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Do technological innovation and financial development affect inequality? Evidence from BRICS countries

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Abstract

While technological innovation and financial development are broadly credited as important drivers of economic growth of developed nations, its impact on inequality (especially in emerging economies) remains understudied. This study employs panel Dynamic Ordinary Least Squares (PDOLS) and panel Fully Modified Ordinary Least Squares (PFMOLS) with annual data sourced from the Standardized World Income Inequality Database, IMF and World Bank (1990-2017) to investigate the impact of technological innovation and financial development on income inequality in BRICS countries. The results suggest that technological innovation increases income inequality in the BRICS nations, while financial development has income reducing effect on inequality. Our results are robust, using alternative estimation with various sub-indicators of financial development (such as financial markets, financial institution), including other measures proxied by access to credit provided by commercial bank.

Keywords: BRICS, PFMOLS, PDOLS, technological innovation, inequality.

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1. Introduction

Regional integration has emerged as the new economic order in fulfilment of economic development (Swarup 2017). Five emerging economies from four continents form a different type of cooperative block called BRICS. BRICS is an abbreviation for the association of emerging economies of Brazil, Russia, India, China, and South Africa. BRICS is not a block of regional integration, it is a block of emerging economics formed to improve their 'strategic position' in an almost unipolar world scenario (Swarup, 2017). All BRICS member countries are fast growing economies which have momentous influence on regional affairs (Rostogic and Gaikwad, 2017). Rapid and high demand growth in recent years has been one of the main reasons behind the rise of BRICS countries (Swarup, 2017). In 2014, BRICS countries account for approximately 40 percent of the total population, 30 percent of the total earth surface and 20 percent of the economics output (Swarup, 2017). In 2019 the GDP of BRICS countries had accounted for 23,5 of the world's total (Zhang, 2021) In addition to that, these five countries hold large reserves of natural resources such as energy and mineral resources, water, and fertile land (Scerri and Lastress, 2013).

Over the last few decades, the BRICS countries have undergone an extreme economic and social changes. In addition to their rapid economic growth, which reaches about 6, 9 in China and 7, 5 in India in 2015 for example, the reduction of inequality in these countries is one of the most conundrums facing these economies (Younsi and Bechetini 2018. The trend of inequality in BRICS countries except Brazil has been increasing since the 1990s following the rapid economic growth (Scerri and Lastress 2013). Rising inequality can push societies to the brink, especially in developing countries where the majority of the population are already living in poverty. Thus, reduction of inequality in this countries is one of the most important issues to preserve their economic, political and social stability (Younsi and Bechetini 2018). All BRICS economies exhibit an increased generation of frontier technological activities (Lacasa, et al., 2019). The technology of these countries (BRICS) has been significantly improved (Zhang 2021). According to the endogenous growth theory, technological progress is the main driving force for economic growth (Liu and Lawell, 2015). However, Kim (2012) argued that technology may both improve and exacerbate the condition of economic equality. On the one hand, technology can contribute to a greater equality by destroying old causes of wealth creation. While on the other hand, it can create more inequality by allowing new method of wealth accumulation. The development of the financial sector of a country can also have an impact on economic growth and its distribution. When the financial sector of any country starts developing through several channels, namely banking and financial services sector, it directly affects the economic growth pattern and consequently, the distribution of income (Destek et al., 2020). According to the financial Kuznets curve hypothesis, the financial development initially led to deterioration in income distribution. However as financial development reaches a certain level where the low-income families will easily access the financial instruments and the income inequality will be reduced (Dogan, 2018).

Although there is a growing body of literature on the relationship between innovation and income inequality (see for Caiani et al. 2016; Liu and Lawell 2015; Agchion et al.2019), the nexus between technological innovation, development of financial sector and inequality, have not been investigated in the BRICS countries. Thus, the main aim of this paper is to examine if technological innovation and development of financial sector improve equality or exacerbate inequality in the BRICS economies. The remainder of this paper is structured as follows: Section 2 provides an overview of the relevant literature on the effect of technological innovation and development of financial sector on income inequality. Section 3 describes the data and the econometric methodology. Section 4 presents the empirical finding. Section 5 draws conclusion.

