Investigating the Effect of ICT on Human Development – Study of BRICS

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Abstract

Purpose : The long-run objective of this study was to analyze the impact of Information and Communication Technology (ICT) on the Human Development Index (HDI) for BRICS countries using annual data for the period from 2000–2022.

Methodology : The long-term link between ICT and HDI for the BRICS countries from 2000 to 2022 was examined in the paper using panel cointegration and FMOLS approaches, taking into account control variables, including the gender inequality index, carbon emissions, GDP per capita, and population growth.

Findings : Empirical findings demonstrated a strong long-term correlation between the GDP per capita, gender disparity, ICT, HDI, carbon emissions, and population growth rate. The grouped mean–FMOLS estimates' signals agreed with theoretical theories regarding the relationships between the variables. While gender inequality and carbon emissions had a negative influence on HDI, ICT and GDP per capita exhibited a favorable benefit. A substantial causative relationship between HDI and ICT, GDP per capita, population growth, and carbon emissions was found by looking at Granger causality results. However, it was shown that gender inequality did not contribute to HDI.

Practical Implications : The digitalization of services and digital payments has transformed the functioning of the economies to ensure inclusive and accelerated growth. Against this backdrop, the study analyzed the effect of ICT in promoting the development of human capital in the economy. BRICS was the choice of the sample as these countries have the potential to ride the digital progress in the global economy.

Originality : This paper contributed to the literature by exploring the relationship between BRICS countries by incorporating different variables that can affect HDI. Moreover, in light of significant economic progress, the factors that affect human development keep on evolving in countries. New studies would help the countries gain useful insights in policy making.

Keywords : **human development index, information and communication technology, panel cointegration, Granger causality, BRICS**

JEL Classification Codes : C330, O2, O150

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Digitalization and growth in Information and Communication Technology (ICT) in recent years have transformed how economic activities are performed across the globe. According to the World Bank (2024) report, digital technology has enhanced access to information and reduced transaction costs, leading to better educational attainment, labor force participation, income, consumption, and welfare. The rising middle class in the majority of developing economies has led to the increased usage of the Internet for knowledge, payment, and other online activities. As per the International Telecommunications Union (2023) statistics, the world gained 1.5 billion new internet users between 2018 and 2022. The COVID-19 epidemic accelerated the growth of internet users in middle-income countries. ICT leads to innovation and is inclusive with a marked spillover effect on different sectors of the economy. High and middle-income countries have experienced this

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potential through the use of IT-enabled services. According to the World Bank (2024), the IT services segment has grown twice as fast as compared to the global economy. The report states that "the total value added of the ICT sector exceeded US$6.1 trillion in 2022, representing around 6% of global GDP." ICT can also transform human lives by changing the way they think and behave. It can significantly improve people's lives worldwide and have an impact on the growth of human capital in the economy by extending its sphere of influence to important sectors like health and education.

This study examines the effect of ICT on HDI for the BRICS (Brazil, Russia, India, China, and South Africa) economies for the years 2000–2022 in light of these trends. The choice of BRICS stems from the fact that these countries have large markets, a rising middle-class population, and reasonably developed digital infrastructure, which can further help them delve into the new dimensions of human development and economic growth (D'silva, 2022). Governments in these countries have focussed on developing a base of digital public infrastructure that can help them attain the targets of sustainable development goals (SDGs) and thus help achieve inclusive growth. For example, the Indian government launched a program (Pradhan Mantri Jan Dhan Yojana) for universal access in 2015. This cleared the path for the launch of digital insurance, DBT, UPI, and other payment systems (Thakur, 2022). The introduction of these programs helped people to use digital platforms in all sectors of the economy. India's National Digital Communications Policy (Ministry of Electronics and Information Technology (MEITY), 2018) promotes the development of the digital economy and focuses on the further development of digital infrastructure and the use of big data and AI.

The study also focuses on other control factors like gender inequality, carbon emissions, economic growth, and population growth, which may impact the development of human capital in these economies. All these factors concern the BRICS economies, especially carbon emissions. According to Wang and Huang (2023), BRICS countries collectively represent a sizable portion of the global economy and have witnessed significant economic expansion throughout the years. The BRICS nations have a considerable impact on global energy, which can be attributed to the large populations and availability of cheap labor in these countries. Together, they account for around 38% of world carbon dioxide equivalent (CO2) emissions, contributing significantly to total global CO2 levels. This, in turn, can lead to environmental degradation, leading to pollution, and a greater incidence of climate disasters. Hence, this study uses CO2 as a control variable and analyses its impact on HDI.

