53 years.

These patterns demonstrate that digital connectivity, health-service coverage, and population longevity all exhibited pronounced secular improvement during the study period. This simultaneous upward movement also underscores the importance of controlling for common time effects when estimating the relationship between digital connectivity and health outcomes.

4.2 Bivariate Relationships Among Digital and Health Indicators

Table 2 presents the Pearson correlations among the principal variables.

Table 2. *Correlations Among Digital Connectivity, Health-System, and Socioeconomic Indicators*

Variable	Internet	Mobile	UHC	Life Expectancy	Health Exp.	GDP per Capita	Urbanization
Internet	1.000						
Mobile	.768	1.000					
UHC	.716	.621	1.000				
Life expectancy	.712	.589	.855	1.000			
Health expenditure	.384	.201	.376	.329	1.000		
GDP per capita	.655	.475	.639	.677	.224	1.000	
Urbanization	.605	.461	.661	.658	.283	.657	1.000

At the bivariate level, both digital-connectivity indicators were strongly and positively related to health-system and population-health outcomes. Internet penetration correlated positively with UHC ($r = .716$) and life expectancy ($r = .712$). Mobile subscriptions were also positively associated with UHC ($r = .621$) and life expectancy ($r = .589$).

The strongest health-related correlation occurred between UHC and life expectancy ($r = .855$), indicating that countries with broader essential health-service coverage generally exhibited substantially higher longevity.

GDP per capita was also strongly related to Internet penetration, UHC, life expectancy, and urbanization. These relationships indicate that simple digital-health correlations may partly capture broader differences in socioeconomic development. Consequently, the bivariate findings were followed by increasingly restrictive panel models designed to separate cross-country differences from within-country changes and common global trends.

4.3 Digital Connectivity, Universal Health Coverage, and Life Expectancy

4.3.1 Universal Health Coverage

The association between digital connectivity and UHC changed substantially according to model specification.

In the pooled model, mobile subscriptions were positively associated with UHC ($\beta = 0.052$, $p < .001$), whereas Internet penetration was not independently significant after controlling for GDP per capita, health expenditure, and urbanization ($\beta = 0.027$, $p = .191$).

After introducing country fixed effects, the mobile coefficient remained positive and became strongly significant ($\beta = 0.044$, $p < .001$). Internet penetration remained statistically nonsignificant ($\beta = -0.005$, $p = .651$). This indicates that within-country increases in mobile connectivity were associated with greater UHC coverage before common year effects were taken into account.

The preferred two-way fixed-effects model, which simultaneously controlled for stable country characteristics and common year effects, produced a different pattern.

Table 3. *Two-Way Fixed-Effects Models for UHC and Life Expectancy*

Predictor	UHC β	p	Life Expectancy β	p	Life Expectancy + UHC β	p
Internet penetration	-0.104	<.001	-0.035	<.001	-0.018	.021
Mobile subscriptions	0.012	.044	0.007	.026	0.005	.095
UHC	—	—	—	—	0.171	<.001
ln GDP per capita	4.866	<.001	1.844	.010	1.010	.099
Health expenditure	0.199	.106	-0.029	.707	-0.063	.360
Urbanization	0.342	<.001	0.079	.050	0.020	.610
Observations	4,221		4,221		4,221	
Countries	186		186		186	
R ²	.977		.966		.969	

In the two-way fixed-effects UHC model, mobile subscriptions retained a small positive association with UHC ($\beta = 0.012$, 95% CI [0.0003, 0.0241], $p = .044$). A 10-subscription increase per 100 people therefore corresponded to approximately 0.12 additional UHC index points, holding other modeled factors constant.

In contrast, Internet penetration exhibited a negative coefficient ($\beta = -0.104$, 95% CI [-0.135, -0.073], $p < .001$). This result contrasted sharply with the strong positive raw correlation and indicates that the positive international association between Internet use and UHC did not persist when each country was compared against its own historical trajectory and common global year effects were removed.

Economic development remained positively associated with UHC ($\beta = 4.866$, $p < .001$), as did urbanization ($\beta = 0.342$, $p < .001$). Current health expenditure as a percentage of GDP was not independently significant in the two-way model.

