Journal of Economics and Behavioral Studies (ISSN: 2220-6140)
Vol. 15, No. 2, pp. 20-32, June 2023

# ICT Innovation, FDI and Economic Growth: Evidence from BRICS

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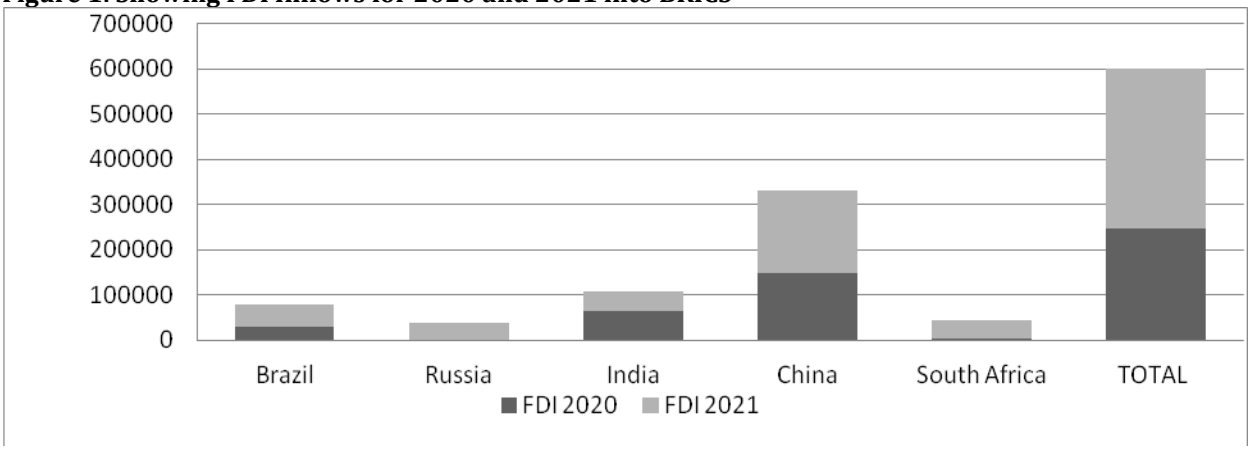
**Abstract:** We make a comprehensive investigation of ICT innovation, FDI and economic growth nexus for BRICS countries for the periods between 1990 and 2021 using autoregressive distributed lag (ARDL) techniques. We use input-based ICT and non-ICT resources to capture ICT innovations, foreign direct inflows, gross domestic product and quantity of labor for this economic bloc. From our estimation, the following summary can be made. ICT is found to be consistently and significantly contributing to the economic growth rate of BRICS countries. However, with the negative impact of FDI on the growth rate, its interaction with ICT input resources was found to help mitigate the negative impact of FDI on economic growth which by implication suggests that adequate ICT infrastructure complemented with foreign-oriented investment can play a formidable role in increasing the growth process of the economies of BRICS. Also, non-ICT input resources and quantity of labor growth rate were found to be necessary variables worthy of giving appropriate consideration in explaining the growth rate of the economies. The study thus suggests the higher provision of both ICT and non-ICT input resources in the BRICS and a policy to attract able hands from developing countries to turn various resources for economic progress.

**Keywords:** *ICT input resources, FDI, economic growth and BRICS.*

## 1. Introduction

In its high-level dialogue on global development, the BRICS countries emphasize the need for high investment in ICT and digitalization of the economy as part of formidable measures to stabilize their economies after the COVID-19 pandemic (BRICS summit, 2022). Before this period, specifically in their 2016 summit, BRICS countries were made aware of the importance of strengthening exchanges and trade cooperation among BRICS through a decisive effort towards developing ICT sectors in the BRICS. In a way to make this achievable, China (as one of the BRICS) soar to the position of making supporting policies, investing in the digital economy and sharing experiences for member countries (BRICS report, 2016 and Huang & Huang, 2018). There is now overwhelming evidence confirming the efforts of these countries in the development and high level of investment in information and communication technology in their countries (Faisal et al., 2020; Khan et al., 2022).

**Figure 1: Showing FDI Inflows for 2020 and 2021 into BRICS**




Aside from ICT infrastructure for the growth rate of BRICS, the importance of foreign direct investment to the BRICS economies has been re-iterated in the literature (see Latif et al., 2018 and Soomro et al., 2022). In the Fact sheet of the United Nations Conference on Trade and Development for 2022, stock of FDI inflows for the

four countries out of five rose respectively in the following order: Russia, by 16.2%; India, by 7.1%, China by 7.6% and South Africa, by 30.2%. The percentage for Brazil was rather found to fall by -0.4%. As for the nominal value of the FDI inflows[1] and the growth rate between the year 2020 and 2021, China remains number one in terms of value, but least in terms of growth rate. By growth rate, South Africa has the highest rate while the rate for India was negative for the year (see WIR, 2022). The forgoing however suggests the efficacy of FDI and ICT in ensuring improved economic growth for the BRICS' economies. Given the works of Latif et al. (2018) and Soomro et al. (2022), one can infer that some contributions can still be made with respect to the FDI-ICT-growth nexus for the BRICS countries. Existing literature offers evidence that the joint impact of both FDI and ICT has some implications for economic growth (see Adedoyin et al., 2020).

When the positive impact of FDI outweighs its negative impact (through environmental degradation), we will expect its overall impact on the economy to be positive and with the presence of ICT infrastructure, the impact could rather become more pronounced, otherwise the outcome could go in the opposite. It then becomes a necessity to verify this stance in the case of BRICS. Additionally, we give credence to both ICT input-based resources and non-ICT input-based resources with an available quantity of labor resources. By so doing, we account for the level of utilization of both resources with the available quantity of labor resources in the BRICS bloc. From the methodological approaches of the previous studies (i.e., OLS, FMOLS, DOLS and GMM), they mainly account for long-run analysis. However, our choice of estimation which is largely ARDL accounts for the relationship between FDI-ICT and growth for the BRICS in the long run and the short-run periods. Having information about the short-run behavior, in this case, is highly necessary as it will offer us the extent to which any shift, in the long run, can be adjusted and as a way to put the economy back in the right direction. These are the plausible contributions that this study makes to the existing body of literature.

We can therefore make a quick recap of our findings. We found ICT to be consistently contributing positively and significantly to the economic growth rate of BRICS countries, while FDI was found not to have been properly annexed to energies economic growth. Also, non-ICT input resources and quantity of labor growth rate are found to be necessary variables worthy of giving appropriate consideration in explaining the growth rate of the economies in this bloc. Additionally, the interaction of ICT and FDI growth rate is found to help mitigate the negative impact of FDI on economic growth which by implication suggests that adequate ICT infrastructure complemented with foreign-oriented investment can play a formidable role in increasing the growth process of the economies of BRICS bloc. The remainder of this study is thus structured as follows. After this section, we present a brief literature review in section 2 and we deal with methodology in section 3. Section 4 presents a preliminary analysis of our model and a summarized stylized fact on the variables of concern is presented in section 5. The main result together with the results from the alternative methodology and conclusion are respectively presented in sections 6 and 7.