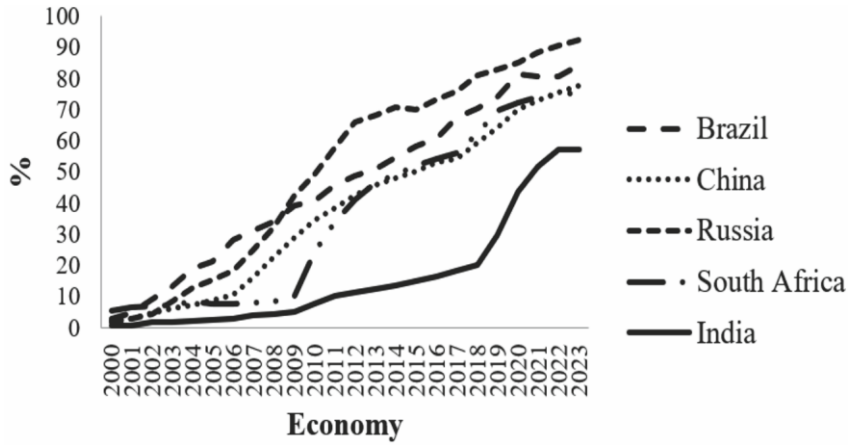
Trends in ICT Infrastructure – BRICS Countries

ICT infrastructure, along with digital payments, e-commerce, digital services, the use of digital data, and infrastructure based on artificial intelligence, have transformed the shape of the economies worldwide (Ansari & Jamaluddeen, 2023). The case of the five BRICS countries is particularly interesting as they have a large, untapped potential to build a digital economy. They have large markets with the rising middle class, which can accentuate digital adoption and pave the way for future transformations in the digital world.

This section analyzes the trends in ICT developments in the BRICS countries. The quality of digital infrastructure can be assessed based on access to Mobile broadband coverage, smartphone/mobile phone usage, Internet access, the cost and speed of the Internet, and the frequency of digital payments (Kakkad & Jadhav, 2021). A more relevant concept of digital adoption is "Universal and Meaningful Connectivity" (A4AI, 2022; International Telecommunications Union, 2023). To be meaningfully connected, a person must be able to use the Internet frequently and own a gadget that is suitable for the digital age to stay connected and have access to sufficient data and quick connections. This facilitates the integration of inclusive digital societies.

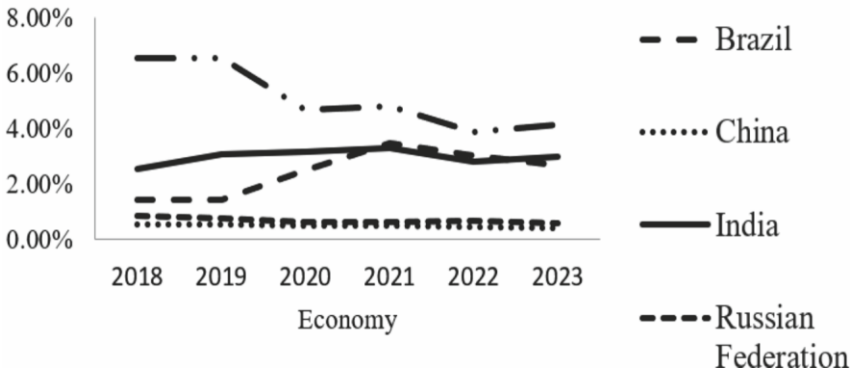
In this regard, the BRICS countries' tendencies indicate that a growing number of people are using the Internet in these economies as a result of cheaper and easier access. After the epidemic in 2020, when lockdowns around the world increased the use of digital services, the growing tendency became especially apparent (see Figures 1 and 2).

Figure 1. ***Individuals Using the Internet (%)***



Source : International Telecommunications Union, ITU DataHub, 2024.

Figure 2. ***Price of Broadband Services as a Percentage of Gross National Income per Capita – Fixed Broadband***

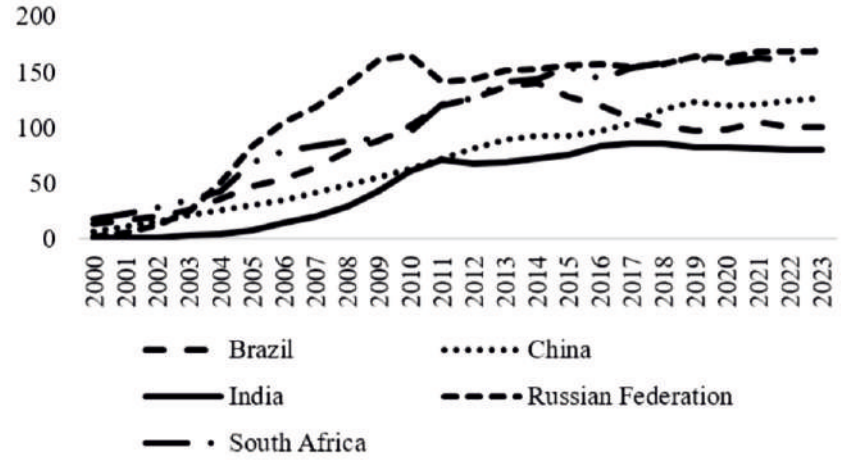


Source : International Telecommunications Union, ITU DataHub, 2024.