2. Literature Review

The linkage between technology, financial development and inequality is multidimensional and constantly questioned (Biyase and Chisadza 2023; 1988; King & Levine, 1993; United Nations, 2018; Mbona, 2022). Undoubtedly, income inequality is one of the paramount threats to societal stability (Kharlamova, Stavytskyy & Zarontiadis, 2018). Rising inequality can push societies to the brink, especially in developing countries where the majority of the population are already living in poverty. Nevertheless, global inequality between countries has declined over the past two decades, primarily as a result of key actions taken to boost economies and reduce poverty in developing economies (Roser, 2013; Čihák & Sahay, 2020; World Inequality Lab, 2022).

Economic theory acknowledges that financial development and technical innovation both contribute to economic growth. By examining the performance and operations of the financial markets, banks, bond markets, and financial institutions, one can gauge the depth, scale, accessibility, and soundness of the financial system (Arestic et al., 2001; Stiglingh, 2016). Through an effective and efficient banking sector that discovers and finances profitable investments, a well-developed financial sector plays a critical role in fostering growth and innovation (Schumpeter, 1912). According to Pagano (2013), financial development can enhance economic growth by raising the productivity of investments and reducing transaction costs and thus increase the share of savings channelled into productive investments. Advances in financial sector policies and financial technology enable financial inclusion, allowing poor households and small enterprises to partake more effectively in the formal economy (Čihák & Sahay, 2020).

In reality, financial development is always inclusive of technological innovation. One perspective stem from the classical school of thought which proposes that because of technology and economic institutions, labour efficiency is bound to increase, thereby improving economic performance through increased output (Fourie & Burger, 2012; Knell, 2016). This is known as one aspects of the Solow growth model (Greenhalgh & Rogers, 2010), which to a certain degree stem from Schumpeter's theory (1939) which maintains that a well-developed financial system promotes technological innovation and growth by providing services and financial resources to entrepreneurs with a high probability of successful implementation of innovative products and processes. In other words, financial development could facilitate technological innovation and therefore economic development in general (King & Levine, 1993). This argument is supported by Stiglingh (2015:82): "when the degree of financial development is higher in a country, then the availability of financial services will be wider." In fact, Hicks (1969) argued that financial development played a crucial role in England's industrialisation process through the facilitation and mobilisation of capital. Demirguc-Kunt and Levine (2009) and Mbona (2022) also contends that a well-developed financial sector can absorb the impact on household earnings by letting the poor continue to invest in their human capital rather than choosing less skilled jobs when they experience income shocks.

In the same vein, there is the endogenous approach which to some extend agrees with the classical theory that changes in technology are one of the key contributors to economic growth because of technological externalities which are assumed to be positive such as knowledge transfers (Romer, 1986; Sala-I-Martin, 1997). Marxists were also of the assumption that improving and creating new technology resulted in essential modifications in the structure of the economy (Knell, 2016).

Be that as it may, most of these theories, especially long-run theories, still linked technologically related economic expansion to underlying forces of inequality in society (Freeman, 2000; Maddison, 2007). The one side of the spectrum contends that some of these theories on technology and financial development ignore the most important practical consequence which is characterised by high income and wealth inequality that arises from assumptions they are based on (Ayres, 1953). Hence, technological innovation arising from financial development on the other hand can be regarded as double-edged sword, in the sense that even though it may raise productivity thereby increasing information sharing and growth among others, it may likewise shape employment levels, kinds of employment, wage distribution, and spending patterns, thereby affecting inequality. In fact, early scholarly work (e.g., Jerome 1934; Nelson & Phelps 1966; Schultz 1975) point to the industrial revolution through developments in technology in the early 1900s as having perpetuated social inequality (Krueger 1993; Greenwood, Hercowtiz & Yorukoglu 1997; Goldin & Katz 1998; Caselli 1999). Although it may be important for economies to strive for efficient and innovative financial systems, past financial crises have shown that high financial development may not really be a good thing since economies which were most affected by the 2008 global financial crisis (e.g., Spain, Portugal) were the ones with high financial depth.