## 2. Literature Review

Generally, literature on ICT-Growth nexus for BRICS can be categorized into three strands. The first strand focuses on the impact of ICT on economic growth (see Tariq and Tayba, 2018 and Fiodorov and Ochara, 2019) while the second strand extends the literature tentacle to investigating the joint impact of ICT and FDI in mitigating or contributing to the environmental pollution (see Haseeb et al., 2019; Bhujabal et al., 2021 and Khan et al., 2022). An additional strand has rendered effort in verifying the extent to which ICT can contribute to an increase in foreign flows into the BRICS countries (see Latif et al., 2018 and Soomro et al., 2022). We also have some works that investigate Digitalization and health nexus for BRICS (see Jiang et al., 2022). In this study, our objective is rather to re-investigate the extent to which ICT input and non-ICT input can contribute to an increase in foreign capital investment for the BRICS countries and the spillover effect on domestic economic growth. Given this view, our review in this section will solely dwell on studies that have dabbled into investigating the dynamics between ICT and FDI with respect to the economic growth of BRICS. In attempting this course, we notice very scarce studies in this regard.

We hereby review them, by paying attention to their focus and area of weakness, which this study lingers on to contribute. Attributing the economic growth and FDI inflows to investment in ICT, Latif et al. (2018)

[1] figure 1 compares the FDI inflows for 2020 and 2021 respectively

investigate to evaluate the dynamics connection between ICT and Growth in the presence of other variables such as globalization and FDI inflows for BRICS countries for the periods between 2000 and 2014. The study proxies ICT with the composite index of information and communication technology which is derived through landline telephones, mobile phones, internet service, internet users and fixed broadband. Given the approach of OLS with fixed effect and additional methodologies (FMOLS and DOLS); they are able to come to terms that ICT contributes positively to economic growth while both FDI and globalization equally have a long-run impact. The study by Ulucak et al. (2020) investigates the nexus between ICT and economic growth while recognizing the role of globalization in BRICS economies in the period 1990 and 2015. They find a positive relationship between CO2 emissions and ICT. The study further accounts for the role of coal rents in ICTs and FDI in promoting the industrial revolution. However, while recognizing the important role of coal rents, ICTs and FDI on economic growth, they also consider the dampening effect of ICTs on FDI under the 4.0 industrial scenarios. Adedoyin et al. (2020) have also looked into the connection among air transportation, ICT, energy resources, FDI and growth in the United States. They particularly investigate the causal and long-run relationship among these variables and their relevance to the fourth industrial revolution (4.0 industrial).

Also, Jiang et al. (2022) have also investigated the impact of digitalization and green technology on the health outcome of BRICS countries for data spanning the periods between 1993 and 2019. With the aid of ARDL, it is revealed by their study that digitalization often leads to increasing life expectancy for BRICS members except Brazil but for the green technology, its impact is only found for Russia and China in the long run. Also, GDP and health expenditure contribute to health improvement for most BRICS countries in both runs. Soomro et al. (2022) have equally paid attention to investigating the dynamics relationship between FDI, ICT, trade openness and growth for the BRICS countries for the periods between 2000 and 2018. The study captures economic growth with Gross Domestic Product while telephone subscriptions, mobile subscriptions, broadband subscriptions, internet subscribers and secure internet savers were used to proxy ICT. With the GMM results, it was found that ICT has a positive effect on the growth for many of the BRICS countries while at the same time both trade openness and foreign direct investment cause the growth to decline. In the earlier period, Bhujabal et al. (2021) focused on the examination of the effect of FDI and ICT in causing environmental pollution in the BRICS countries. The data applies to the studies run from 1990 to 2018 and the methodological approach is pooled mean group and causality test. Their finding reveals that ICT and FDI affect environmental pollution negatively. By implication, rising ICT decreases environmental pollution significantly. On the causality, the study found the existence of causality between ICT and FDI for the concerned countries.

Sapuan and Rolly (2021) have also examined the contribution of ICT diffusion with FDI in promoting economic growth for ASEAN countries. They applied annual data from 2003 to 2017 using panel regression. The outcome of their findings gives significant importance to FDI and ICT in causing growth and development in the economies of ASEAN countries. The focus of Chien et al. (2021) is on investigating the role of ICT in mitigating the environmental effect on the growth of the BRICS economies using quantile regression. The data is annual between 1995 and 2018. The study finds that information and communication technology is effective in controlling the impact of environmental degradation on economic development at a lower emission quantile. Ofori and Asongu (2021) equally pay attention to the role of ICT (computed as usage, access and skill) and FDI with respect to inclusive growth in the sub-Sahara report. Within the period 1980 and 2019, FDI and ICT are found to exert a significant role and induce a significant portion of growth in the region. Zafar et al. (2022) critically investigate the link between ICT, tourism and trade in ensuring the environmental sustainability of BRICS countries. The data coverage for the study spans between 1990 and 2018 with cross-sectional autoregressive distribution lag (CS-ARDL). The outcome of the finding suggests a greater impact of tourism and trade on growth while ICT is found to help in accelerating a sustainable environment among the BRICS economies.

Ha and Huyen (2022) focused on the impact of digitalization in influencing foreign investment across the European region, during the time of COVID-19 pandemic. The study uses data from 23 European countries from the pre-COVID-19 era (2015 to 2019) and during the time of COVID-19 (2020) in estimating the impact of digitalization on the region. It is found that digitalization is more critical in promoting FDI flows before the crisis and these roles enhance trading activities through electronic media in the time of COVID-19 pandemics. Along the same line, Belloumi and Touati (2022) find evidence on how FDI inflows and ICT have affected the

economic growth of selected Arab countries using panel ARDL with data spanning from 1995 to 2019. It is revealed that both ICT and FDI inflows have positive and significant effects on economic growth in the long run while ICT indicators have a positive impact on FDI inflows in the long run for the selected Arab economies. In a related work, Renesa (2021) examines the impact of the COVID-19 pandemic on digital intensity and digital maturity in the ICT sectors of the Nordic countries. These countries are Finland, Denmark, Norway and Sweden. By the outcome of the analysis from the study in relation to the performance of each of the countries during the pandemic, it is found that despite the negative impact posed by the COVID-19 pandemic, the Nordic countries do better in using their level of digital transformation, digital innovation and financial capability of ICT to handle the COVID-19 situation.

