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THE ROLE OF ICT DEVELOPMENT IN DRIVING INNOVATION: AN EMPIRICAL ANALYSIS USING IDI AND GII

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Abstract

This study investigates the relationship between the Information and Communication Development Index (IDI) and the Global Innovation Index (GII), emphasizing the role of digital infrastructure and connectivity in shaping innovation ecosystems. Using Spearman correlation analysis, the findings reveal strong and significant positive relationships between IDI and GII scores, as well as their sub-dimensions. The total IDI score demonstrates a robust correlation with the total GII score (r=0.847), confirming the pivotal role of ICT development in enhancing innovation capacities across countries. Sub-dimensions of IDI, Universal Connectivity (r=0.819) and Meaningful Connectivity (r=0.839), are also significantly associated with GII, highlighting the importance of high-quality digital connectivity. Moreover, the study identifies strong correlations between IDI and GII sub-dimensions such as Infrastructure (r=0.879), Human Capital & Research (r=0.842), and Knowledge & Technology Outputs (r=0.826), underscoring the critical role of ICT in fostering technological innovation and knowledge production. Meaningful Connectivity is shown to have a stronger impact on creative outputs than Universal Connectivity, emphasizing the significance of quality over mere access. These findings underscore the importance of digital infrastructure investments to enhance innovation ecosystems, addressing disparities in digital connectivity and fostering sustainable development. The study contributes to the existing literature by providing empirical evidence of ICT's influence on innovation, offering valuable insights for policymakers aiming to leverage digital technologies for economic growth and competitiveness.

Keywords: *ICT development index, Global innovation index, Universal connectivity, Meaningful connectivity, Innovation capacity.*

Jel Code: *O20, O10, O14.*

Bilgi ve İletişim Teknolojileri Gelişiminin Inovasyona Etkisi: IDI ve GII Kullanarak Ampirik Bir Analiz

Öz

Bu çalışma, Bilgi ve İletişim Teknolojileri Gelişim Endeksi (IDI) ile Küresel Yenilik Endeksi (GII) arasındaki ilişkiyi araştırarak, dijital altyapının ve bağlantının yenilik ekosistemlerini şekillendirmedeki rolünü vurgulamaktadır. Spearman korelasyon analizi sonuçları, IDI ve GII puanları ile alt boyutları arasında güçlü ve anlamlı pozitif ilişkiler olduğunu ortaya koymaktadır. Toplam IDI puanı ile toplam GII puanı arasında güçlü bir korelasyon (r=0.847) bulunmuş, bu da ülkelerin yenilik kapasitelerinin artırılmasında ICT gelişiminin merkezi bir rol oynadığını doğrulamaktadır. IDI alt boyutlarından Evrensel Bağlantı (r=0.819) ve Anlamlı Bağlantı (r=0.839) da GII ile anlamlı bir ilişki göstermiştir ve yüksek kaliteli dijital bağlantının önemini ortaya koymuştur. Ayrıca, çalışma IDI ile GII alt boyutları arasında güçlü ilişkiler tespit etmiştir; özellikle Altyapı (r=0.879), İnsan Sermayesi ve Araştırma (r=0.842) ve Bilgi ve Teknoloji Çıktıları (r=0.826) üzerinde belirgin etkiler gözlenmiştir. Anlamlı Bağlantı'nın yaratıcı çıktılar üzerindeki etkisinin Evrensel Bağlantı'dan daha güçlü olduğu gösterilmiş, bu da erişimden ziyade bağlantı kalitesinin önemini vurgulamıştır. Bu bulgular, dijital altyapı yatırımlarının yenilik ekosistemlerini geliştirmedeki önemini vurgulamakta, dijital bağlantıdaki eşitsizliklerin giderilmesi ve sürdürülebilir kalkınmanın teşvik edilmesi gerektiğini göstermektedir. Çalışma, ICT'nin yenilik üzerindeki etkisini ampirik olarak ortaya koyarak, ekonomik büyüme ve rekabet gücü için dijital teknolojilerin nasıl kullanılacağına dair politika yapıcılara öneriler sunmaktadır.

Anahtar Kelimeler*: ICT gelişim endeksi, Küresel inovasyon endeksi, Evrensel bağlantı, Anlamlı bağlantı, İnovasyon kapasitesi.*

Jel Kodu: *O20, O10, O14.*

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1. Introduction

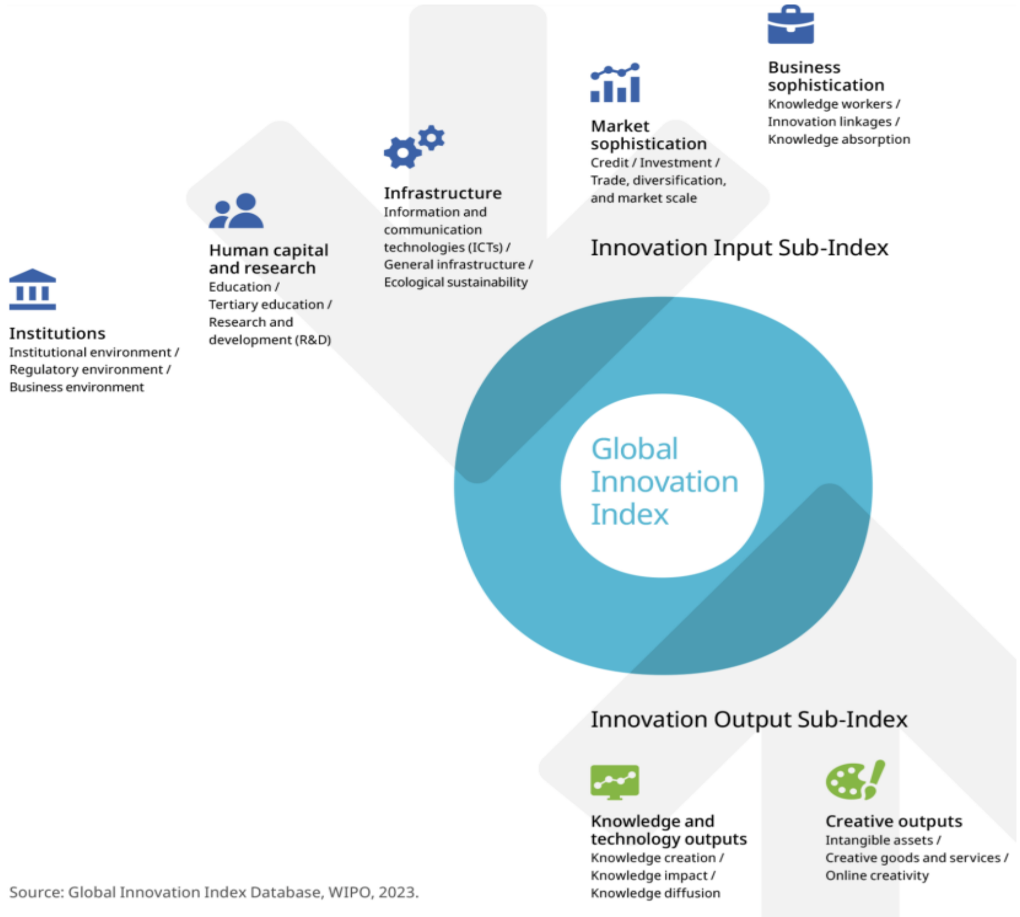
The development of information and communication technologies (ICT) and the enhancement of innovation capacity are pivotal drivers of economic growth and sustainable development in the modern era. ICT serves as a foundational pillar for fostering innovation ecosystems, enabling knowledge dissemination, improving productivity, and facilitating collaboration across sectors (Pradhan et al., 2022). The integration of ICT into national economies not only accelerates technological progress but also creates opportunities for new business models and societal transformation. However, embedding technology and innovation into the economy requires governments to adopt a multidimensional approach that includes investments in human capital, infrastructure, and institutional reforms, while also addressing the potential adverse effects on income distribution and social cohesion (Mitra et al., 2023; Schwab, 2019).