Technology influences inequality through its influence on the types of skills an economy needs to fully gain from technological innovation. To explain this, Bogliacino (2014) uses the term ‘skill based technological change’ which implies that technological innovation may favour educated employees over uneducated and unskilled ones, fuelling increased demand by employers for those with higher qualifications and those more skilled (Giri, Pandey & Mohapatra, 2021). At the same time, unskilled and those poorly skilled may find themselves replaced by automation (Kharlamova et al., 2018). This overtime may increase the education premium, thereby widening the income gap between the poor, who are most likely to be uneducated and unskilled, and the rich, who are more probable to be educated and skilled (Zhu & Trefler, 2005; Levine, 2012). This viewpoint was in fact predicted in the mid-1930s, where Jeremy (1934:402) argued that: “in the future there is considerable reason to believe that the effect of further [mechanization] will be to raise the average skill required”.

Another viewpoint stems from technological innovation from a land perspective, because colonial times gave the already wealthy preferential land rights which were large (Farooq & Wegerich, 2014), what the modern times brought was technological innovation that led to an expansion in commercial agriculture, pushing out small-scale farmers out of business, consequently benefiting the already wealthy (Shah, 2008; Rahman, 2012). “In unequal societies, fast wealth accumulation by the elites may put excessive pressure on key natural resources thus affecting the dependent poor population.” (Mirza, Richter, van Nes & Scheffer, 2019:216). This inevitably widens the inequality gap. This entire argument can be regarded as a manifestation of capitalism, whereby capitalistic development excessively fuels inequality since its gains accrue to one portion (wealthy) of the society; not benefiting those most in need (United Nations, 2018).

Economic theory has also examined inequality and technological innovation through the lens of globalisation. Mainstream economics in favour of free capital (financial or otherwise) movement between countries as beneficial to an economy through greater economic efficiency (Weisse, 1998) has also come at the cost of skewed income distribution in developing countries benefiting those at the top, consequently causing widening convergence between the rich and poor countries (Singh & Dhumale, 2000; Blanchard & Willmann, 2011; Sampson, 2014). This meant that poor countries that do not have innovation capacity and the right institutions take long to catch up to their developed counterparts (United Nations, 2021). The next subsection looks at empirical findings on the topic at hand.

2.1 Review of empirical literature

In terms of empirical research, several studies have been done on the link between technology, financial development and inequality and the general results show that not everyone is society will benefit from an improvement in these aspects and even if there are benefits, they will not accrue in the same magnitude.

2.1.1 Technological innovation and inequality

Mirza et al. (2019) conducted a study on technology driven inequality, poverty and resource depletion in developing countries. Using a stylised social-ecological model, they discovered that technological innovation may feed local inequality by its favourable relationship to wealth, which can lead to resource degradation, the collapse of ecological resources, and an unforeseen intensification in poverty. Another study by the United Nations (2018) on technology and inequality in Asia and the Pacific region finds that as technology was on the rise in the last two decades enabling remarkable and sustained economic transformation, almost half of the people in this region were not benefiting from this, whether one looks at access or not. In fact, this brought about more income and wealth inequalities, with the poorer remaining poor, the rich remaining richer and the environment on a degrading path. Through the use of a model featuring biased heterogeneity, factor proportions, and labour market frictions, in their study investigating the impact of technological changes on income inequality in the European Union countries pre and post the global financial crisis, Kharlamova et al. (2018) found that the effect of technology depends on the development status of a country, and also on its existing levels of income inequality. Specifically, their results show that technological development does not deepen income inequality in developed countries such as those Central in the region including the United Kingdom, while countries at the periphery become more affected. Lastly, inequality reactions to technological innovation in countries with already high-income inequality are found to be both positive and negative.