4.3.2 Life Expectancy

The pooled life-expectancy model initially showed a positive association for Internet penetration ($\beta = 0.040$, $p = .001$), while mobile subscriptions were not significant at the .05 level ($\beta = 0.010$, $p = .095$).

With country fixed effects, the Internet coefficient became nonsignificant ($\beta = 0.005$, $p = .414$), while mobile connectivity became strongly positive ($\beta = 0.021$, $p < .001$).

After both country and year effects were included, Internet penetration again changed direction and was negatively associated with life expectancy ($\beta = -0.035$, $p < .001$). Mobile subscriptions retained a smaller positive association ($\beta = 0.007$, $p = .026$).

GDP per capita remained positively associated with life expectancy, while urbanization was marginally positive. Health expenditure as a percentage of GDP was not independently significant in the fully adjusted model.

A subsequent specification added UHC to the life-expectancy model. UHC emerged as a strong positive correlate of longevity ($\beta = 0.171$, 95% CI [0.115, 0.227], $p < .001$). In substantive terms, a 10-point increase in UHC was associated with approximately 1.71 additional years of life expectancy, conditional on the other variables and fixed effects.

Once UHC was included, the magnitude of the Internet coefficient was reduced by approximately half, from -0.035 to -0.018 , although it remained statistically significant. The mobile coefficient also declined and became nonsignificant at the conventional .05 level ($p = .095$).

The increase in model fit from $R^2 = .966$ to $R^2 = .969$, together with the highly significant UHC coefficient, indicates that variation in health-service coverage contributed additional explanatory information beyond digital connectivity and the socioeconomic controls.

4.4 Within-Between Decomposition and Lagged Relationships

Because the direction of the Internet coefficients differed markedly between the raw correlations and the fixed-effects models, the analysis decomposed each digital indicator into within-country and between-country components.

For UHC, the within-country Internet coefficient was negative and statistically significant ($\beta = -0.054$, $p = .017$). In contrast, the between-country Internet coefficient was positive but nonsignificant ($\beta = 0.108$, $p = .193$).

Mobile connectivity exhibited the opposite pattern. Its within-country component was positively associated with UHC ($\beta = 0.025$, $p < .001$), while its between-country coefficient was not significant ($\beta = 0.076$, $p = .102$).

For life expectancy, the distinction was particularly clear. The between-country Internet coefficient was positive and significant ($\beta = 0.145$, $p < .001$), indicating that countries characterized by higher long-run average Internet use tended to exhibit longer life expectancy. However, the within-country Internet coefficient was not significant ($\beta = -0.014$, $p = .233$).

Mobile connectivity again showed a different pattern. Its within-country coefficient was positive and significant ($\beta = 0.013$, $p < .001$), whereas its between-country coefficient was nonsignificant ($\beta = 0.016$, $p = .434$).

Thus, the positive global association between Internet use and longevity was primarily a between-country relationship, whereas the positive mobile association was more clearly observable in within-country change.

Lagged Models

One-, two-, and three-year lags of digital connectivity were subsequently examined.

The negative Internet association with UHC remained statistically significant at all three lag periods: one-year lag, $\beta = -0.103$, $p < .001$; two-year lag, $\beta = -0.102$, $p < .001$; and three-year lag, $\beta = -0.098$, $p < .001$. Lagged mobile connectivity, however, did not significantly predict UHC after country and year effects were included.

For life expectancy, lagged Internet penetration also remained negative across all three specifications. In contrast, mobile connectivity was positively associated with life expectancy at each lag: one-year lag, $\beta = 0.0085$, $p = .011$; two-year lag, $\beta = 0.0085$, $p = .009$; and three-year lag, $\beta = 0.0086$, $p = .007$.

When UHC was incorporated into the lagged life-expectancy models, UHC remained strongly positive at all lag periods. Its coefficient declined modestly from 0.167 at the one-year lag to 0.144 at the three-year lag, but remained highly significant throughout.

These results reinforce the distinction between Internet penetration and mobile connectivity. The longitudinal association of mobile access with life expectancy was more persistent across lagged specifications, whereas the strong positive cross-national relationship involving Internet use did not translate into a positive within-country temporal effect.