Indices such as the ICT Development Index (IDI) and the Global Innovation Index (GII) are critical tools for assessing and comparing countries' performance in these areas. The IDI, developed by the International Telecommunication Union (ITU), evaluates ICT access, use, and skills, providing insights into the digital divide and a country's readiness for digital transformation (ITU, 2023). Complementing this, the GII, established in 2007 through a collaboration between the World Intellectual Property Organization (WIPO), INSEAD, and Cornell University, ranks countries based on their innovation capabilities and outcomes (WIPO, 2023). By examining dimensions such as institutions, human capital, infrastructure, and innovation outputs, the GII offers a comprehensive framework for understanding the interplay between innovation and economic development.

The insights provided by these indices are invaluable for policymakers, business leaders, and academics, offering evidence-based guidance for fostering innovation-driven economies. According to Arvanitis et al. (2016), information and communication technologies (ICT) facilitate process innovation. Recent studies highlight that nations with robust ICT infrastructures and high innovation scores tend to exhibit enhanced economic resilience and competitiveness in the global market (Castellacci & Natera, 2013; WIPO, 2024). As digital technologies increasingly shape economic landscapes, leveraging tools like IDI and GII becomes essential for crafting strategies that align technological advancements with sustainable development goals (World Bank, 2022).

Figure 1

GII and Levels (WIPO, 2023)

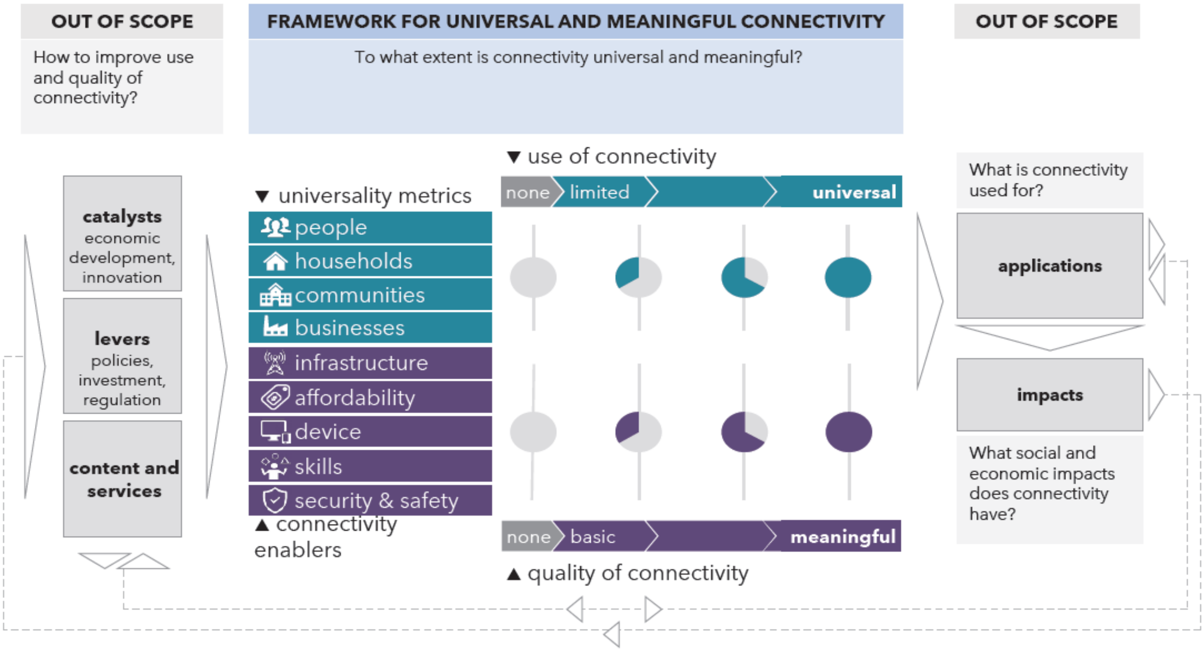


GII measures the innovation performance of economies using seven pillars, each representing critical areas of the innovation ecosystem (Figure I). According to WIPO's GII Report "institutions" pillar assesses the political, regulatory, and business environments that support or hinder innovation. It includes factors such as government effectiveness, regulatory quality, and ease of starting a business, highlighting the importance of stable and well-structured institutions for fostering innovation. Innovation relies heavily on the availability of skilled labor and robust research activities. And also the other pillar "human capital and research" pillar measures education (both primary and higher), the quality of universities, R&D investment, and the concentration of researchers. High levels of investment in education and research drive breakthrough innovations. The other pillar "infrastructure" refers to the physical and digital assets that facilitate innovation. The infrastructure pillar assesses factors like ICT access, energy efficiency, and environmental sustainability, reflecting the need for both digital and physical infrastructure in building an innovative society. Market dynamics play a crucial role in promoting innovation. "Market sophistication" pillar includes indicators like credit availability, investment, and trade conditions, which enable businesses to scale and finance innovative ideas. Developed capital markets and a vibrant financial sector are key to supporting startups and new technologies. "Business sophistication" pillar looks at how well businesses foster innovation, including how industries collaborate with universities, the presence of knowledge-intensive jobs, and the level of technology absorption. A high level of business sophistication often leads to stronger innovation ecosystems. "Knowledge and technology outputs" pillar measures the outputs from investments in research and development, such as patents, high-tech exports, and knowledge-intensive services. Economies excelling in this area often lead the way in cutting-edge technology and high-value industries. Beyond technology, “creative outputs” pillar focuses on the cultural and creative outputs of innovation, including trademarks, design creations, and the global presence of creative industries. It highlights how creativity contributes to economic growth through industries like media, advertising, and entertainment. Together, these pillars offer a comprehensive view of an economy's innovation capacity, with top performers in 2023 including Switzerland, Sweden, and the United States.