The percentage of mobile devices in the GDP of each of the BRICS nations is steadily rising. While fixed telephone subscribers show a diminishing tendency (Figure 4), their mobile cellular subscriptions have shown an increasing trend as mobiles have become the most significant instrument for connectivity worldwide (see Figure 3). According to Kemp (2024), mobile has become the most preferred medium for using the Internet. However, the cost of broadband services in all five countries remains below the global average (International Trade Centre, 2022). The countries are substantially covered by the 4G mobile technology, which also emerges as the most important technology in these countries. However, there has been a significant shift in these countries toward the 5G technology. China and Brazil show the fastest increase toward 5G technology, while India, China, and Russia have made slow progress (see Figure 5). BRICS countries have fast Internet speeds, with China being the leader in the group. However, as per the International Telecommunications Union (2023), the internet speeds in these countries are still below the global average.

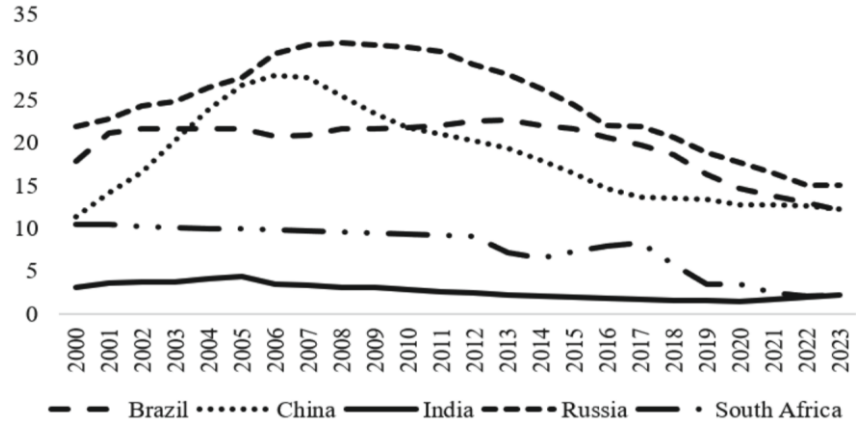
Along with ICT access, digital services are also used extensively for transactions, receiving salaries and wages, remittances, paying utility bills, and e-commerce (Singh et al., 2022). Figure 6 illustrates how, in comparison to 2017, there was significant growth in the usage of ICT for digital transactions in 2021 (Demirguc-Kunt et al., 2022). However, only China and Russia have made substantial progress in using digital payment and transaction methods. As of 2021, India's performance within the group has not improved considerably. The use of

Figure 3. ***Mobile Cellular Subscriptions (per 100 People)***



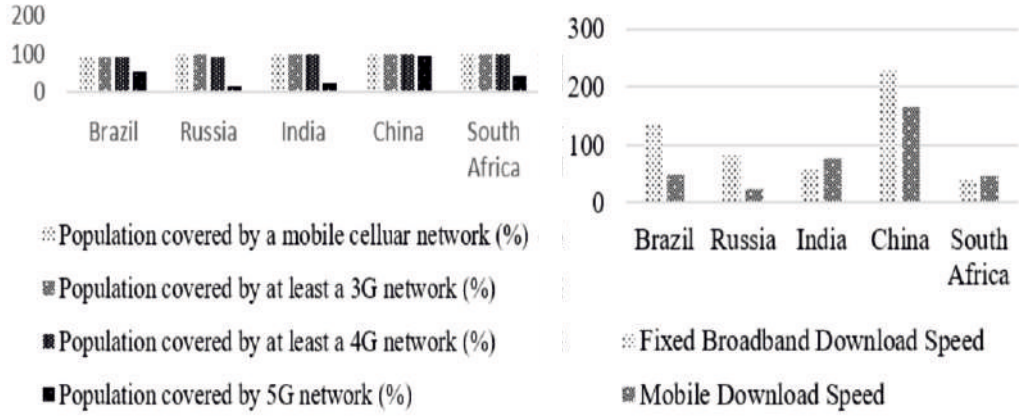
Source : International Telecommunications Union, ITU DataHub, 2024.