4.5 Nonlinearity, UHC Components, and Robustness Analyses

4.5.1 Nonlinear Mobile-Connectivity Effects

Quadratic models were estimated to test whether the relationship between mobile connectivity and health outcomes changed at high subscription levels.

For UHC, the linear mobile term was positive ($\beta = 0.0569$, $p = .001$) while the squared term was negative ($\beta = -0.000285$, $p = .001$), indicating an inverted-U relationship. The estimated turning point was approximately 99.8 mobile subscriptions per 100 people.

A similar relationship was observed for life expectancy. The linear mobile coefficient was positive ($\beta = 0.0237$, $p < .001$) and the squared term negative ($\beta = -0.000100$, $p = .001$), producing an estimated turning point of approximately 118.8 subscriptions per 100 people.

Comparable thresholds were identified for mortality outcomes. The estimated turning points were approximately 100.6 subscriptions per 100 people for infant mortality, 100.3 for under-five mortality, and 104.7 for maternal mortality. For the mortality outcomes, increasing mobile connectivity was associated with declining mortality until approximately universal subscription density was reached, after which the estimated marginal improvement weakened.

Taken together, the nonlinear models suggest that the strongest health-system associations occur while countries move from limited mobile penetration toward broad population connectivity. Additional subscriptions beyond approximately one subscription per person appear to yield progressively smaller health-related returns.

4.5.2 UHC Service Components

Separate models were estimated for the major components of the UHC index.

Mobile connectivity exhibited its clearest positive association with the infectious-disease service coverage component ($\beta = 0.050$, $p = .001$). The mobile coefficient was not statistically significant for noncommunicable-disease coverage, reproductive-maternal-newborn-child health coverage, or service capacity and access.

Internet penetration showed negative coefficients for the infectious-disease, noncommunicable-disease, and reproductive-maternal-newborn-child health components after two-way fixed effects were applied. No statistically significant Internet relationship was observed for service capacity and access.

The component findings therefore suggest that aggregate UHC relationships are heterogeneous across service domains rather than representing a uniform digital-connectivity effect.

4.5.3 Robustness Checks

The principal findings were tested using the balanced 130-country sample and a pre-COVID period ending in 2019.

The negative Internet coefficients remained statistically significant in both the UHC and life-expectancy models in the balanced sample. For UHC, the balanced-panel Internet coefficient was -0.107 ($p < .001$), while the corresponding life-expectancy coefficient was -0.037 ($p = .001$).

Mobile connectivity remained positively associated with UHC in the balanced sample ($\beta = 0.015$, $p = .046$). Its association with life expectancy was positive but slightly above the conventional significance threshold ($\beta = 0.0069$, $p = .057$).

When the analysis was restricted to 2000–2019, the Internet coefficients remained negative for both outcomes. However, mobile connectivity was no longer statistically significant for either UHC or life expectancy. This indicates that the positive mobile coefficients in the complete 2000–2023 panel were less robust to the exclusion of the pandemic and post-pandemic period than the Internet coefficients.

Overall, the sensitivity analyses indicate that the central empirical finding is not a simple positive digitalization effect. Instead, the results demonstrate substantial differences according to the type of connectivity, whether variation occurs between or within countries, the health outcome examined, and the level of connectivity already achieved.

4.6 Discussion

4.6.1 Digital Connectivity and Health-System Performance

The results reveal a considerably more complex relationship between digital connectivity and health-system performance than is suggested by the raw international correlations. At the descriptive level, the evidence appears straightforward: countries with greater Internet and mobile penetration tend to have higher UHC coverage and longer life expectancy. Internet penetration correlated at more than .70 with both UHC and life expectancy, while

UHC itself correlated at .855 with longevity. These patterns are consistent with the broader literature reporting favorable relationships between digital development, healthcare access, and population health.

However, the longitudinal panel models demonstrate that being a highly connected country and becoming more connected within a country are not equivalent empirical phenomena. This distinction represents one of the principal findings of the study.