IDI is an index that assesses countries' ICT infrastructures, access, and usage. Developed by the International Telecommunication Union (ITU), the IDI was first published in 2009 as part of ITU's efforts to measure and evaluate ICT development. IDI is a composite indicator first published in 2009 by ITU. Publication was discontinued after 2017, owing to issues of data availability and quality. The purpose of the IDI is to assess the extent to which a country's connectivity is both universal and meaningful. Figure 2 shows the analytical framework guiding the development of the IDI.

Figure 2

Universal and Meaningful Connectivity Framework (ITU, 2023)



The 2023 IDI report emphasizes two critical sub-dimensions: Universal Connectivity and Meaningful Connectivity. Universal Connectivity refers to the foundational goal of ensuring that every individual, regardless of geographical location or socio-economic status, has access to the internet. It encompasses the physical infrastructure, such as broadband coverage, mobile networks, and digital devices, required to provide uninterrupted and equitable internet access to all citizens. The primary focus is on closing the digital divide by establishing widespread availability of affordable and reliable connectivity. Meaningful Connectivity goes beyond mere access to the internet. It emphasizes the quality and relevance of digital connectivity, ensuring that individuals not only have access but also possess the skills, tools, and opportunities to effectively engage with the digital world. This sub-dimension focuses on enabling users to leverage digital technologies in ways that enhance their economic, educational, and social well-being. It stresses the importance of factors such as high-speed internet, regular internet usage, ownership of smart devices, and the ability to participate meaningfully in the digital economy and society. Both dimensions aim to bridge the gap between access and effective use of digital technologies, fostering inclusive growth in an increasingly digital global landscape.

Today, various indices that measure countries' development and innovation levels play a crucial role in international strategic decision-making and policy development processes. IDI and GII are two such indices. The IDI measures fundamental development indicators such as health, education, and living standards, while the GII evaluates countries' innovation capacities and performances. However, there is a lack of in-depth analysis regarding the relationships between IDI and GII in the existing literature. This gap necessitates more detailed research to understand the potential relationship between IDI levels and GII levels.

Understanding how a country's development level impacts its innovation capacity is crucial for developing effective development strategies and innovative policies. For example, gaining insights into how innovation levels trend in countries with high IDI values and the factors influencing innovation levels in countries with low IDI values could help these countries reassess their development strategies. Similarly, understanding the relationship between GII and IDI could deepen the understanding of the dynamics between development and innovation and contribute to the creation of more effective policies in these areas.

Therefore, there is a need for studies examining the relationship between IDI and GII. The results of such research could reveal how countries' development policies can be integrated with innovation strategies, thereby gaining competitive advantages internationally. Additionally, such an analysis would provide valuable insights into enhancing the effectiveness of international development projects and innovation promotion programs. In this context, determining the relationship between IDI and GII could make significant contributions to shaping more effective policies in development and innovation.

Despite the extensive use of IDI and GII as benchmarking tools, there remains a significant research gap regarding the direct relationship between these two indices. While prior studies have acknowledged the individual roles of ICT development and innovation capacity in economic growth, the extent to which a country’s ICT infrastructure influences its innovation performance remains underexplored. This study aims to fill this gap by empirically analyzing the correlation between IDI and GII, thereby assessing how digital infrastructure impacts national innovation capacity.

While both the ICT Development Index (IDI) and the Global Innovation Index (GII) serve as crucial benchmarks for assessing technological progress and innovation capacity, the direct relationship between these indices remains underexplored. Existing literature lacks a comprehensive examination of how digital infrastructure development, as measured by IDI, influences national innovation performance, as reflected in GII scores. This gap presents a critical research problem that requires further empirical investigation.

This study seeks to answer the following primary research question:

- Is there a significant relationship between the total IDI score and its sub-dimensions, and the total GII score and its sub-dimensions across countries?

In addition, the study explores the following sub-questions:

- How do the sub-dimensions of IDI—Universal Connectivity and Meaningful Connectivity—impact the sub-dimensions of GII, such as Institutions, Human Capital & Research, Infrastructure, Business Sophistication, Knowledge & Technology Outputs, and Creative Outputs?
- Do higher levels of ICT infrastructure correspond to stronger innovation outputs across different income groups?

- What policy implications can be derived from the relationship between IDI and GII to enhance national innovation performance?

This study aims to fill a gap in the existing literature by providing a comprehensive analysis of how digital infrastructure influences innovation at the national level. The findings will offer valuable insights for policymakers, helping them design strategies that integrate technological development with innovation-driven economic growth.

Understanding this relationship is critical for policymakers and economic strategists, as it provides a data-driven foundation for designing policies that integrate technological development with innovation growth. By identifying how improvements in ICT infrastructure contribute to a nation's ability to innovate, this research offers valuable insights into optimizing national development and innovation strategies. The findings will be particularly relevant for governments aiming to align their digital transformation agendas with sustainable economic growth and global competitiveness.

2. Literature Review

The impact of Information and Communication Technology (ICT) development on innovation performance has been extensively investigated in recent years. A direct relationship has been identified between ICT development and global innovation, with both the Information and Communication Technology Development Index (IDI) and the Global Innovation Index (GII) playing a crucial role in assessing countries' innovation capacities (Nasir & Zhang, 2024).

A recent study analyzing innovation factors in 105 countries examined the relationship between ICT infrastructure and innovation outcomes, concluding that ICT development directly enhances innovation efficiency (Nasir and Zhang, 2024). Similarly, Bate, Wachira, and Danka (2023) conducted an innovation performance analysis of 63 countries and found that the relationship between GII and ICT development varies depending on national income levels (Bate et al., 2023).

Oturakci (2023) applied canonical correlation analysis to conduct a comprehensive assessment of GII and its link to economic and technological factors, demonstrating that ICT development plays a statistically significant role in enhancing innovation capacity (Oturakci, 2023). Furthermore, Khan et al. (2021) conducted a comparative study between India and China, investigating the effects of ICT infrastructure on innovation performance. Their findings suggested that ICT infrastructure has a bidirectional relationship with innovation outcomes, influencing and being influenced by innovation performance (Khan et al., 2021).

A study by Choi and Kim (2020) analyzed the relationship between ICT infrastructure, investment environment, and innovation performance, highlighting that ICT investments and regulatory frameworks significantly impact innovation outcomes, reinforcing the strong link between IDI and GII. Additionally, Vukoszavlyev (2019) examined the correlation between GII and economic indicators, finding that ICT development supports the innovation ecosystem and contributes to economic growth. Moreover, Niebel (2018) argues that digitalization significantly contributes to innovation-driven economic growth, emphasizing that ICT infrastructure plays a crucial role in shaping a country's innovation ecosystem.