**Theoretical Guide:** Virtually all growth theories have one or two things in common regarding the relationship between foreign capital, technological progress and economic growth. They all indicated a channel through which foreign variables and ICT can possibly be related to economic growth. For instance, the neoclassical model discussed the importance of capital accumulation in the growth process of an economy and emphasized the exogeneity of the parameter of growth which is said to be determined outside the model. This applies to other models such as neoclassical theory with a somewhat different approach. However, the endogenous model is quite distinctive, given the nature and the role attached to ICT and foreign capital. It recognizes two types of capital: the physical and the human capital. The physical can either be domestically generated or derived from foreign countries. The distinctive nature of the endogenous growth model gives credence to the economy's savings as a way of generating investment activities. When savings are sufficient enough and much higher to produce optimum investment for the economy, the excess could flow out to foreign economies in the form of foreign investment. In the same way, there is a possibility of having a shortfall of savings in the home country for needed investment activities.

The difference in the saving-investment ratio gives rise to seeking international savings to bridge the gaps and provide the opportunity for the economy to thrive. International saving of this nature is regarded as foreign capital flows, which in this case include foreign direct investment. This theoretical framework has been very famous with the AK model, developed by Frankel (1962) and which was modified by Pagano (1993). It has also been extended by Bailliu (2010), Adeola (2017) and Gabriel et al. (2019) in explaining finance-growth nexus. In this case, the aggregate output is a linear function of aggregate capital stock and technological progress of the form: $Y_t = AK_t$ (1)

This is a standard growth function, where $Y_t$ is the total output in period (t), $K_t$ is the stock of capital in period (t) which is a combination of physical and human capital; and A is the technological progress of an economy (or sometimes refers to as the total factor productivity). The assumptions that are often made are: (i) that there is a constant return to scale; and (ii) that the economy produces only one good which is either consumed or invested. By assumption one, output is expected to grow at the same rate as capital stock.

In this model, we do not have to neglect human capital because by the endogenous growth model capital and labor are augmented by additional inputs in the production function, and by implication, it involves ICT. However, to align our focus on FDI and ICT as the subject matter in this study, we will assume human capital to be constant, thus we have:

$$Y_t = f(AK_t, 1) \quad (2)$$

By implication, equation 3.2 reduces the source of growth in the economy to changes in the stock of capital. However, the assumption that the economy is investing in only one type of good while holding that capital stock is depreciating in every period (t) at a rate of $\rho$ will leaves gross investment to

$$I_t = K_{t+1} - (1 - \rho)K_t \quad (3)$$

This equation implies that total investment at period (t) equals the change in capital stock (new capital stock) plus the replaced capital due to wear out. By assuming further that the economy is closed, all domestic savings equals investment.

$$\vartheta S_t = I_t \quad (4)$$

If all domestic savings are invested, then the parameter $1 - \vartheta$ equals the charges by the financial intermediary for financial services rendered.

In this case, $\vartheta$ will refer to the proportion of savings left for investment purposes. To analyze the growth rate of output in this model of closed economy where investment depends on domestic savings, we have:

$$g_y = A\left(\frac{I}{\gamma}\right) - \rho = A\vartheta\gamma - \rho \quad (5)$$

From this equation, $g_y$ the growth rate of output $\gamma$ is the saving rate and A is the route through which technology can find its course on the economy. If we allow foreign capital into this model, the economy becomes open and foreign investors are allowed to interact and invest in the economy. In our case, through aggregate FDI, equation 3.5 becomes

$$\rho(S_t + FDI_{t,i}) = I_t \quad (6)$$

Where $FDI_t$ is the foreign direct investment at period (t), and for the country (i) $S_t$ is the domestic savings and $I_t$ is the total investment. With this, the steady-state growth rate becomes:

$$g_y^* = A^*\vartheta^*\gamma^* - \rho \quad (7)$$

With foreign direct investment and ICT input base, it is expected that $g_y^*$ will be greater than $g_y$ , $\gamma^*$ will be greater than $\gamma$ and by implication $I_t^*$ will be greater than $I_t$. The equation above shows how FDI and ICT (input-based) can contribute to the long-run growth of an economy. Rest on this, our empirical specification can be made by integrating FDI, ICT input-based and non-ICT input based into the equations.

## 3. Methodology

Again, our attention to this study is to investigate the impact of ICT input resources and FDI on the economic growth of BRICS. We further add non-ICT input resources and quantity of labor in the models. Our choice of methodology, given the features exhibited by our variables, is ARDL. Hence the functional equation model for this study can be presented as follows:

$$GDP\_GR_{t,i} = F(ICT\_GR_{t,i}, FDI\_GR_{t,i}, NICT\_GR_{t,i}, LQT_{t,i}) \quad (8)$$

Where $GDP\_GR$ is the GDP growth rate, $ICT\_GR$, $FDI\_GR$, $NICT\_GR$ and $LQT$ are respectively growth rate in ICT input resources, foreign direct investment, non-ICP input resources and growth rate of labor quantity for the BRICS countries. Further description of variables of choice with sources is provided in Table 1. We can then present our basic model as follows using the ARDL approach.

$$\begin{aligned}\Delta gdp\_gr_{t,i} = {} & \alpha_0 + \rho gdp\_gr_{t-1,i} + \beta_1 ict\_gr_{t-1,i} + \beta_2 fdi\_gr_{t-1,i} + \beta_3 nict\_gr_{t-1,i} + \beta_4 lqt\_gr_{t-1,i} \\ & + \sum_{r=1}^{r-1} \delta_{1,r}\Delta gdp\_gr_{t-1,i} + \sum_{r=1}^{s-1} \gamma_{1,j}\Delta ict\_gr_{t-1,i} + \sum_{j=0}^{w-1} \gamma_{2,j}\Delta fdi\_gr_{t-1,i} + \sum_{j=0}^{x-1} \gamma_{3,j}\Delta nict\_gr_{t-1,i} \\ & + \sum_{J=0}^{y-1} \gamma_{4,j}\Delta fdi\_gr_{t-1,i}\,\epsilon_t\end{aligned} \quad (9)$$

$$\begin{aligned}\Delta gdp\_gr_{t,i} = {} & \alpha_0 + \rho gdp\_gr_{t-1,i} + \beta_1 ict\_gr_{t-1,i} + \beta_2 fdi\_gr_{t-1,i} + \beta_3 (ict_{gr} * fdi_{gr})_{t-1,i} + \sum_{r=1}^{p-1} \delta_1 \Delta gdp\_gr_{t-1,i} \\ & + \sum_{r=1}^{r-1} \gamma_{1,j}\Delta ict\_gr_{t-1,i} + \sum_{j=0}^{w-1} \gamma_{2,j}\Delta fdi\_gr_{t-1,i} + \sum_{v=1}^{s-1} \delta_{3,r}\Delta (ict_{gr} * fdi_{gr})_{t-1,i} + \epsilon_t\end{aligned} \quad (10)$$