The literature reviewed in Section 2.1 generally characterizes digital connectivity as an enabling infrastructure for better health-system performance. Studies such as Kan et al. (2025) report strong relationships between national digital-health maturity and primary healthcare performance, while Erku et al. (2023) and related reviews describe improvements in access, coordination, and service delivery associated with digital-health systems.

The present findings broadly support the proposition that digital development and health-system development occur together at the international level. However, they also demonstrate that this relationship becomes substantially weaker and more differentiated after country-specific characteristics and worldwide time trends are removed.

This finding reinforces the distinction between digital infrastructure and effective digital-health capability. Internet penetration indicates that people can connect to the Internet; it does not indicate that healthcare providers possess interoperable electronic systems, that patients have meaningful access to telemedicine, that health workers are digitally competent, or that connectivity is integrated into service-delivery processes. Consequently, the results do not imply that digital connectivity is unimportant. Rather, they suggest that connectivity alone is insufficient to explain improvements in health-system performance.

4.6.2 Internet Penetration: Strong Between-Country Association but Limited Within-Country Evidence

One of the most important results concerns Internet penetration. The literature consistently reports that countries and populations with greater Internet use tend to experience better health outcomes. Pu et al. (2025), Byaro et al. (2023), Bayar et al. (2024), and related studies have documented positive associations between Internet access and life expectancy or other population-health indicators.

The present study reproduced this pattern at the descriptive level. Internet penetration was strongly positively correlated with both UHC and life expectancy. The pooled life-expectancy model likewise produced a positive coefficient. However, the relationship disappeared when countries were compared against their own histories using country fixed effects and reversed after year effects were introduced.

The within-between decomposition helps explain this apparent contradiction. Countries with higher average Internet penetration had significantly higher average life expectancy, but increases in Internet penetration within the same country were not associated with corresponding increases in life expectancy once broader developmental and temporal factors were considered.

This suggests that Internet penetration may function partly as a marker of a broader development package. Countries with widespread Internet use are also likely to possess higher incomes, stronger educational systems, more developed infrastructure, more urbanized populations, stronger institutions, and more advanced healthcare systems.

The negative two-way fixed-effects coefficient should therefore not be interpreted as evidence that increasing Internet access reduces health or shortens life expectancy. Such an interpretation would conflict both with the descriptive evidence and with the conceptual mechanisms identified in previous research. Instead, the coefficient indicates that, after removing the global secular improvements shared across years, countries experiencing faster increases in Internet penetration did not necessarily experience proportionately faster improvements in UHC or longevity.

Internet penetration therefore appears to identify digitally and socioeconomically advanced countries very well, but it is a weaker independent predictor of short- to medium-term health improvement within countries. This distinction is crucial for policy interpretation.

4.6.3 Mobile Connectivity Shows a Different Pattern

Mobile connectivity produced a notably different empirical profile. Whereas Internet penetration displayed a stronger between-country relationship, mobile subscriptions demonstrated more consistent positive within-country associations. Increases in mobile subscriptions were positively associated with UHC and life expectancy in the principal models, and the within-between decomposition confirmed positive within-country coefficients.

The lagged life-expectancy models provide additional support for this relationship. Mobile connectivity remained positively associated with life expectancy when measured one, two, and three years earlier.

These findings are compatible with literature emphasizing the practical service-delivery role of mobile technologies. Mobile networks can facilitate appointment reminders, communication between community health workers and facilities, emergency coordination, disease surveillance, health education, follow-up care, and mobile financial transactions without requiring the same level of fixed digital infrastructure as broadband-dependent systems.

The UHC-component analysis also provides an informative result. Mobile connectivity showed its strongest positive association with infectious-disease service coverage. This may be plausible because mobile technologies are especially well suited to communication-intensive and geographically distributed interventions such as surveillance, treatment reminders, community case management, follow-up, and public-health messaging.

However, the robustness analyses require caution. Mobile coefficients became weaker when the sample was restricted to the pre-COVID period, suggesting that the relationship may vary across historical periods. The pandemic substantially expanded telemedicine, mobile communication, remote service delivery, and digitally mediated healthcare, potentially increasing the practical health-system value of mobile connectivity after 2020.