The Information and Communication Technology Development Index (IDI), developed by the International Telecommunication Union (ITU), is a comprehensive measure of ICT development across countries, capturing dimensions of access, usage, and skills. It provides an essential benchmark for assessing the digital divide and monitoring ICT progress globally (ITU, 2023). ICT has been consistently highlighted in the literature as a fundamental driver of economic growth, innovation, and global competitiveness. Studies emphasize that advancements in ICT infrastructure and capabilities are not only enablers of technological progress but also catalysts for economic and social transformation (Ollo-López & Aramendía-Muneta, 2012; Pradhan et al., 2022). Furthermore, ICT adoption is regarded as a crucial determinant of national innovation performance, as it enhances connectivity, facilitates knowledge sharing, and enables advanced technological applications (Nasir & Zhang, 2024).

Similarly, the Global Innovation Index (GII), developed by the World Intellectual Property Organization (WIPO), serves as a holistic tool for evaluating a nation's innovation capacity and performance. By integrating metrics such as institutions, human capital, infrastructure, and innovation outputs, the GII provides insights into how countries develop and leverage innovation to enhance economic competitiveness (WIPO, 2022). The GII and IDI overlap in capturing the critical role of infrastructure, market sophistication, and human capital as key determinants of economic and innovation success. Studies have indicated that well-developed ICT infrastructure contributes positively to national innovation performance, as measured by the GII, by fostering digital transformation, reducing transaction costs, and enabling collaborative innovation (Bate et al., 2023).

The relationship between ICT development, as captured by IDI, and innovation performance, as measured by GII, has drawn significant attention in recent studies. Pradhan et al. (2022) examined G-20 economies and demonstrated a positive correlation between ICT development and innovation outputs, underscoring the importance of digital infrastructure and ICT skills in fostering innovation ecosystems. Their findings suggest that ICT acts as a conduit for innovation by enabling knowledge dissemination, improving productivity, and facilitating collaboration across sectors. Similarly, Castellacci and Natera (2013) argue that the absorptive capacity of a country, heavily influenced by ICT development, plays a critical role in determining its innovation outcomes. Empirical studies have further corroborated these findings, demonstrating that nations with advanced ICT infrastructures tend to experience higher innovation performance due to enhanced digital readiness and technological capabilities (Choi & Kim, 2020; Khan et al., 2021).

The GII 2024 report further highlights the importance of ICT in innovation systems, noting that countries with advanced ICT infrastructures, such as Singapore and South Korea, consistently rank high in innovation performance. These nations leverage their robust digital ecosystems to drive technological advancements, high-tech manufacturing, and creative outputs, demonstrating the interconnectedness of ICT and innovation (WIPO, 2024). This is supported by findings from Zhu and Kraemer (2005), who note that countries investing in ICT infrastructure tend to experience significant gains in business innovation and productivity. In a comparative study between India and China, Khan et al. (2021) found a bidirectional relationship between ICT infrastructure and GII, illustrating how improvements in ICT capabilities reinforce innovation performance, while increased innovation efforts further enhance ICT adoption.

Ollo-López and Aramendía-Muneta (2012) extend this argument by illustrating that ICT adoption improves firm-level competitiveness, facilitating access to global markets and enhancing operational efficiency. Their study highlights that ICT's impact is particularly pronounced in areas such as knowledge and technology outputs, where digital tools enable innovation through increased collaboration and data sharing. The World Bank (2022) adds that ICT-driven innovation is critical in reducing barriers for small and medium-sized enterprises (SMEs), fostering inclusive growth, and supporting sustainable development. Recent research by Oturakci (2023) reinforces these findings by demonstrating that digital transformation significantly affects countries' innovation rankings, as measured by the GII, with a strong positive correlation between ICT investment and national innovation outputs.

Despite its transformative potential, challenges persist. The digital divide remains a significant issue, with disparities in ICT access and skills hindering the equitable distribution of innovation benefits. Mitra et al. (2023) critique the oversimplified narrative of techno-solutionism, which assumes that ICT alone can address complex societal challenges such as inequality and climate change. They emphasize the need for comprehensive policy frameworks that integrate ICT with broader socio-economic and institutional reforms. Additionally, while ICT development positively impacts innovation performance, its effectiveness varies across countries due to differences in regulatory environments, digital literacy, and financial constraints (Vukoszavlyev, 2019).

While ICT development has been widely recognized as a driver of innovation and economic transformation, an overly deterministic view of technology as a universal solution has been critiqued under the concept of Techno-Solutionism. Morozov (2013) argues that Techno-Solutionism assumes that complex social, economic, and institutional problems can be solved merely through technological advancements, disregarding structural and systemic inequalities. In the context of innovation, this perspective risks oversimplifying the factors contributing to national innovation performance by overlooking critical elements such as governance, human capital investment, and regulatory frameworks (Mitra et al., 2023).

Additionally, research suggests that while digital infrastructure is necessary for innovation, it is not a sufficient condition on its own. Khan et al. (2021) highlight that disparities in ICT access, digital literacy, and financial resources create an uneven playing field, where high-income countries benefit disproportionately from digital transformation, whereas low-income nations struggle to leverage ICT for innovation effectively. Furthermore, excessive reliance on technological solutions without addressing underlying social challenges can lead to "innovation stagnation," where technological advancements fail to translate into broad-based economic and social progress (Niebel, 2018).

The critiques of Techno-Solutionism suggest that for ICT-driven innovation to be truly effective, it must be accompanied by well-structured policies that ensure equitable access to digital tools, digital literacy programs, and inclusive economic frameworks. Without these elements, ICT development alone may reinforce existing socio-economic disparities rather than mitigating them (Vukoszavlyev, 2019).

In conclusion, the interplay between IDI and GII underscores the importance of ICT as a foundational pillar of innovation ecosystems. While advanced ICT infrastructure and capabilities are strongly correlated with high innovation performance, addressing systemic barriers and ensuring equitable access to digital resources are critical for maximizing ICT's potential. Future research should explore the longitudinal effects of ICT investments on innovation outcomes, particularly in low-income regions where digital disparities persist.

The increasing interconnection between ICT development and innovation performance, as evidenced in the existing literature, highlights the necessity of examining their relationship in greater detail. While prior studies have established correlations between IDI and innovation outputs (Pradhan et al., 2022; WIPO, 2024), the specific mechanisms through which ICT dimensions, such as connectivity and meaningful usage, influence GII sub-dimensions, including institutions and creative outputs, remain underexplored. This study aims to bridge this gap by providing a nuanced analysis of the relationships between IDI and its sub-dimensions with GII and its components. "Is there a significant relationship between the total IDI score and its sub-dimensions, and the total GII score and its sub-dimensions across countries?" research question guided for the research.