This is ARDL $(r, s, y, w, x, z)$ where $\Delta$ is the first stage of differentiation and $\epsilon_t$ is the white noise error term. From the equation above, the short-run impact is captured by $\gamma_1$, $\gamma_2$ and $\gamma_3$ with respect to each of the variables while the long-run impact is represented by $\frac{\beta_1}{1-\rho}$, $\frac{\beta_2}{1-\rho}$, $\frac{\beta_3}{1-\rho}$ and $\frac{\beta_3}{1-\rho}$ respectively for ICT, FDI, NICT and LQT. The ECM term is thus captured $1-\rho$ in this analysis. For a more comprehensive analysis of the derivation of the ARDL model of various orders, see Salisu (2022)[2].

[2] This can be found using this link: https://www.researchgate.net/publication/363534421.

**Table 1: Variable Description**

| s/n | Variable | Measures | Sources |
|---|---|---|---|
| 1 | GDP_GR | Growth of GDP, change in the natural log | CBTED |
| 2 | ICT_GR | Growth of capital services provided by ICT assets, change in the natural log. | CBTED |
| 3 | NICT_GR | Growth of Capital Services provided by Non-ICT Assets, change in the natural log | CBTED |
| 4 | FDI_GR | Growth rate of Foreign Direct investment inflows | Macro trends |
| 5 | LQT | Growth of Labor Quantity, change in the natural log | CBTED |

**Preliminary Analysis:** We devote our attention to giving information about the features exhibited by our variables of consideration for this study. Essentially, we focus on the implication of the presence of information and communication technology and activities of foreigners in terms of foreign investment in influencing the economic growth of BRICS countries for the period between 1990 and 2021. By implication, we consider the growth rate of GDP for these countries and the growth rates in ICT-based input and foreign direct investment. We further consider non-ICT input, the total quantity of labor and other variables like productive capacity index for information and communication for these countries for robustness checking in this study. The data for FDI is sourced from macro trends - an online database on FDI for over 150 countries[3] while data for other variables is sourced from conference board total economy data (CBTED).[4] Going by the information in Tables 2 to 7, the average growth rate for GDP in the entire BRICS is 3.9 for the period between 1990 and 2021 with a slightly high dispersion level of 4.76, negatively skewed (-1.04) and moderately peaked, having a value that is higher than the threshold (5.16).

This value is higher than the growth rate value for Brazil, Russia and South Africa (with respective growth rate values of 2.02, 1.58 and 2.0) but lower than that for China and India (which are 8.67 and 5.66 respectively). This implies that the average economic growth rate for China and India combined is higher than the rate for the entirety of BRICS. The growth rate for ICT input for BRICS is 19.21, higher than any other in the respective individual countries, except for China and South Africa with a growth rate of 25.72 and 20.28 respectively. This rate is highly dispersed (value of 12.13 for BRICS) and negatively sloped. As for the kurtosis, it peaked at the value of 4.98 and is statistically normal. The information about the non-ICT input shows that its average value is 4.32 with a standard deviation of 4.28 (highly dispersed). It is positively skewed and moderately flat with a value that is very close to the threshold of 3 (the value of 2.85). For this variable, the growth rate for China is highly exceptional (a value of 10.2) while that of Russia, on average was negative. There are 32 observations for each country and this makes 160 observations for the entire BRICS.

**Table 2**: **Descriptive Statistics for BRICS**

| Variables | Mean | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | Prob. | Observations |
|---|---|---|---|---|---|---|---|
| GDP_GR | 3.8823 | 4.7641 | -1.0402 | 5.1644 | 60.0850 | 0.0000 | 160 |
| ICT_GR | 19.2073 | 12.1252 | -0.7342 | 4.9850 | 40.6441 | 0.0000 | 160 |
| FDI_GR | 7.1189 | 31.8870 | 5.2191 | 39.0021 | 9367.3850 | 0.0000 | 160 |
| NICT_GR | 4.3168 | 4.2847 | 0.2018 | 2.8528 | 1.2301 | 0.5406 | 160 |

**Table 3**: **Descriptive Statistics for BRAZIL**

| | Mean | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | Prob. | Observations |
|---|---|---|---|---|---|---|---|
| GDP_GR | 2.025000 | 2.967 | -0.566 | 2.796 | 1.766 | 0.414 | 32 |
| ICT_GR | 15.27188 | 6.317 | -0.430 | 2.018 | 2.271 | 0.321 | 32 |
| FDI_GR | 0.246165 | 0.588 | 1.039 | 3.828 | 6.673 | 0.036 | 32 |
| NICT_GR | 2.443750 | 1.153 | 0.065 | 2.392 | 0.516 | 0.772 | 32 |

[3] This information can be accessed using the link: www.macrotrends.net
[4] See https://www.conference-board.org/data/economydatabase/index

**Table 4: Descriptive Statistics for RUSSIA**[5]

| | Mean | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | Prob. | Observations |
|---|---|---|---|---|---|---|---|
| GDP_GR | 1.576 | 5.656 | -0.941 | 3.269 | 4.368 | 0.113 | 32 |
| ICT_GR | 11.855 | 13.804 | -0.946 | 3.335 | 4.458 | 0.108 | 32 |
| FDI_GR | 0.386 | 0.899 | 0.951 | 3.019 | 4.368 | 0.113 | 32 |
| NICT_GR | -0.448 | 2.768 | -1.053 | 2.765 | 5.428 | 0.066 | 32 |

**Table 5: Descriptive Statistics for INDIA**

| | Mean | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | Prob. | Observations |
|---|---|---|---|---|---|---|---|
| GDP_GR | 5.6645 | 3.3336 | 0.2551 | 1.8172 | 2.2124 | 0.3308 | 32 |
| ICT_GR | 6.7857 | 1.4643 | 0.0019 | 1.8869 | 1.6521 | 0.4378 | 32 |
| FDI_GR | 1.0395 | 3.2768 | -2.7149 | 16.8580 | 295.3692 | 0.0000 | 32 |
| NICT_GR | 1.2727 | 0.8548 | 0.5440 | 2.9814 | 1.5788 | 0.4541 | 32 |