Figure 4. ***Fixed Telephone Subscriptions (per 100 People)***



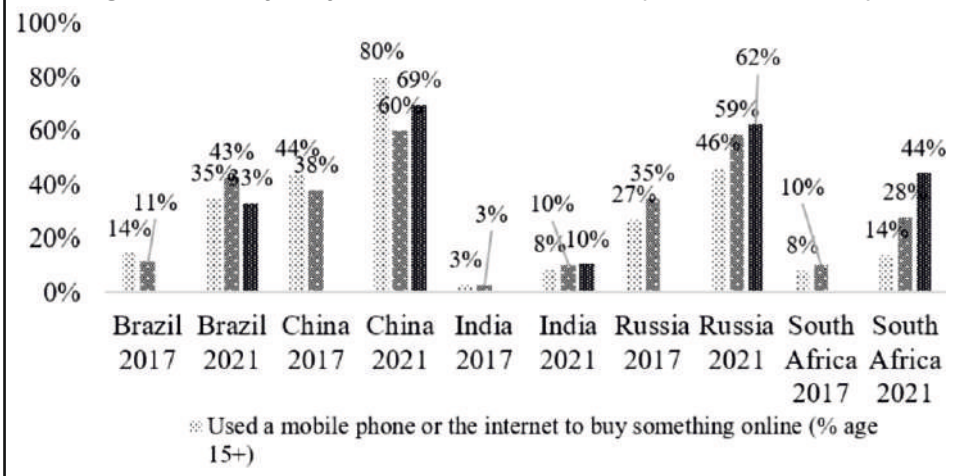
Source : International Telecommunications Union, ITU DataHub, 2024.

Figure 5. ***Mobile Technology and Internet Speeds in BRICS – 2024***



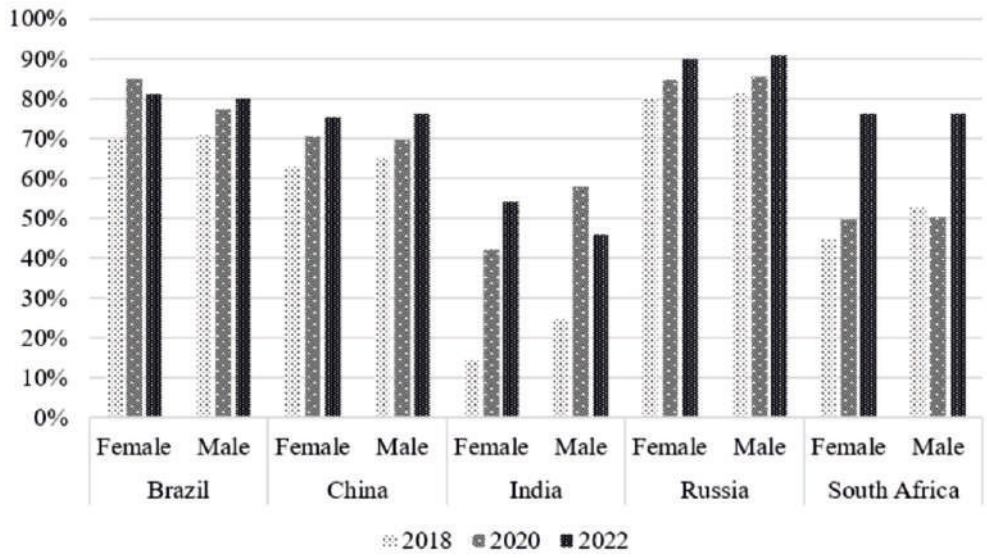
Source : World Bank (2024).

Figure 6. ***Use of ICT for Transactions – BRICS (2017 versus 2021)***



Source : World Bank Global Findex Database, 2021.

Figure 7. ***Gender Disparity in Internet Use – BRICS***



Source : International Telecommunications Union, ITU DataHub, 2024, Internet and Mobile Association (IAMAI) Report India, various issues and Research ICT Africa reports on gender divide and ICT.

high-speed Internet facilitates improvements in digital payments in these countries, the use of smartphones/mobile phones, and stringent cyber security laws adopted (ITU, 2023).

There are, however, gender and regional disparities that exist in these countries that can harm their human development and growth. Figure 7 suggests that the gender gap in Internet use in all five countries has narrowed down significantly from 2018 to 2022. Further correction of these inequities is required, as women's increased usage of ICT or IT-enabled services contributes to the goal of inclusive growth.

Similar regional differences exist; in Brazil, 82% of Internet users are found in urban regions in 2022, whereas 72.4% of users are found in rural areas. China's Internet users in rural areas made up 57% of the total in 2021, compared to 82% in metropolitan areas. India also revealed a difference in internet usage between rural and urban

areas, with 41% of users in the former and 71% in the latter. Russia, however, has comparatively fewer geographical differences.

The goal of "Internet for all" or "Universal and Meaningful Connectivity" is limited by gaps in ICT access and use, which hinders economic progress.

The affordability of digital services remains the biggest obstacle to accessing and using ICT services, especially in countries like India and South Africa. Governments need to work cohesively and cooperatively to reduce ICT pricing.