4.6.4 Diminishing Returns to Mobile Connectivity

The nonlinear results provide further evidence that the health benefits associated with digital connectivity are unlikely to increase indefinitely.

For UHC, the estimated mobile turning point was approximately 100 subscriptions per 100 people. The corresponding thresholds for mortality measures clustered close to the same level, while the life-expectancy model produced a somewhat higher turning point of approximately 119 subscriptions per 100 people.

These results are consistent with the literature on diminishing digital returns reviewed in Section 2.5. The largest potential gain occurs when additional subscriptions represent previously unconnected individuals entering the telecommunications network. Once approximately universal subscription density has been reached, further increases increasingly represent additional SIM cards or devices held by people who are already connected.

Thus, an increase from 20 to 60 subscriptions per 100 people represents a fundamentally different social transformation from an increase from 120 to 160. The finding also cautions against treating mobile subscriptions as a linear proxy for population connectivity. At high levels, the indicator increasingly measures subscription intensity rather than population inclusion.

4.6.5 Universal Health Coverage and Population Longevity

Among the principal findings, the relationship between UHC and life expectancy was particularly strong and stable.

After controlling for digital connectivity, economic development, healthcare expenditure, urbanization, country effects, and year effects, each one-point increase in the UHC Service Coverage Index was associated with approximately 0.17 additional years of life expectancy. A 10-point difference therefore corresponded to approximately 1.7 years of additional longevity, conditional on the modeled variables.

This result is consistent with the fundamental premise underlying UHC: health outcomes depend not merely on the existence of healthcare technologies or financial resources but on the actual coverage of essential services. Related panel evidence from ASEAN points in the same direction: UHC service coverage remained positively associated with labor productivity and life expectancy in two-way fixed-effects and lagged models covering 2000–2023 (Patron et al., 2026).

The reduction in the Internet and mobile coefficients after UHC was introduced is also noteworthy. It suggests that health-system coverage captures part of the same developmental pathway through which digital and socioeconomic conditions may ultimately relate to population health. However, the analysis does not establish causal mediation. The finding is more appropriately interpreted as showing that UHC provides substantial additional explanatory power in the relationship between national development characteristics and longevity.

This may be one of the most important substantive messages of the paper. Digital connectivity may provide infrastructure through which healthcare can be organized and delivered, but service coverage represents a more proximal health-system mechanism linking national capacity with population outcomes.

4.6.6 Socioeconomic Development Remains Fundamental

Economic development remained positively associated with both UHC and life expectancy across the principal models. Urbanization was likewise positively associated with UHC.

These findings reinforce the argument that digital health should not be viewed independently from the broader development environment. Connectivity may enable health-system improvement, but its benefits depend on complementary infrastructure, financial capacity, institutional organization, human capital, and service availability.

This interpretation is consistent with the literature on digital inequality. Cai (2026), Yao et al. (2021), D.-L. Zhang et al. (2022), and related studies show that digital access does not produce equal benefits across socioeconomic groups. Populations with better education, income, infrastructure, and digital literacy are generally better positioned to transform connectivity into useful health information and healthcare access.

The results of the present study extend this reasoning to the national level. The dramatic difference between the positive raw correlations and the more restrictive fixed-effects estimates suggests that a substantial portion of the apparent digital-health advantage reflects the wider socioeconomic ecosystem in which connectivity develops. Comparable regional evidence from ASEAN indicates that productivity gains between 2000 and 2023 were not reliably accompanied by improvements in child survival, consistent with distributional, sectoral, and health-system channels conditioning whether economic progress translates into health gains (Atento & Quinto, 2026).

4.6.7 Overall Interpretation

Taken as a whole, the findings do not support a simple proposition that greater digital connectivity automatically produces better health outcomes. Instead, four conclusions emerge.

First, digital connectivity is strongly associated with health-system performance across countries. Highly connected countries generally have greater UHC coverage and longer life expectancy.

Second, Internet penetration predominantly reflects between-country differences. Countries with consistently high Internet penetration tend to be healthier, but increases in Internet use within countries do not independently reproduce the same positive association after common global trends are controlled.