3. Method

3.1. Research Design

In the current study, a correlational research method, one of the relational screening models, was utilized. A correlational research method examines the relationship between two or more variables without manipulating them, making it particularly suitable for understanding naturally occurring associations (Creswell & Creswell, 2018). This method is frequently employed in studies investigating the interaction of quantitative variables across large datasets, where the aim is to identify patterns and strengths of relationships (Fraenkel et al., 2019).

The correlational method was selected as the most appropriate approach for this study because it allows for the examination of the relationships between countries' scores on the ICT Development Index (IDI) and the Global Innovation Index (GII), as well as their respective sub-dimensions. This approach aligns with prior studies in the field that explore the associations between technological development and innovation performance using similar methodological frameworks (Pradhan et al., 2022; Yousefi, 2011). Additionally, correlational research provides valuable insights into the strength and direction of relationships, which is critical for addressing the research questions and hypotheses posed in this study.

By employing a correlational design, this research aims to contribute to the growing body of literature examining the interplay between digital infrastructure, connectivity, and innovation systems, as emphasized by Castellacci and Natera (2013). The method is also particularly advantageous for large-scale comparative studies, as it enables the analysis of associations across diverse contexts while maintaining methodological rigor (Bryman, 2016).

3.2. Data Collection Tool

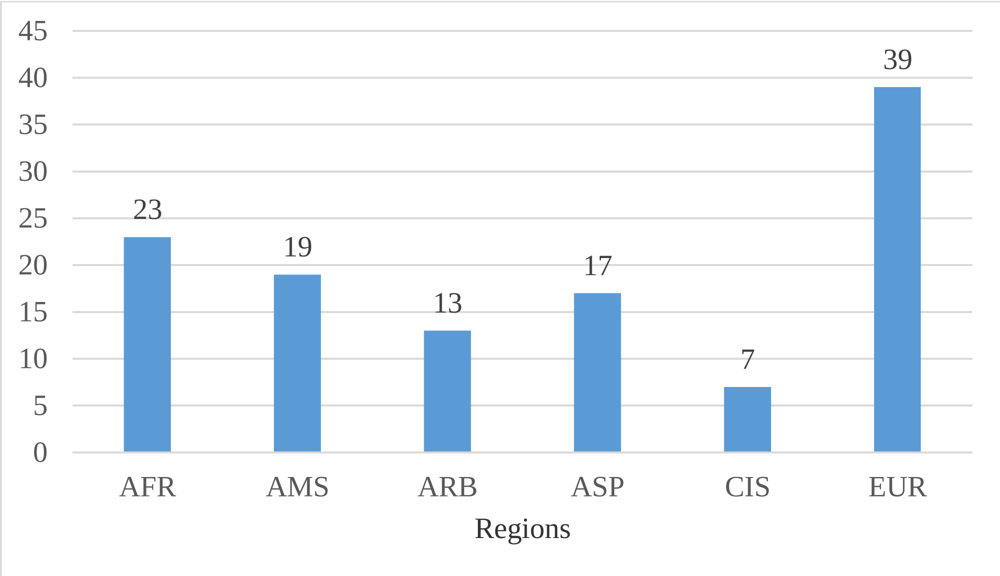
The data used in this study were obtained from the latest available reports and datasets provided by the International Telecommunication Union (ITU) and the World Intellectual Property Organization (WIPO). IDI data was retrieved from the 2023 ITU report titled "Measuring Digital Development: Facts and Figures 2023" (International Telecommunication Union [ITU], 2023). This dataset provides country-level scores for Universal Connectivity and Meaningful Connectivity, which were used to compute the IDI scores in this study. GII data was obtained from the "Global Innovation Index 2023" report, published by WIPO in collaboration with INSEAD and Cornell University (World Intellectual Property Organization [WIPO], 2023). The dataset includes the rankings and scores for GII and its sub-dimensions, covering 132 economies.

All data used correspond to the most recent 2023 release of these indices. However, it should be noted that the ITU discontinued the IDI's full publication after 2017 due to data availability issues. Therefore, the 2023 IDI dataset used in this study follows ITU's revised methodology, which focuses on the two sub-dimensions: Universal Connectivity and Meaningful Connectivity. The datasets provided by ITU and WIPO contain comprehensive country-level statistics. However, a few countries had missing data points for some sub-dimensions, particularly in the GII dataset. To maintain consistency, countries with missing IDI or GII scores were excluded from the analysis. In cases where sub-dimension values were missing but the total index score was available, interpolation methods were considered; however, ultimately, only countries with complete data were included to ensure methodological rigor. The final dataset used in this study includes 118 countries, as indicated in Figure 3. Thus, the decision to employ Spearman correlation analysis was methodologically justified based on the empirical evidence from normality tests, ensuring the statistical rigor of the analysis.

In this study, data on telecommunications development and economic growth from the 2023 IDI report for 118 countries, categorized under six regions (Africa-AFR, Americas-AMS, Arab States-ARB, Asia Pacific-ASP, Commonwealth of Independent States-CIS, Europe-EUR), as well as data on economic innovation ecosystem performance from the 2023 GII report for these countries, have been utilized. The number of countries whose data were used in the study, classified by regions, is presented in Figure 3.

Figure 3

Region Countries Counts



As shown in Figure 3, the study group consists of data on the IDI and GII sub-dimensions for a total of 118 countries, including 23 from the Africa region, 19 from the Americas region, 13 from the Arab States region, 17 from the Asia-Pacific region, 7 from the Commonwealth of Independent States region, and 39 from the Europe region.

3.3. Data Analysis

In calculating the IDI score (IDIS) of countries, the Universal Connectivity score (UCS) and the Meaningful Connectivity score (MCS), which are sub-dimensions of the IDI, were used (ITU, 2023). The IDI scores of countries were calculated by taking the arithmetic mean of these two scores, as shown in Formula 1.

Formula 1: IDIS = (UCS + MCS) / 2

The Universal Connectivity scores (UCS) of countries were calculated by taking the arithmetic mean of their "Individuals using internet (%)" score (UCS1), "Households with Internet Access at Home (%)" score (UCS2), and "Mobile-broadband subscriptions per 100 inhabitants" score (UCS3), as shown in Formula 2.