Another constraint in the efficient and universal adoption of ICT is knowledge and digital literacy. According to Demirguc-Kunt et al. (2022), the percentage of individuals who can use a bank account at a financial institution without help is 59% for Brazil, 44% for Russia, only 26% for India, 62% for China, and 51% for South Africa. Similarly, individuals who can use a mobile money account without help from a mobile money agent are 16%, 6%, 11%, and 21% for Brazil, India, China, and South Africa respectively. This research employs gender inequality, GDP, carbon emissions, and population growth as control variables to objectively analyze the influence of ICT on HDI in the BRICS countries between 2000 and 2022.

Literature Review

The linkages between human development, ICT growth, and economic growth have been analyzed in different ways in the literature. There are a plethora of studies that evaluate the above linkage by adding different control variables and conducting them for different sets of countries and regions. Studies may yield different results for different countries (Kazar & Kazar, 2014). The main question addressed by the research that has examined this relationship is whether the expansion of ICTs contributes to the economic growth of the nation or region. Additionally, this has aided policymakers in creating suggestions for accelerating the expansion of the ICT industry in order to achieve the goal of positive economic growth and development.

Numerous studies in the literature suggest that ICT growth has a positive and significant impact on the economic growth of a country (Ahmed & Ridzuan, 2013; Albiman & Sulong, 2017; Donou-Adonsou, 2019; Ghosh, 2017; Latif et al., 2018; Pradhan et al., 2018; Sepehrdoust, 2018; Vu, 2013). The causal relationship between ICT and economic growth is another field of study. Studies in this area include those by Ahmed and Krishnasamy (2012), Chakraborty and Nandi (2011), Pradhan et al. (2016 a, b), Pradhan et al. (2017 a, b), Saidi et al. (2018), and many more. These studies have been conducted for countries such as Singapore, South Africa, India, Japan, Australia, and India. Different regions and groups covered by the studies are MENA, SSA, South Asia, OECD, BRICS, OPEC, East Asian countries, Egypt and Gulf countries, etc.

There are also some studies that, along with economic growth, study the impact of ICT infrastructure on the human development index (HDI). In this section further, there is a brief review of some recent literature in the same respect.

Badri et al. (2019) investigated the impact of ICT on HDI using a panel of 15 developing countries from 2012 to 2017. The estimation results show that ICT has a positive and significant effect on HDI. Gupta et al. (2019) studied the impact of ICT on HDI in the South Asian Region over the period 2000–2016 by employing panel fixed effects. The empirical analysis's findings point to a significant positive correlation between HDI and internet penetration, technological readiness, and mobile usage.

Azam et al. (2021) analyzed the linkages between ICT, renewable energy, economic growth, and human development indices with CO_2 emissions and remittances as control variables from 1990 to 2017 in 30 developing countries. They use the panel vector autoregressive (PVAR) model and find that a causal relationship exists between ICT, renewable energy, economic growth, and HDI. The study also suggests a unidirectional causality from HDI to ICT. Bhattacharya (2021) found a positive and significant impact of ICT on HDI for both high and medium HDI countries during the period 2001–2018.

Zheng and Wang (2022) investigated the impact of ICT and renewables on HDI by using static and dynamic panel models for 26 countries for the period 2000 and 2018. They also use other factors, including carbon dioxide emissions, renewable energy production, economic growth, and population. They find an insignificant impact of renewables on ICT both in the short-run and long-run. The impact of ICT on HDI is positive in the short run but becomes insignificant in the long run. Together, ICT and renewables affect ICT in the long run. They also found a positive impact on economic development and a negative impact on HDI from carbon dioxide emission.

Ebrahimi et al. (2022) studied the impact of ICT and other economic policy variables on the economic growth of the MENA group for the period 2010–2017 using a panel-GMM technique. One of their results suggested that a 1% increase in the ICT Development Index (IDI) caused economic growth to increase by 0.175%. Behera and Sahoo (2022) examined the relationship between ICT, globalization, and human development in India using data from 1991 to 2019 by employing the non-linear autoregressive distributed lag (NARDL) model. They hypothesized an asymmetric nature of the relationship in India. Their findings indicate that, over time, there is a positive correlation between ICT indicators and human development and a negative correlation between globalization and human development.

Saba et al. (2023) conducted a study to analyze the nexus between economic growth/development and ICT infrastructure for 73 countries from 2000 to 2018. Their panel consisted of regions such as sub-Saharan Africa (SSA), the Middle East and North Africa (MENA), and Latin America and the Caribbean (LAAC). They suggest a long-run equilibrium relationship between the variables by applying panel vector autoregression (PVAR) utilizing the generalized method of moments (GMM) estimate strategy. The results show that ICT is more widely used in MENA countries' economic development and growth.

Latif et al. (2023) analyzed the direct and indirect effects of ICT on environmental quality. A modified environmental Kuznets curve (EKC) is explored in this study, which incorporates data for the BRICS economies from 1996 to 2020. In Brazil, China, and South Africa, but not in India or Russia, the authors uncover a strong relationship between finance, the environment, and ICT. Hammed and Ademosu (2023) investigated the nexus between ICT innovation, FDI, and economic growth for BRICS countries between 1990 and 2021 using autoregressive distributed lag (ARDL) techniques. According to their analysis, ICT regularly and significantly raises the rate of economic growth in the BRICS nations.