Third, mobile connectivity demonstrates stronger evidence of a within-country relationship, particularly for life expectancy and selected dimensions of health-service coverage. However, this relationship is not uniformly robust across periods.

Fourth, the benefits associated with mobile connectivity appear to diminish around universal subscription density, indicating that the expansion of access matters more than the accumulation of additional subscriptions among populations that are already connected.

These findings suggest a distinction between digital access, digital use, and digital-health integration. Expanding networks may be necessary for digital health, but infrastructure alone does not guarantee better health-system performance. The greatest benefits are likely to arise when connectivity is deliberately integrated with essential healthcare services, UHC expansion, institutional capacity, and equitable access.

Accordingly, the principal contribution of the study lies not in demonstrating another correlation between technology and health, but in showing that the nature of that relationship changes substantially depending on whether the analysis examines differences between countries, changes within countries, common global trends, service domains, and levels of connectivity saturation.

5. Conclusions and Recommendations

5.1 Conclusions

This study examined the relationship between digital connectivity, health-system performance, and population health using a 24-year panel of countries and economies from 2000 to 2023. Internet penetration and mobile cellular subscriptions were analyzed as distinct dimensions of digital connectivity, while Universal Health Coverage service coverage and life expectancy were used as the principal health-system and population-health outcomes.

The findings confirm that digital connectivity is strongly associated with health outcomes at the international level. Countries with higher Internet penetration and greater mobile connectivity generally exhibited higher UHC coverage and longer life expectancy. These relationships were evident in the descriptive statistics and bivariate

correlations, reinforcing the broader literature that links digital development with improved healthcare access and population well-being.

However, the longitudinal panel analysis demonstrated that the relationship is considerably more complex than the raw cross-country associations suggest. Internet penetration showed a strong positive relationship with UHC and life expectancy across countries, but this relationship weakened substantially when country-specific characteristics and common year effects were controlled. The within-between decomposition further showed that the positive relationship between Internet penetration and life expectancy was primarily a between-country phenomenon. Countries with persistently higher Internet penetration tended to have better health outcomes, but increases in Internet use within individual countries did not consistently correspond to proportionate health improvements.

This suggests that Internet penetration may function partly as an indicator of broader socioeconomic and institutional development rather than as an independent driver of health-system improvement. Countries with widespread Internet access also tend to possess stronger economies, more developed infrastructure, higher levels of urbanization, better education systems, and more mature health institutions. Consequently, the positive international relationship between Internet access and health should not be interpreted as evidence that Internet expansion alone will automatically improve health outcomes.

Mobile connectivity exhibited a different empirical pattern. Mobile subscriptions demonstrated more consistent positive within-country associations with UHC and life expectancy. Lagged models also showed that higher mobile connectivity in preceding years remained positively associated with life expectancy. These findings suggest that mobile telecommunications may have a more direct functional relationship with healthcare access and service delivery, particularly through communication, remote consultation, community health coordination, health-information dissemination, and other mobile-enabled health services.

However, the relationship between mobile connectivity and health was not unlimited. The nonlinear analysis indicated diminishing returns at high levels of mobile penetration. The estimated turning points were generally close to 100 subscriptions per 100 people for UHC and mortality outcomes, with a somewhat higher threshold for life expectancy. This indicates that the greatest potential gains occur while countries are moving from limited mobile access toward broad population connectivity. Once connectivity becomes nearly universal, additional subscriptions increasingly represent multiple devices or SIM cards rather than meaningful expansion of access.

Universal Health Coverage emerged as one of the strongest and most consistent predictors of population longevity. Even after controlling for digital connectivity, GDP per capita, health expenditure, urbanization, country-specific characteristics, and global year effects, higher UHC coverage remained significantly associated with longer life expectancy. A 10-point increase in the UHC Service Coverage Index corresponded to approximately 1.7 additional years of life expectancy in the fully adjusted model.

This finding emphasizes that digital connectivity is most appropriately understood as an enabling infrastructure rather than as a substitute for effective health-service delivery. Connectivity may support healthcare systems, but the actual expansion of essential health-service coverage appears to be more directly related to population health outcomes.