**Table 6: Descriptive Statistics for CHINA**

| | Mean | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | Prob. | Observations |
|---|---|---|---|---|---|---|---|
| GDP_GR | 8.659 | 2.529 | -0.124 | 3.329 | 0.227 | 0.893 | 32 |
| ICT_GR | 25.719 | 9.784 | 0.487 | 2.662 | 1.416 | 0.493 | 32 |
| FDI_GR | 0.168 | 0.366 | 3.170 | 12.103 | 164.075 | 0.000 | 32 |
| NICT_GR | 10.409 | 2.287 | -0.335 | 2.673 | 0.741 | 0.690 | 32 |

**Table 7: Descriptive Statistics for SOUTH AFRICA**

| | Mean | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | Prob. | Observations |
|---|---|---|---|---|---|---|---|
| GDP_GR | 2.003 | 2.507 | -1.325 | 5.557 | 18.083 | 0.000 | 32 |
| ICT_GR | 20.278 | 8.504 | 0.527 | 2.801 | 1.535 | 0.464 | 32 |
| FDI_GR | 2.737 | 7.639 | 3.241 | 13.846 | 212.887 | 0.000 | 32 |
| NICT_GR | 2.534 | 1.376 | 0.155 | 2.575 | 0.370 | 0.831 | 32 |

**Stylized Facts: GDP, FDI and ICT for the BRICS:** In this section, we present some stylized facts for the BRICS in relation to essential variables in this study. This includes GDP, foreign direct investment and ICT input resources between 1990 and 2022. The BRICS bloc contains five countries with similar economic structures among emerging economies. They are Brazil, Russia, India, China and South Africa. In this stylized fact, we categorized our discussion into three decades. The first runs from 1990 to 2000 and the second, from 2001 to 2010. The last decade covers 2011 to 2021. In the first decade, the growth rate in GDP for China was the highest (a value of 9.36). This is followed by that India with a growth rate value of 5.63 while the least was that of Russia which was even negative (-3.84). As for the ICT growth rate in this decade, India was the first with a rate of 32.02 and China was the second with 29.0. This was immediately followed by South Africa with a value of 25.25 and the least was for Russia, around -8.15. In terms of the FDI inflows into these countries, Brazil had about 0.46 growth rate with an average value of $1.10 million, this is far higher than that of India and South Africa put together ($0.95 million). However, the average value of FDI inflows for China was $1.77 million, higher than the inflows of Russia, South Africa and India altogether ($1.75 million).

As for the value of GDP for these countries, China has the highest with a value of $936 million, followed by Russia, India, Brazil and South Africa with respective values of $696, $562, $283 and $225. In the second

[5] The data for Russia started from 1993 and the values for 1990 to 1992 were generated by finding the average of five periods ahead of the concerned period (e.g., for 1990, average of values for 1993 to 1997 and so on)

decade, all of them perform better than in the first decade. For instance, China's growth rate for GDP rises to 10.03 as against 9.36 in the previous decade. For India, it was 7.09 from a value of 5.63 for the previous year. As for the input ICT, its growth values fall for countries like South Africa [from 25.15 to 20.9] and India [from 32.02 to 27.92]. By absolute value, the average values of GDP for all these countries are $1003, $709 and Russia, $634. In the last decade, the performance of all these variables could have been more striking if not for the COVID-19 pandemic. For instance, the average growth rate for South Africa was 1.13 instead of 1.99, if we control for the COVID-19 pandemic. As for the growth of FDI stock, all of them had positive growth rates for the year 2021 except for the case of Brazil with a growth rate of -0.4. The graphical representation of our variables in Figures 2 to 6 also indicates similar patterns for GDP and ICT input resources and the impact of the COVID-19 pandemic was very obvious with a sharp fall in this period. However, the negative growth recorded by Russia in terms of GDP growth rate and ICT in the first decade could be possibly attributed to the defunct USSR from where Russia erupted which could be termed as a period of recovery after the breakaway while the high level of technological innovation and huge human capital resources could partly explain exceeding performance of China in this bloc.