The present study differs from the existing studies and analyzes the impact of ICT on human development for BRICS countries for the period 2000–2022. The reason for choosing BRICS countries is that these countries have a huge potential in the ICT infrastructure sector, especially India and South Africa, which can, in turn, have a significant impact on growth in the world economy. In light of the literature examined, we incorporate variables such as the HDI index, ICT, real GDP per capita, gender inequality index, carbon emissions per capita, and rate of population growth. The expected relationship between these variables and HDI and the empirical model is explained in Section 4.

Empirical Model

In light of the literature reviewed, the empirical model in the paper investigates the long-run cointegrating relationship between ICT, HDI, economic growth, carbon emissions, gender inequality, and population for five BRICS countries over the period 2000–2022. Despite the significant impact of socio-economic factors on HDI (Fadillah & Setiartiti, 2021), the effects of ICT infrastructure and environmental quality on HDI are relatively less explored, especially for BRICS countries. Evidence from the literature suggests that ICT infrastructure is expected to positively affect the HDI as ICT devices and their use for the acquisition of knowledge, information, transactions (e-commerce), and other purposes help in improving the standards of living, acquiring more skills and making the everyday lives more satisfying (Zaremohzzabieh et al., 2014). According to Mansha et al. (2022), increasing gender inequality contributes negatively to human development. This is because an increase in the

value of GII indicates rising disparities between females and males, which can be a setback for the growth and development of the economy (Campbell et al., 2021).

Further, economic growth is also posited to affect human development positively (Kuswanto, 2021). The nature of this relationship is bidirectional (Chiappero-Martinetti et al., 2015) for both theoretical and policy considerations. Control variables such as the rate of growth of the total population affect human development positively (Tripathi, 2021).

Finally, in the present scenario, it is observed that environmental degradation and climate change consequences tend to affect human development negatively. This could have health impacts (due to pollution, natural calamities, etc.), financial loss, and other harmful effects that could destabilize the development objectives of an economy.

In light of this discussion, the paper postulates the following empirical model to study the long-run cointegrating relationship between ICT and HDI along with economic growth, carbon emissions, gender inequality, and population growth. Table 1 explains the expected signs for each explanatory variable.

$$HDI_{it} = f(ICT_{it}, RGDP_{it}, GII_{it}, CO2_{it}, PG_{it}) \quad (1)$$

where,

HDI = Human Development Index,

ICT = Information and Communications Technology Index,

RGDP = per Capita Real GDP (a proxy for economic growth),

GII = Gender Inequality Index,

CO2 = Carbon dioxide emissions per capita,

PG = Rate of growth of population.

Table 1. ***Expected Signs of the Variables***

Variable	Expected Sign
ICT	+
RGDP	+
GII	–
CO2	–
PG	+

Econometric Methodology and Data

Methodology

As a first step, we construct an ICT index using the method outlined in the ICT Development Index report, 2024. The information and communication technology index is constructed using ICT indicators such as Mobile-cellular telephone subscriptions per 100 inhabitants, Fixed-telephone subscriptions per 100 inhabitants, percentage of individuals using the Internet, and Broadband subscriptions per 100 inhabitants. The effects of various units are eliminated by normalizing a subset of the indicators. This is accomplished by rescaling all indicators to a common range of 0 to 100 by applying the min–max technique. The formula used in this approach is as follows:

$$score_{i,w} = \frac{value_{i,w} - min_i}{max_i - min_i} \quad (2)$$

where $score_{i,w}$ refers to the normalized score of the economy w's value for indicator i. minimum and maximum values of the indicator are the threshold and target values of the variable, respectively.[1]

From now on, all indications will be given equal weights in order to generate an overall score for the ICT index in accordance with the International Telecommunications Union (2024). In the lack of definite conceptual and statistical explanations, this aggregation strategy appears reasonable (International Telecommunications Union, 2024). The resulting ICT score is a variable in our model.

As a second step, the paper applies panel techniques such as cointegration, fully modified OLS (FMOLS), and panel Granger causality to study the impact of ICT and economic growth on HDI. The static panel methods, such as fixed and random effects, are inappropriate here as they do not control for endogeneity in the data. Furthermore, cross-sectional heterogeneity is not taken into account by dynamic panel techniques like system GMM and difference GMM, which presume homogeneity among variables.

Within this step, the study first carries out first-generation panel unit root tests based on (Levin et al., 2002; Maddala & Wu, 1999) and second-generation tests (Pesaran, 2007). The first-generation tests do not allow for cross-sectional dependence in the data, while the second-generation test allows for it. In case of non-stationarity of variables, the long-run relationship between variables can be tested using the panel cointegration tests. The study then conducts residual-based tests of panel cointegration based on (Kao, 1999; Pedroni, 1999, 2004).