The study also showed that digital-health relationships differ across service domains. Mobile connectivity was most clearly associated with the infectious-disease component of UHC, while relationships with noncommunicable diseases, reproductive and maternal health, and service capacity were less consistent. This indicates that digital infrastructure may support some health-system functions more effectively than others.

Overall, the study concludes that digital connectivity is associated with stronger health systems and better population health, but its effects are conditional, heterogeneous, and dependent on the broader development context. The strongest benefits are likely to occur when digital infrastructure is translated into actual healthcare access, integrated into service-delivery systems, supported by adequate institutional capacity, and directed toward expanding Universal Health Coverage.

The results therefore caution against technologically deterministic interpretations of health development. Expanding Internet and mobile infrastructure can create the conditions for improved health-system performance, but connectivity by itself is insufficient. Digital development becomes consequential for health when it is combined with effective healthcare institutions, equitable access, sufficient economic resources, and broad service coverage.

5.2 Recommendations

Governments should treat digital connectivity as part of health-system infrastructure rather than merely as a telecommunications objective. Investments in Internet and mobile networks should be coordinated with health-service planning so that increased connectivity is translated into practical applications such as telemedicine, appointment systems, remote monitoring, community-health communication, health-information exchange, and digital referral networks.

Policy emphasis should focus not only on increasing national connectivity rates but also on ensuring effective and equitable use. High national Internet penetration does not guarantee that all population groups can benefit from digital health. Governments should therefore address affordability, device access, digital literacy, rural connectivity, disability-related barriers, language accessibility, and inequalities in technological competence.

Countries with low or moderate levels of mobile penetration may obtain significant health-system benefits from expanding basic mobile connectivity. The study's nonlinear results suggest that the largest marginal gains occur before mobile access becomes nearly universal. This implies that investments in basic network coverage and population access may be particularly important in countries where substantial proportions of the population remain disconnected.

Countries that already possess high levels of digital connectivity should shift emphasis from expanding access alone toward improving the quality and integration of digital health systems. At high levels of penetration, additional subscriptions or Internet users may generate limited health benefits unless connectivity is embedded within effective healthcare processes. Priorities should therefore include interoperability, electronic health records, cybersecurity, health-data governance, health-worker training, clinical decision support, and integration between digital platforms and conventional healthcare services.

Digital-health strategies should be aligned explicitly with Universal Health Coverage objectives. Digital infrastructure should support the expansion of essential health services rather than operate as a parallel technological system. Policymakers should evaluate digital-health investments according to whether they increase actual service coverage, improve continuity of care, reduce geographic barriers, strengthen health financing, or extend access to underserved populations.

The strong association between UHC and life expectancy supports continued investment in broad health-service coverage. Digital transformation should therefore complement rather than substitute for conventional health-system investments in healthcare personnel, facilities, medicines, public-health programs, financing, and primary care.

Governments should monitor digital-health performance using indicators that go beyond basic connectivity. Internet penetration and mobile subscriptions are useful measures of infrastructure, but they do not directly measure digital-health maturity. National monitoring systems should include indicators such as telemedicine utilization, electronic-record adoption, interoperability, digital-health workforce capability, patient access to digital services, digital literacy, and equitable service utilization.

International development organizations should tailor digital-health support according to the level of technological and health-system development of individual countries. Countries with limited digital infrastructure may require basic connectivity expansion, while more digitally advanced systems may benefit more from governance, integration, advanced analytics, and service optimization.

5.3 Contributions of the Study

The study contributes to the digital-health and health-systems literature in several ways. First, it distinguishes Internet penetration from mobile connectivity rather than combining both indicators into a single measure of digital development. The findings demonstrate that these two forms of connectivity exhibit different relationships with health outcomes.

Second, the study simultaneously examines UHC and life expectancy, thereby linking digital infrastructure with both health-system performance and a broad population-health outcome.

Third, the analysis distinguishes between-country relationships from within-country change. This is particularly important because strong international correlations can obscure the fact that increases in digital connectivity within individual countries may not produce the same relationships observed across countries.