**Figure 2: Co-Movement among Variables for Brazil**

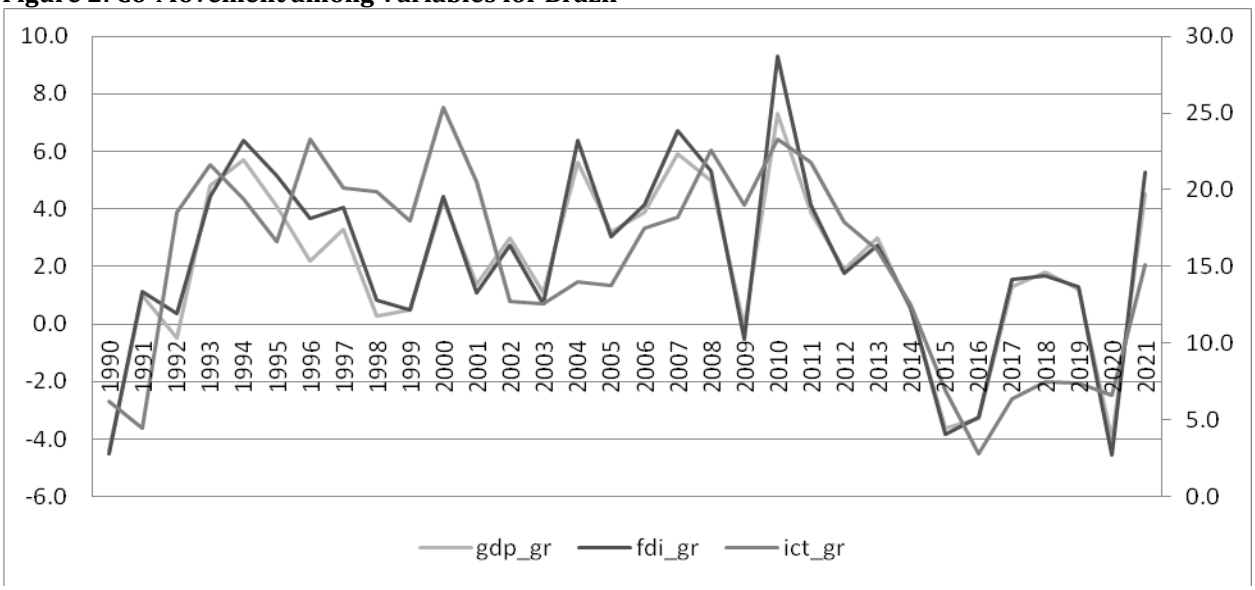



**Figure 3: Co-Movement among Variables for Russia**

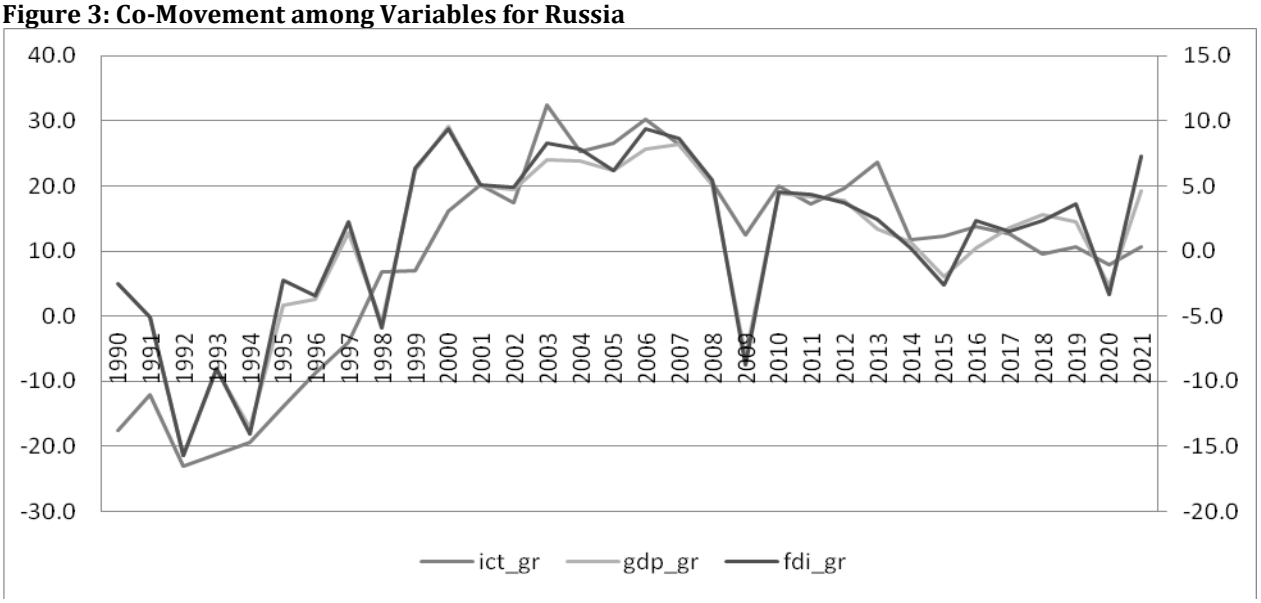


**Figure 4: Co-Movement among Variables for India**

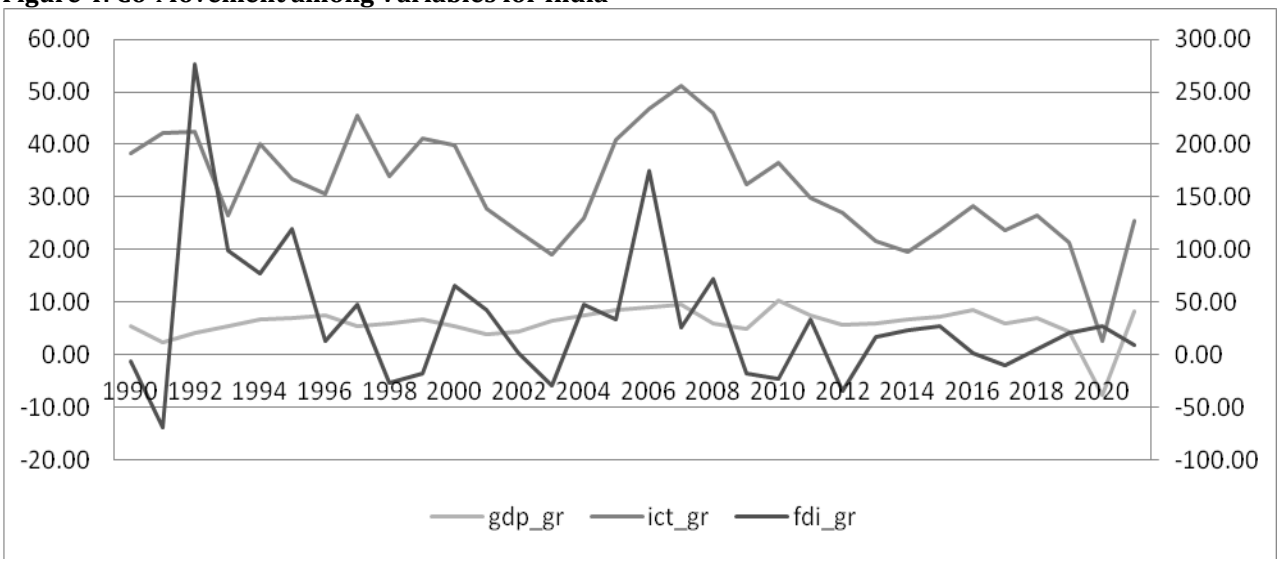



**Figure 5: Co-Movement among Variables for India**

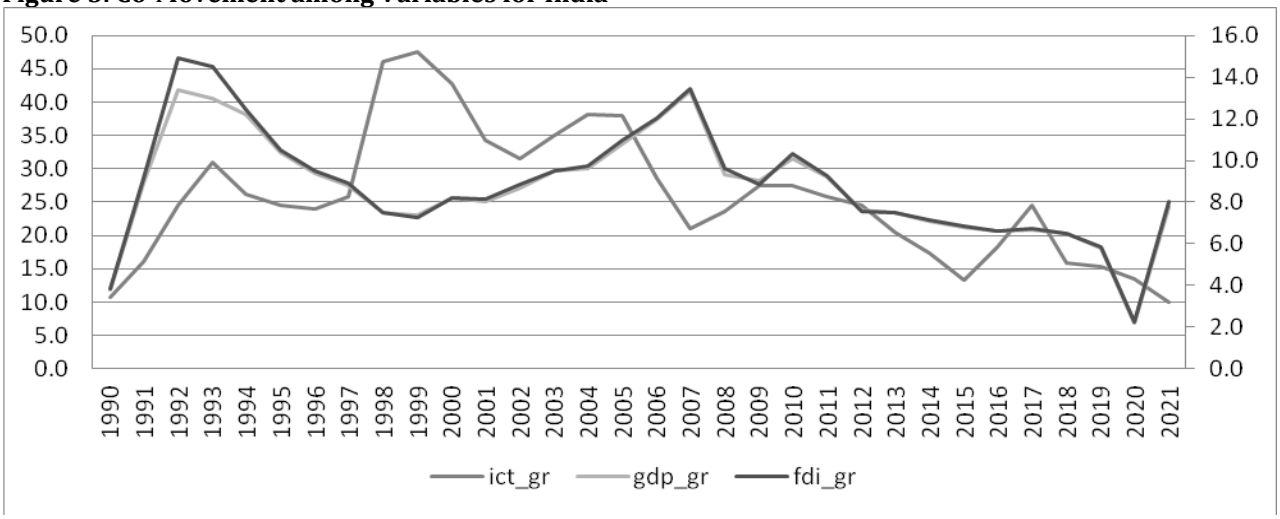
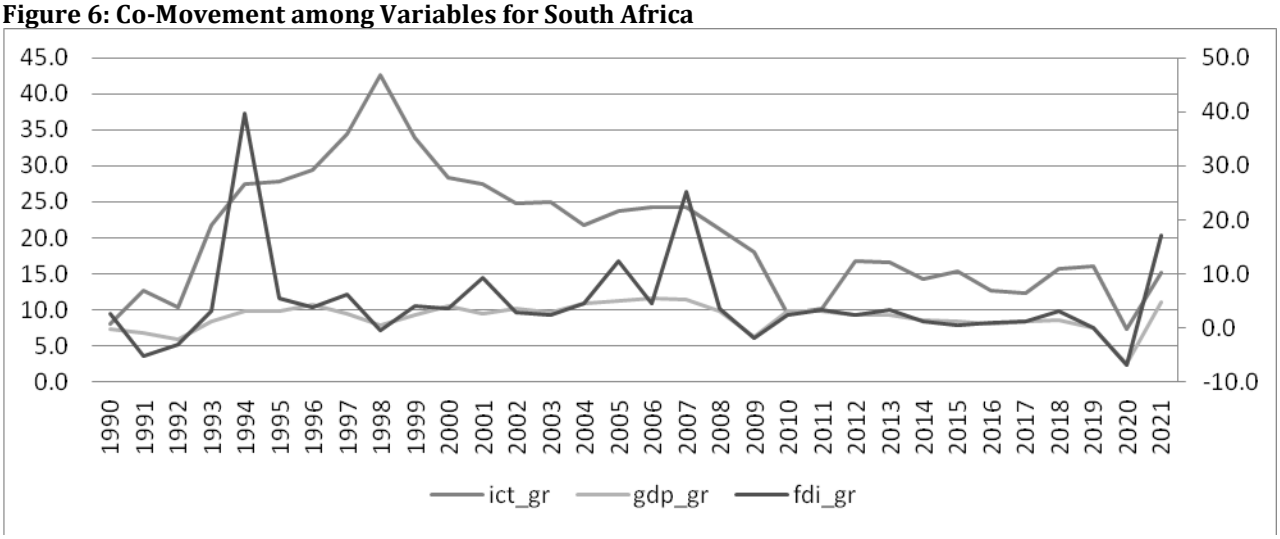



**Figure 6: Co-Movement among Variables for South Africa**



## 4. Results and Discussion

**Unit Root Test:** As a form of pretest for our estimation, we test for both the unit root and co-integration analysis for our variables. As shown in Table 8, we use varieties of the method to test for the unit root for our variables which include Levin, Lin and Chu (LLC), Im, Pesaran and Shin (IPS), Augmented Dickey-Fuller (ADF) and Philips Perron Fisher (PP). The results indicate that our variables are a combination of I(0) and I(1) variables. For instance, the GDP growth rate is I(0) while the ICT growth rate is I(1). Given this feature, the appropriate model that has the ability to capture this scenario is the ARDL model. Hence, our estimation is done with the ARDL estimation technique. However, another requirement for using ARDL is the establishment of a long-run relationship among the variables of choice; as such we carry out the Pedroni co-integration test. The null hypothesis of no co-integration is tested against the alternation of the presence of co-integration. The results as shown in Figures 9 and 10 rather suggest the presence of co-integration among our variables.

**Table 8: Unit Root Test**

| Variable | LLC | | IPS | | ADF | | PPF | | |
|---|---|---|---|---|---|---|---|---|---|