Next, a long-run cointegration relationship is estimated using the group-mean FMOLS panel cointegration technique (Pedroni, 2004). FMOLS is a semi-parametric technique that controls for endogeneity and serial correlation in panel estimation and produces heteroscedasticity and autocorrelation-consistent estimators of a long-run covariance matrix. The study uses a group mean FMOLS technique that makes FMOLS adjustments to each member of the panel individually and then computes the average of the corresponding cointegrating estimators.

Lastly, the Granger Causality test is conducted using pairwise Dumitrescu Hurlin Panel Causality Tests based on (Dumitrescu & Hurlin, 2012).

Data

The present study uses a panel of five BRICS countries (Brazil, Russia, India, China, and South Africa) for the period 2000–2020. For this analysis, the variables used, definitions, transformations, and sources are described in Table 2.

Table 2. ***Data Description and Sources***

Variable	Definition	Transformation done in the study	Source
HDI	**Human Development Index :** It is a measure of economic development in an economy and is calculated by computing an average of indicators such as a long and healthy life, being knowledgeable, and having a decent standard of living. The index is computed as a geometric mean of normalized indices for all three dimensions.	None	https://hdr.undp.org/
ICT	**Individuals who use the Internet (%) :** This refers to the percentage of people who used the Internet over a fixed or mobile network from	None	https://datahub.itu.int/

[1] As suggested by International Telecommunications Union (2024) the present study uses a threshold value of 0 for all 4 variables. For % of internet users, a target value of 100% is used. For the rest of the variables, a 95th percentile value is used as a target.

	any location throughout the last three months.		
	Active mobile-broadband subscriptions (per 100 inhabitants) : Refers to the sum of active handset-based and computer-based (USB/dongles) mobile-broadband subscriptions that allow access to the Internet.	Log Transformation before normalization	https://datahub.itu.int/
	Mobile-cellular subscriptions per 100 inhabitants : Refers to public mobile telephone services that use cellular technology to connect to the PSTN. The number of postpaid subscriptions and active prepaid accounts is divided by the population and multiplied by 100.	Log Transformation before normalization	https://datahub.itu.int/
	Fixed-telephone subscriptions per 100 inhabitants : The sum of active analog fixed-telephone lines, voice-over-IP (VoIP) subscriptions, fixed wireless local loop (WLL) subscriptions, ISDN voice-channel equivalents, fixed public payphones, and satellite-based subscriptions provided to fixed locations for voice communication, divided by population and multiplied by 100.	Log Transformation before normalization	https://datahub.itu.int/
RGDP	**Real GDP per capita :** Real GDP (constant 2010 US$) (billion dollars).	Log Transformation	https://databank.worldbank.org/
GII	**Gender Inequality Index :** Proposed by UNDP, the Gender Inequality Index (GII) provides insights into gender disparities in health, empowerment, and the labor market. Higher values in the GII signal worsening inequalities between the female and male populations.	None	https://hdr.undp.org/
CO2	Total carbon dioxide emissions per capita (production) (tonnes).	None	https://hdr.undp.org/
PG	Population growth rate (%).	None	https://databank.worldbank.org/

Empirical Analysis and Results

The using the econometric methodology discussed in the previous section. We first construct an empirical model provided in the previous section is estimate an ICT development index using the methodology described above. The ICT index thus obtained is used as an explanatory variable in Equation 1. Next, the panel unit root tests are conducted, and all the series are found to be nonstationary and integrated of order one ($I(1)$)[2]. Since the individual series are integrated into order one, we can then test for a long-run cointegrating relationship between the variables. Table 3 presents the result of the residual-based tests for panel cointegration. There may be a long-term cointegrating link between the variables, according to the results shown in the table. As a result, the group-mean estimation should be chosen over the pooled estimation to account for cross-sectional variability. The results in Table 4 show that the model fails the slope homogeneity test.

As suggested earlier, the estimation of the cointegration vector can be done using the group-mean FMOLS estimation technique (see Table 5). The group-mean FMOLS estimation results indicate that the HDI, ICT, economic growth, per capita carbon emissions, gender inequality, and population growth rate have a long-term

[2] The results of panel unit root tests are not included in the paper for the sake of brevity.