Fourth, the study incorporates country fixed effects, year fixed effects, lagged models, nonlinear specifications, balanced-panel robustness tests, and UHC-component analyses. This provides a more comprehensive assessment than conventional cross-sectional or pooled regressions.

Fifth, the identification of diminishing returns in mobile connectivity contributes to the interpretation of telecommunications indicators. The findings indicate that mobile subscription density should not be assumed to have a constant linear relationship with health-system outcomes.

Finally, the study provides large-scale international evidence that digital connectivity should be conceptualized as an enabling infrastructure whose health value depends on its integration with broader socioeconomic and healthcare systems.

5.4 Limitations of the Study

Several limitations should be considered when interpreting the findings. First, the study relied on country-level observational data. The estimated associations therefore cannot establish direct causal relationships. Even with country and year fixed effects, unobserved time-varying factors may influence both digital connectivity and health outcomes.

Second, the study used national aggregate indicators. Relationships observed at the country level should not automatically be interpreted as equivalent relationships at the individual or household level. This limitation reflects the possibility of ecological inference error.

Third, Internet penetration and mobile subscriptions are broad measures of connectivity rather than direct measures of digital-health use. A country may have high Internet penetration without widespread telemedicine, electronic health records, digital-health literacy, or integrated health-information systems.

Fourth, mobile subscriptions per 100 people may overstate actual population access because individuals can hold multiple subscriptions or SIM cards. This issue becomes particularly important when subscription rates exceed 100.

Fifth, the study did not directly measure the quality of Internet access, affordability, network reliability, device ownership, digital literacy, or differences between urban and rural connectivity. These characteristics may substantially influence whether digital access translates into healthcare benefits.

Sixth, UHC was measured using the available service-coverage indicators. Although useful for international comparison, aggregate UHC indices may conceal differences in service quality, financial protection, implementation effectiveness, and population-level inequality.

Seventh, the study period included the COVID-19 pandemic, which disrupted life expectancy and simultaneously accelerated the use of telemedicine and digitally mediated healthcare. Although pre-COVID robustness analyses were conducted, the pandemic may still have affected some of the longitudinal relationships.

Finally, data availability varied across countries and indicators. The primary analysis therefore relied on an unbalanced panel, although a balanced-panel sensitivity analysis was conducted to assess the stability of the findings.

5.5 Directions for Future Research

Future research can extend the present study in several directions. Subsequent studies should incorporate more direct measures of digital-health maturity, including electronic health-record adoption, telemedicine utilization, interoperability, health-data infrastructure, digital-health governance, and workforce digital competence.

Future analyses could explicitly test whether digital connectivity has different effects across income groups, geographical regions, or levels of health-system development. Interaction models could determine whether digital access produces larger benefits in low-income or middle-income settings than in already highly connected economies.

Research should examine rural-urban disparities more directly. National averages may conceal substantial internal inequalities in both connectivity and healthcare access.

Future studies could explore causal identification strategies using natural experiments, major telecommunications infrastructure expansions, broadband rollouts, or policy changes that created exogenous variation in digital access.

More detailed mediation analyses could investigate whether the relationship between digital connectivity and population health operates through UHC, healthcare utilization, health literacy, economic development, public-health information, or other intermediate mechanisms.

The nonlinear relationships identified in this study warrant further investigation. Future work could test alternative threshold models, spline regressions, or quantile approaches to determine whether connectivity effects differ systematically at low, moderate, and high levels of digital penetration.

The relationship between digital connectivity and specific health-service domains deserves further examination. Infectious-disease services, maternal and child health, chronic disease management, emergency care, and preventive health may respond differently to digital infrastructure.

Finally, future research should examine whether the rapid expansion of artificial intelligence, digital diagnostics, remote monitoring, and integrated health platforms changes the relationship between connectivity and health-system performance. As digital-health systems become more sophisticated, general Internet or mobile access may increasingly represent only the foundational layer of a much broader digital-health ecosystem.

Overall, future studies should move beyond asking whether connectivity is associated with health and instead examine when, where, through which mechanisms, and under what institutional conditions digital connectivity translates into measurable health-system improvement.

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