Formula 2: UCS = (UCS1 + UCS2 + UCS3) / 3

The Meaningful Connectivity scores (MCS) of countries were calculated using the scores for "Population covered by at least a 3G mobile network (%)" (MC1_a), "Population covered by at least a 4G/LTE mobile network (%)" (MC1_b), "Mobile broadband Internet traffic per subscription (GB)" (MC2), "Fixed broadband Internet traffic per subscription (GB)" (MC3), "Mobile data and voice highconsumption basket price (% GNI p.c.)" (MC4), "Fixed-broadband Internet basket price (as % GNI p.c.)" (MC5), and "Individuals owning a mobile phone (%)" (MC6), as shown in Formula 3:

Formula 3: MCS = ((0.4 x MC1_a + 0.6 x MC1_b) + ((ln(MC2 + 1) - ln(1)) / (ln(MC2 + 1) - ln(1)) x 100) + ((ln(MC3 + 1) - ln(1)) / (ln(MC3 + 1) - ln(1)) x 100) + MC4 + MC5 + MC6) / 6

The GII score of countries was calculated by taking the simple arithmetic mean of the input and output sub-indices. The Innovation Input sub-index includes scores for Institutions (INST), Human Capital (HC), Infrastructure (INF), Market Sophistication (MS), and Business Sophistication (BS). The Innovation Output sub-index includes scores for Knowledge and Technology Outputs (KTO) and Creative Outputs (CO). The formula used by WIPO (2023) to calculate the GII score (GIIS) for countries is shown in Formula 4.

Formula 4: GIIS = (INST + HC + INF + MS + BS + KTO + CO) / 7

To determine the relationship between countries' IDI levels and GII levels, Spearman's Rank-Order Correlation was used due to the lack of normal distribution in the data, as indicated by the results of the Kolmogorov-Smirnov and Shapiro-Wilk normality tests. Spearman correlation is a nonparametric test that assesses the strength and direction of monotonic relationships between two variables, making it suitable for the current dataset. For interpretation, thresholds proposed by Cohen (1988, 1992) for correlation effect sizes were adapted: correlations up to 0.20 indicate small effects, correlations between 0.20 and 0.50 suggest medium effects, and correlations greater than 0.50 reflect large effects. Cohen noted that these thresholds are relative and should be contextualized within the specific field of study and the nature of the research methods employed (Cohen, 1988, p. 25). Regression analysis was not conducted as the normality assumption required for parametric regression was not met. Instead, the study focuses on interpreting the correlations to explore the relationships between IDI and GII levels and their respective sub-dimensions.

3.4. Ethical Approval

This study adhered to established ethical guidelines and procedural standards throughout the research process. The research was conducted in compliance with institutional and international ethical principles, ensuring the integrity and transparency of the study. No human participants, sensitive data, or personally identifiable information were involved, eliminating the need for formal ethical board approval. However, all data sources were publicly available, and appropriate citations were provided to ensure academic integrity and responsible data usage.

4. Findings

The IDI shows a mean value of 76.87 with a standard deviation of 18.97, indicating substantial variation in ICT development among countries. The skewness value of -1.26 suggests a negatively skewed distribution, meaning that a majority of countries have scores concentrated toward the higher end. The kurtosis value of 0.66 indicates a relatively peaked distribution, reflecting some clustering around the mean.

Table 1

Descriptive Statistics of IDI Dimensons and GII Dimensions

IDI Dimension	N	Min.	Max.	Mean	Std. Deviation	Skewness	Kurtosis
IDI	118	23,00	98,20	76,87	18,97	-1,26	0,66
Universal Connectivity	118	11,70	100,00	71,56	22,40	-0,998	0,06
Meaningful Connectivity	118	32,80	99,30	82,18	16,62	-1,67	1,84

The first dimension, Universal Connectivity, has a mean of 71.56 and a standard deviation of 22.40, which highlights a wider variability compared to the overall IDI. The skewness value of -0.998 indicates a mild negative skew, showing that countries tend to cluster toward higher connectivity scores. The kurtosis value of 0.06 suggests a distribution that is close to normal, with minimal extremity in the values. These findings suggest that while access to ICT infrastructure varies significantly across countries, many countries perform relatively well in terms of basic connectivity.

In contrast, Meaningful Connectivity, the second dimension of IDI, exhibits the highest mean value of 82.18 with a standard deviation of 16.62, reflecting strong performance in the quality and utility of ICT use among the sampled countries. The skewness value of -1.67 demonstrates a pronounced negative skew, indicating that most countries have high-quality ICT connections. Additionally, the kurtosis value of 1.84 reflects a more peaked distribution with greater clustering around higher scores, suggesting that meaningful connectivity is less varied and more consistently developed compared to universal connectivity.

Overall, the descriptive analysis highlights the varying levels of ICT development among countries, with Meaningful Connectivity showing a relatively more uniform and higher performance compared to Universal Connectivity. These results emphasize the importance of not only expanding access to ICT but also ensuring the quality and effectiveness of its use to maximize its impact on development and innovation systems.

Table 2

Descriptive Statistics of GII

GII Dimension	N	Min.	Max.	Mean	Std. Deviation	Skewness	Kurtosis
Global Innovation Index	118	10,30	67,60	33,14	14,09	0,58	-0,60
Institutions	118	30,90	93,30	63,50	14,27	0,30	-0,52
Human Capital	118	7,70	65,40	34,50	15,65	0,32	-1,05
Infrastructure	118	16,10	75,60	46,28	14,13	0,01	-0,73
Market Sophistication	118	13,90	74,00	45,68	10,54	0,30	0,43
Business Sophistication	118	8,50	66,30	37,39	12,30	0,36	-0,51
Knowledge and Technology Outputs	118	1,60	72,10	27,46	16,93	0,73	-0,32
Creative Outputs	118	5,10	63,90	29,45	15,57	0,32	-0,94

Table 2 presents the descriptive statistics for the GII and its sub-dimensions. The GII itself exhibits a mean value of 33.14, with a standard deviation of 14.09, indicating considerable variation in innovation capacity among the countries. The skewness value of 0.58 suggests a slight positive skew, implying that a greater number of countries have scores below the mean, while the kurtosis value of -0.60 indicates a relatively flat distribution with fewer extreme values.

Among the dimensions of GII, Institutions displays a mean of 63.50 and a standard deviation of 14.27, highlighting that institutional quality is relatively stable across countries. Its skewness (0.30) and kurtosis (-0.52) values suggest a near-normal distribution. Human Capital, with a mean of 34.50 and a standard deviation of 15.65, shows greater variability, reflecting disparities in education and research capabilities across the countries. The negative kurtosis value of -1.05 indicates a flatter distribution with fewer extreme values.

Infrastructure has a mean of 46.28 and a standard deviation of 14.13, with a near-symmetric distribution (skewness = 0.01) and moderately flat kurtosis (-0.73). This reflects relatively consistent access to basic and technological infrastructure. Market Sophistication, with a mean of 45.68 and a standard deviation of 10.54, exhibits the lowest variability among the dimensions, suggesting more uniformity in market conditions across countries. Its positive kurtosis (0.43) suggests a slightly peaked distribution with values clustering around the mean.