Table 3. ***Panel Cointegration Tests : Residual-Based Methods***

Statistic	Model
Kao Cointegration Test	
Modified Dickey–Fuller *t*-statistic	–1.367*
Dickey–Fuller *t*-statistic	–1.349**
Pedroni Cointegration Test	
Phillips–Perron *t*-statistic	–2.175**
Augmented Dickey–Fuller *t*-statistic	–1.568**

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

Table 4. ***Testing for Slope Heterogeneity (Pesaran & Yamagata, 2008)***

Null: *Slope Coefficients are Homogeneous*	**Model**
Test Statistic	7.458***

Note. *** $p<0.01$

Table 5. ***Panel Cointegration Estimation***

(Dependent Variable : Human Development Index)

VARIABLES	FMOLS(GM)
ICT Index	0.126***
	(0.031)
RGDP	0.110***
	(0.015)
GII	–0.112***
	(0.040)
CO2	–0.100***
	(0.037)
PG	0.063**
	(0.031)
Number of Countries	**5**

Note. Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

cointegrating relationship. The expected signals are provided in Table 2, and the results are consistent with economic theory. The estimation results suggest that ICT has a positive and significant impact on HDI. This is plausible because BRICS nations possess huge potential for the development of an economy powered by digital infrastructure. These countries have quite large markets in the domestic economy with a rising middle class. These countries have also developed digital public infrastructure through various government initiatives in various economies, and they are prepared to take the next step toward artificial intelligence, cutting-edge technologies, and data-dependent strategies to maximize efficiency and capture significant portions of the developing digital economy. In countries like India and South Africa, the younger cohort of the population is expanding, which is more skilled digitally and may help in an upward spiral in the digital development of the economy. China and Russia, on the other hand, may face a downward trend due to their demographic profile of a rising older population in the former and a stagnant population in the latter (International Trade Centre, 2022).

Table 6. ***Dumitrescu - Hurlin Panel Granger Causality Tests***

Variable	Null: X does not Granger Cause HDI
ICT Index	6.792***
RGDP	5.703***
GII	1.507
CO2	4.301*
PG	3.288*

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

The positive impact of economic growth on HDI suggests that as the economies progress, they tend to accumulate wealth, increase expenditure, and invest in technological innovations. An increase in income of people will widen their choices and will thus increase human development (Ranis, 2004). The HDI and gender inequality have a negative association, indicating that wider gaps between male and female socioeconomic norms will undermine efforts to empower women as well as the more general purpose of attaining human and, therefore, economic development. As a result, the human development score will decrease as the index value increases. Furthermore, carbon emissions impact HDI negatively owing to the harmful effects of environmental degradation on the health, finance, and social satisfaction of individuals.

Finally, the paper conducts a test for Granger causality in panel data in the presence of cross-sectional heterogeneity, as shown in Table 6. The null hypothesis assumes no causal relationship between the variable and HDI for any of the cross-section units, and the null hypothesis is rejected for all the variables except GII. This implies that gender inequality insignificantly Granger causes HDI. A significant bivariate causality exists between ICT, GDP per capita, population growth, and HDI. However, the direction of causality is from CO2 emissions to HDI and not vice versa.

Conclusion and Policy Implications

The objective of this study is to analyze the effect of ICT infrastructure on HDI in BRICS countries for the period 2000–2022. To conduct this analysis, the study uses several control variables, such as GDP per capita, gender inequality, population growth, and carbon emissions per capita in each country. An ICT index is constructed using the weighting and aggregation methodology used in the International Telecommunications Union (2024). The approach combines four key indicators, such as the percentage of internet users, mobile-cellular subscriptions, fixed-telephone subscriptions, and broadband subscriptions in these countries, to create an ICT index.

The paper finds a long-run and significant relationship between HDI and these variables. The study corrects for heterogeneity in panels by using the grouped-mean FMOLS estimation technique. The findings imply that GDP per capita and ICT have a positive and considerable impact on HDI. Nonetheless, the HDI is significantly and negatively impacted by gender inequality and carbon emissions. Significant causation between the HDI and variables like ICT, GDP per capita, population growth, and carbon emissions per capita is shown by Granger causality results. Granger's HDI has not been linked to gender inequality.

The study has some important implications for BRICS countries. Since these countries exhibit greater potential to drive rapid expansion of digitalization in the global economy, they should further cooperate to reduce the digital divide, improve digital governance, and devise ways to measure the digital economy. The study also suggests greater public-private cooperation in these countries to continuously help innovate new digital technologies. The orientation of new technology should be focused on green innovations that can also help mitigate the harmful effects of environmental degradation.

Limitations of the Study and Scope for Further Research

The present study gives us useful insights into the effect that ICT products and services may have on human development. Every empirical study has its limitations. The biggest limitation of this study is the availability of data. There is an absence of long historical data for ICT indicators in most countries. Thus, the choice of ICT infrastructure variables is constrained by data for all five countries. Some countries like India and South Africa also do not have data for some indicators for the most recent periods. Hence, there needs to be some work on data collection in the future to make the study more broad-based. This work can be further extended to analyze the impact of ICT on the sub-components of human development, like education, health, and employment generation.

Author's Contribution

The idea of the paper, data extraction, literature review and empirical estimations were solely done by the author, Dr. Deepika Goel, herself.

Conflict of Interest

The author certifies that she has no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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