| | LEVEL | FD | LEVEL | FD | LEVEL | FD | LEVEL | FD | Remarks |
| GDP | -1.7649[b] | -3.5292[a] | -3.0294[a] | - | 26.2901[a] | - | 50.613[a] | - | I(0) |
| ICT | -0.82575 | -5.5487[a] | -1.41484[c] | -6.6440[a] | 14.7162 | 59.976[a] | 14.3461 | 91.672[a] | I(1) |
| FDI | -4.2316[a] | - | -5.4942[a] | - | 48.316[a] | - | 87.192[a] | - | I(0) |
| NICT | -0.3550 | -3.4337[a] | -0.7871 | -5.3530[a] | 11.167 | 47.584[a] | 9.3418 | 59.614[a] | I(1) |
| LQT | 0.4036 | 1.9824 | -3.5740[a] | -11.705[a] | 31.991[a] | 112.78[a] | 112.08[a] | 141.89[a] | I(1) |

**Table 9: Co-Integration Test (I)**

| Alt. hypothesis: common AR coefs. | (within-dimension) | | | | (between-dimension) | | |
|---|---|---|---|---|---|---|---|
| | Statistic | Prob. | Weighted Stat | Prob. | | Statistic | Prob. |
| P- v-Statistic | 0.0889 | 0.4646 | -0.2024 | 0.5802 | G- rho-Stats | -3.3309 | 0.0004 |
| P- rho-Statistic | -4.1518 | 0.0000 | -3.8529 | 0.0001 | G- PP-Stats | -7.5472 | 0.0000 |
| P- PP-Statistic | -7.1516 | 0.0000 | -6.5021 | 0.0000 | G- ADF-Stats | -3.7533 | 0.0001 |
| P- ADF-Statistic | -4.1184 | 0.0000 | -3.5272 | 0.0002 | | | |

**Table 10: Co-Integration Test (II)**

| Phillips-Peron results (non-parametric) | | | | | Augmented Dickey-Fuller results (parametric) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cross ID | AR(1) | Variance | HAC | Bandwidth | Obs | AR(1) | Variance | Lag | Obs |
| Brazil | 0.0760 | 3.8163 | 3.8163 | 0 | 31 | 0.2790 | 3.7193 | 1 | 30 |
| Russia | -0.0390 | 10.4760 | 9.1803 | 2 | 31 | -0.2630 | 10.2792 | 1 | 30 |
| India | -0.0250 | 6.3303 | 5.4912 | 3 | 31 | -0.2700 | 6.1822 | 1 | 30 |
| China | 0.1860 | 2.2156 | 2.3136 | 1 | 31 | 0.1370 | 2.0197 | 1 | 30 |
| south_africa | -0.0580 | 3.6788 | 2.4212 | 6 | 31 | -0.2210 | 3.7188 | 1 | 30 |