Business Sophistication, characterized by a mean of 37.39 and a standard deviation of 12.30, demonstrates moderate variability. The distribution is slightly positively skewed (0.36), indicating a few countries with significantly higher scores. On the other hand, Knowledge and Technology Outputs and Creative Outputs reveal the lowest mean values (27.46 and 29.45, respectively) among the dimensions, coupled with relatively high standard deviations (16.93 and 15.57), which highlight significant disparities in technological advancements and creative industry contributions among the sampled countries. The positive skewness of Knowledge and Technology Outputs (0.73) suggests a concentration of countries with lower scores, while the near-normal skewness of Creative Outputs (0.32) points to a more balanced distribution.

In summary, the descriptive analysis indicates considerable heterogeneity across countries in terms of innovation performance, with notable disparities in the outputs of technological and creative activities. While institutional and infrastructural factors show more uniformity, dimensions like human capital and innovation outputs underscore the uneven development of critical components of innovation systems.

Table 3

Kolmogorov-Smirnov and Shapiro Normality Tests of IDI, IDI levels, GII and GII Levels

	Kolmogorov-Smirnov			**Shapiro-Wilk**		
	Statistic	df	p	Statistic	Df	p
IDI	0,17	118	0,000	0,85	118	0,000
U. Connectivity	0,19	118	0,000	0,89	118	0,000
M. Connectivity	0,22	118	0,000	0,76	118	0,000
GII	0,11	118	0,001	0,95	118	0,000
Institutions	0,09	118	0,030	0,97	118	0,010
H. Capital	0,09	118	0,032	0,95	118	0,000
Infrastructure	0,05	118	0,200*	0,99	118	0,220
M.Sophist.	0,06	118	0,200*	0,99	118	0,540
B. Sophistication	0,07	118	0,200*	0,98	118	0,030
K.&T. Outputs	0,11	118	0,001	0,94	118	0,000
C. Outputs	0,09	118	0,001	0,96	118	0,000

The Kolmogorov-Smirnov and Shapiro-Wilk tests indicate that most of the variables in the study do not meet the assumption of normal distribution (p<0.05). Specifically, variables such as IDI, GII, and their sub-dimensions, including Universal Connectivity, Meaningful Connectivity, Knowledge & Technology Outputs, and Creative Outputs, do not exhibit normal distribution. However, the variables Infrastructure and Market Sophistication were found to follow normal distribution with p≥0.05. Since normal distribution was not generally observed, a non-parametric test, the Spearman correlation test, was conducted to examine the relationships between IDI and its sub-dimensions and GII and its sub-dimensions.

Table 4

Spearman Correlation Matrix between IDI Levels and GII Levels of The Countries

	1	2	3	4	5	6	7	8	9	10	11
IDI	1										
U. Connectivity	,987*	1									
M. Connectivity	,954*	,903*	1								
GII	,847*	,819*	,839*	1							
Institutions	,826*	,804*	,800*	,863*	1						
H. Capital	,842*	,814*	,834*	,942*	,847*	1					
Infrastructure	,879*	,849*	,868*	,937*	,881*	,953*	1				
M.Sophist.	,679*	,661*	,655*	,804*	,757*	,761*	,796*	1			
B. Sophist.	,829*	,800*	,813*	,937*	,858*	,935*	,947*	,846*	1		
K.&T. Outputs	,826*	,794*	,826*	,956*	,846*	,956*	,940*	,808*	,949*	1	
C. Outputs	,810*	,779*	,805*	,951*	,860*	,947*	,948*	,812*	,936*	,791*	1

*. Correlation is significant at the 0.01 level (2-tailed).

To assess the strength of the relationships observed in this study, Cohen’s (1988) guidelines for effect size interpretation were used. According to these guidelines, correlation coefficients below 0.10 indicate negligible effects, values between 0.10 and 0.29 suggest small effects, those ranging from 0.30 to 0.49 represent medium effects, and correlations of 0.50 or higher are considered large effects. These thresholds provide a useful framework for evaluating the magnitude of relationships in empirical studies.

The Spearman correlation analysis reveals robust and significant positive relationships between the ICT Development Index (IDI) and its sub-dimensions (Universal Connectivity and Meaningful Connectivity) with the Global Innovation Index (GII) and its sub-dimensions. These findings directly address Research Question 1, confirming the overarching relationship between ICT development and innovation performance. The strong correlation between the total IDI score and the total GII score (r=0.847) supports Hypothesis 1, suggesting that countries with higher ICT development levels exhibit greater innovation capacities. Further analysis demonstrates that the sub-dimensions of IDI, Universal Connectivity (r=0.819) and Meaningful Connectivity (r=0.839), are also significantly correlated with the total GII score. This emphasizes the importance of both ICT access and quality in fostering innovation processes, addressing Research Question 2 and providing evidence for Hypotheses 2 and 3. The findings suggest that high-quality connectivity plays a more substantial role in enabling innovation compared to basic access.

Examining the relationships between IDI and its sub-dimensions with the sub-dimensions of GII, the analysis highlights the substantial influence of digital infrastructure and connection quality on both innovation inputs and outputs. The total IDI score is strongly correlated with Infrastructure (r=0.879), Human Capital & Research (r=0.842), and Knowledge & Technology Outputs (r=0.826), supporting Hypothesis 4. These results indicate that investments in ICT infrastructure significantly enhance knowledge production, technological outputs, and the development of human capital, underscoring ICT's role in strengthening foundational and output-driven aspects of innovation ecosystems.

Strong correlations are also observed between IDI and Creative Outputs, with the total IDI score (r=0.810) and its sub-dimensions, Universal Connectivity (r=0.779) and Meaningful Connectivity

(r=0.805), reinforcing the critical role of digital infrastructure in creative industries and cultural innovation. These results also align with Hypothesis 3, which posits that Meaningful Connectivity demonstrates a stronger relationship with creative outputs due to its focus on the quality and effectiveness of ICT use. Moderate-to-strong relationships were observed between Market Sophistication and Universal Connectivity (r = 0.679), implying that while ICT infrastructure influences market conditions, additional economic variables may moderate this relationship. Likewise, the correlation between Business Sophistication and IDI (r = 0.829) suggests that digital infrastructure fosters innovation within the business sector, but firm-level capabilities and regulatory frameworks may also be determining factors. This indicates that ICT development substantially supports innovation within the business sector, aligning with the broader implications of Research Question 3.

These results indicate that investments in digital infrastructure and connectivity improvements yield substantial benefits for innovation-driven economies. Countries with strong ICT ecosystems tend to exhibit higher innovation outputs, reinforcing prior findings that digital transformation accelerates national competitiveness and economic growth (Castellacci & Natera, 2013; Pradhan et al., 2022). The observed effect sizes highlight the necessity of prioritizing ICT investments to enhance innovation capacity globally. The findings provide strong empirical support for the critical role of ICT development (as measured by IDI) in shaping innovation performance (as captured by GII).

While the overall findings indicate a strong positive relationship between ICT development and innovation performance, further analysis at the regional and country level reveals important differences. In high-income countries, particularly in Northern and Western Europe (e.g., Switzerland, Sweden, and Finland), the strong digital infrastructure captured by IDI aligns with their high innovation outputs, as reflected in their GII scores. These nations benefit from well-developed ICT policies, high R&D investments, and knowledge-intensive economies that foster innovation.

In contrast, many countries in Sub-Saharan Africa and parts of South Asia exhibit lower IDI and GII scores, indicating that limited ICT infrastructure may act as a constraint on innovation. For example, Nigeria and Bangladesh show moderate levels of ICT access but relatively lower scores in innovation outputs. This suggests that beyond digital access, other structural factors—such as institutional quality, education, and funding for R&D—also play a crucial role in enhancing innovation capacity.

A closer comparison of South Korea and Brazil further highlights the role of digital connectivity in innovation. South Korea, which ranks among the top in both IDI and GII, has a robust ICT infrastructure that supports high-tech manufacturing and knowledge-based industries. Brazil, despite having a growing ICT sector, still faces challenges in translating digital development into higher innovation outputs, as indicated by a weaker correlation between its IDI and GII sub-dimensions.

These regional and country-specific trends suggest that while ICT development is a key enabler of innovation, its impact varies depending on economic context, policy frameworks, and investment in complementary assets such as education and research. Future research could further explore how digital transformation strategies differ across regions and their implications for innovation-driven growth.

These results demonstrate that investments in digital infrastructure and ensuring high-quality connectivity significantly contribute to enhancing innovation inputs, such as human capital and infrastructure, as well as key outputs, including creative and technological advancements. However, as the regional and country-level comparisons suggest, the extent of this impact varies depending on economic structures, policy environments, and investment levels. High-income economies such as Switzerland, Sweden, and South Korea leverage advanced ICT ecosystems to sustain innovation, while regions with lower digital infrastructure, including parts of Sub-Saharan Africa and South Asia, face barriers in translating digital access into innovation-driven growth. This contrast highlights the importance of complementary policies that go beyond ICT development, including investments in education, institutional quality, and R&D funding.

The study underscores the necessity of a context-specific approach to digital infrastructure investments, where policymakers tailor strategies to regional needs and economic conditions. Strengthening ICT ecosystems is crucial for fostering sustainable development globally, but its effectiveness depends on the integration of digital policies with broader innovation strategies. Future research should further explore how digital transformation policies can be adapted to different regional contexts to maximize innovation potential.

5. Result, Discussion and Conclusion

The findings of this study emphasize the significant role of ICT Development Index (IDI) and its sub-dimensions (Universal Connectivity and Meaningful Connectivity) in shaping the innovation capacity, as measured by the Global Innovation Index (GII) and its sub-dimensions. These results are consistent with existing literature highlighting the transformative impact of ICT infrastructure and quality on fostering innovation ecosystems (OECD, 2021; United Nations Conference on Trade and Development [UNCTAD], 2020). The strong positive correlation between the total IDI and GII scores (r=0.847) provides compelling evidence that higher ICT development levels translate into enhanced innovation performance across countries. This relationship underscores the importance of digital technologies in enabling countries to bridge gaps in their innovation systems.

The analysis further reveals the differential impacts of IDI sub-dimensions. Universal Connectivity, which measures ICT access, and Meaningful Connectivity, which evaluates the quality and utility of ICT usage, are both positively and significantly correlated with GII scores (r=0.819 and r=0.839, respectively). These findings align with prior research suggesting that access to basic digital infrastructure is a prerequisite for innovation, but it is the effective and meaningful use of ICT that ultimately drives higher innovation outputs (World Bank, 2022; Yousefi, 2011).

Examining the relationship between IDI and GII sub-dimensions highlights specific pathways through which ICT influences innovation. The strong correlations between IDI and Infrastructure (r=0.879) and Human Capital & Research (r=0.842) suggest that countries with better-developed ICT infrastructure also excel in building human capital and research capacity. This observation supports the argument that ICT acts as an enabler for educational advancements, research activities, and knowledge dissemination (Lopez-vega and Tell, 2021). Additionally, the robust relationships with Knowledge and Technology Outputs (r=0.826) and Creative Outputs (r=0.810) highlight the impact of ICT on both technological advancements and cultural innovation, reinforcing the dual role of digital infrastructure in fostering both economic and creative development (UNESCO, 2020).

Despite these positive findings, disparities in ICT and innovation development remain significant among countries, as evidenced by the wide standard deviations in both IDI and GII dimensions. This variation reflects challenges related to unequal access to digital resources and uneven levels of capacity development. Prior studies have pointed out that barriers such as affordability, digital literacy, and institutional constraints limit the transformative potential of ICT in less-developed regions (Castellacci & Natera, 2013; ITU, 2023). Addressing these barriers is critical to ensuring that the benefits of ICT-driven innovation are equitably distributed.

The results of this study have important implications for policymakers. First, investments in ICT infrastructure should not only aim to expand basic connectivity but also prioritize the enhancement of quality and meaningful use. Policies targeting improvements in Universal Connectivity and Meaningful Connectivity can foster a more robust and inclusive innovation ecosystem. Second, the strong correlation between ICT development and innovation outputs highlights the need for integrated strategies that link digital infrastructure initiatives with innovation policies. For instance, fostering collaborations between the ICT sector and creative industries could amplify the impact of digital technologies on cultural and technological innovation.

Future research should explore the dynamic interactions between ICT development and other dimensions of innovation, such as societal and cultural factors, which were beyond the scope of this study. Additionally, longitudinal analyses could provide insights into the long-term effects of ICT investments on innovation performance. Expanding the scope to include qualitative analyses, such as case studies of successful ICT-driven innovation policies, would also enrich understanding and offer practical lessons for policymakers.

In conclusion, this study underscores the critical importance of ICT in shaping the innovation capacities of countries. By strengthening digital infrastructure and ensuring equitable access to high-quality connectivity, nations can unlock the full potential of ICT to drive innovation, economic growth, and sustainable development. These findings contribute to the growing body of evidence advocating for the strategic integration of ICT into innovation policies to achieve broader societal and economic goals.

This study provides empirical insights into the relationship between the ICT Development Index (IDI) and the Global Innovation Index (GII). However, further research is needed to analyze this relationship more comprehensively. Future studies could employ time series analysis to examine how the IDI-GII relationship evolves over time, assessing whether the impact of digital technologies on innovation has strengthened in the long term.

Additionally, panel data analysis could offer a more detailed examination of cross-country variations. By accounting for economic development levels, institutional structures, and policy factors, panel models could provide deeper insights into how the IDI-GII relationship differs across countries. Furthermore, Granger causality tests and dynamic panel models could help determine whether IDI directly drives innovation or whether the relationship is bidirectional. Future research should also incorporate sectoral-level analyses to explore how digital infrastructure influences innovation across different industries. These methodological approaches would enhance the robustness of findings and provide policymakers with more strategic insights.

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