**Main Result:** In this estimation, we present four distinct models. In model 1; we estimate the impact of ICT growth rate and FDI growth rate on the Growth rate of Gross Domestic Products for the BRICS. The results indicate a significant and positive impact between ICT and GDP while the impact between FDI and growth rate was negative, though significant. With a one percent increase in ICT growth rate, the GDP growth rate rises by 0.27% while FDI falls by 0.95%. What we can infer from here is that many BRICS countries are rather involved in giving out innovations to other countries and not in many receivers of technological innovation from the rest of the world. In this regard, they make much use of their available ICT input for the growth process of their economy. Also, having a negative impact from FDI on economic growth is not strange in the literature. Adedoyin et al. (2020) came out with similar finding for the case of the US economy and it has

equally been offered that such a pernicious effect of FDI has accounted for more than 11% of findings on the FDI-growth nexus, which rather suggest a state of educational attainment, quality of the institution or the nature of the concerned FDI inflows (Bruno and Campos, 2013 and Agbloyor et el., 2016). In the second model, we introduce one more variable to test for the efficacy of our previous model. In such a way, we combine both input-based ICT and Non-input-based ICT with FDI with respect to the growth rate of GDP. Again, the impact of ICT and FDI remains unchanged while the impact of non-input-based ICT is found to be positive and significant.

By implication, with a one percent change in non-input-based ICT, the GDP growth rate will rise by 0.73%. In another choice of model, as presented in Table 11 where we introduce labor input, we equally found the impact of labor quantity to be positive and significant. In other words, with labor quantity combined in a single model where we have ICT input, non-ICT input and FDI growth rates, the labor quantity growth rate will contribute significantly positively to the positive. With a one percent increase in labor quantity, GDP will rise by 0.203%. Our last model is a replicate of model one, but in this case, we introduce an interactive term between FDI growth rate and ICT growth rate. The interactive term is positive and significant. A one percent increase in both ICT*FDI simultaneously will upgrade the growth rate of GDP by 0.053%. This is a further suggestion that utilization of ICT with foreign-oriented investment will often generate a plausible impact on the growth rate of any BRICS countries. In other words, input-based ICT has some spillover effect in correcting for the negative impact of FDI on the growth rate of GDP (Adedoyin et al., 2020). As a matter of consequence, the BRICS countries should be much more inclined in opting for adequate investment in ICT-based infrastructures for attraction of FDI inflows. With the availability of adequate ICT infrastructure, foreign investors will be enticed to invest in the local economy, which in a way will lead to an increase in economic growth.

**Table 11: Main Model: ARDL (1, 1, 1, 1, 1)**

| Variables | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---|---|---|---|---|---|---|---|---|
| ICT | 0.2693 | 10.1290[a] | 0.048 | 3.562[a] | 0.0575 | 2.526[b] | 0.2253 | 6.8797[a] |
| FDI | -0.9529 | -3.8366[a] | -0.242 | -1.738[c] | -0.4595 | -2.3429[b] | -1.4448 | -4.8527[a] |
| NICT | | | 0.734 | 13.444[a] | 0.3742 | 3.1979[a] | | |
| LQT | | | | | 0.2034 | 2.3777[b] | | |
| ICT*FDI | | | | | | | 0.0534 | 2.3985[b] |
| S-R ECM | -0.5732 | -3.2075[a] | -0.934 | -9.163[a] | -0.7473 | -7.9877[a] | -0.5751 | -3.0140[a] |

**Note:** [a, b] and [c] indicate statistical significance at 1%, 5% and 10% levels respectively.

**Robustness Check:** As a way of ensuring robustness for our estimation, we use an alternative proxy for ICT in our estimation. In this case, we use the productive capacity index for information and communication technology in place of the growth rate of input-based ICT in our main models. As shown in Table A11, at an individual level, PICT now has a negative impact on the GDP, but the interaction of the two variables (i.e., PICT and FDI) is positive and significant in its impact on the economic growth of the BRICS. This fact is retained in both the main models and the alternative choice. This thus gives some level of confidence and robustness for our analysis.

**Table A.11: Alternative Proxy for ICT**

| Variables | Model 1 | | | Model 2 | | |
|---|---|---|---|---|---|---|
| PICT | -0.0504 | -4.3864 | 0.0000 | -0.2122 | -4.9555 | 0.0000 |
| FDI | -0.1830 | -4.1810 | 0.0001 | -0.4740 | -4.3243 | 0.0001 |
| PICT*FDI | | | | 0.0426 | 3.3734 | 0.0012 |
| S-R ECM | -0.7318 | -3.9153 | 0.0002 | -0.7189 | -4.6338 | 0.0000 |

## 5. Conclusion and Recommendations

In this study, we pay attention to the impact of input-based ICT and FDI on the economies of BRICS countries for the periods spanning between 1990 and 2021. Additionally and unlike previous studies, we introduced variables like non-ICT input resources and total quantity of labor in our model. Our choice of methodology (which is ARDL) as suggested by the nature and features exhibited by the series of variables and which account for the long-run relationship among our variables is rather plausible. After satisfactorily testing for the stationarity of our variable and confirming the long-run relationship through a co-integration test, we then estimate our model of choice. In our estimation, we decimate our analysis into four models. For the first model, we use the growth rate of ICT and FDI against the GDP growth rate while we have the addition of non-ICT input resources in the second model. Variable measuring the growth rate in quantity of labor in BRICS is introduced to have model three while we estimate the first model with the additional interactive term between FDI and ICT in our model four. The outcomes from our findings are very striking and can be summarized as follows. One, while ICT consistently contributes positively and significantly to the economic growth rate of BRICS countries, FDI was found not to have been properly annexed to woe economic growth.

This is rather premised on the level of innovation in many of the BRICS countries which is rather to suggest that they are exporters of innovative knowledge rather than importer. Two, non-ICT input resources and quantity of labor growth rate were also found to be necessary variables worthy of consideration in explaining the growth rate of the economic bloc. Three, the interaction of ICT and FDI growth rate was found to help mitigate the negative impact of FDI on economic growth which by implication suggests that adequate ICT infrastructure complemented with foreign-oriented investment can play a formidable role in increasing the growth process of the economies of BRICS bloc. This submission is sustained with a choice of ICT variable. Emphatically, this finding suggests important roles for ICT in the production sector where the addition of foreign factors can bring about economic exploration for the BRICS. Hence, the provision of ICT input is very keen to encourage foreign impact in the process of increasing the growth rate. Also, ICT input resources and non-ICT base input deserve some accolade in this regard and with a high number of the labor force. There is a necessity for the government of each of the countries as investigated here to make adequate funding in the ICT sector which by implication will lead to more available input resources for the labor force.

**Conflict of Interest:** There is no conflict of interest in this study.

**Appreciation:** The authors appreciate the helpful comments of the reviewer which largely contribute to the improvement of this work.

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