In a critical analysis paper on globalisation, technology and income inequality, Singh and Dhumale (2000) concluded that technology as influenced by the phenomenon of globalisation are both likely to be significant factors in explaining the increased inequality in developing countries. The Auto Regressive Distributed Lag (ARDL) method was used in a subsequent study by Giri et al. (2021) to examine the relationship between technological advancement and income inequality in India between 1982 and 2018. The results showed that there is a positive and significant relationship between technological advancement and income inequality. According to additional VECM conclusions based on the Granger causality method, technological advancement, trade, and financial globalisation all contribute directly and indirectly to income disparity through inflation and economic growth.

When analysing the relationship between income inequality and innovation in the US, Aghion, Akcigit, Bergeaud, Blundel, and Hemous (2019) discovered a strong and positive association between the two. In more precise terms, a rise of 1 percent in technological innovation as indicated by the quantity of patents raises the top 1 percent revenue share.While looking at technology, income inequality and government policy in OECD countries, Kim (2012) found that inequality initially goes down with technological progress and then rises at more advanced stages of technological progress. Lastly, using a newly compiled panel of 51 countries including BRICS over a 23-year period from 1981 to 2003 to investigate the relationship between technology, trade and financial globalisation, Jaumotte, Lall and Papageorgiou (2013) found estimates that support a greater impact of technological progress than globalisation on inequality.

2.1.2 Financial development and inequality

Mbona (2022) used panel data for 120 countries from 2004 to 2019 with GMM estimation to examine the effects of financial sector depth and access on income disparity. According to the study, the breadth and accessibility of the financial sector significantly affects income disparity. In both linear and non-linear models, access to financial institutions was found to reduce income disparity. The results on financial depth as indicated by domestic credit showed a U-shaped trend where initially, inequality is reduced; after a certain point, a rise in financial depth causes income inequality to worsen. In Pakistan, Shahbaz and Islam (2011) looked at the connection between financial development and income disparity. The ARDL bounds testing method of cointegration was used in the study to merge data from 1971 to 2005. The findings demonstrate that while financial instability increases income disparity, financial development diminishes it. Contrary to orthodox literature, they discovered that economic expansion aggravated income distribution, which was made worse by the openness of trade, a crucial feature of globalisation. Kapingura (2017) examined the connection between South Africa's financial industry development and inequality over the years 1990 to 2012. Bank credit to the private sector, which is a broad indicator of financial sector development, as well as a measure of financial inclusion were considered in the study. The results from the ARDL approach show that inclusive financial development lowers the level of inequality in South Africa over the long and short terms. The decline in inequality was more significant when access to ATMs is expanded than when financial depth is.

In 45 emerging market economies between 1987 and 2001, Seven and Coskun (2016) demonstrate that the expansion of the stock market and banks leads to an increase in inequality. The Gini index was considered as a proxy for inequality in the study while financial sector development was measured by ratios of private credit, deposit money bank assets, M3, stock market capitalisation, and turnover on the stock exchange to GDP.

De Haan and Sturm (2017) studied how financial development, financial liberalisation, and banking crises are connected to income inequality using a panel fixed effects model for a sample of 121 countries spanning 1975–2005. Their findings imply that every financial factor variable used in the study increases income disparity even when employing cross-country regressions, random effects, and legal origin as measurement tools for financial development. Chiu and Lee (2019) through a panel smooth transition regression model, looked at the non-linear impacts of financial development and country risks on income inequality across a large sample of 59 countries between 1985 and 2015. The findings show that inequality seem to rise under both unstable economic conditions and stable financial and political environments. They found that financial development can reduce income inequality in high-income nations under stable economic and financial conditions. Furthermore, the results show that for low-income nations, there is a positive correlation between financial development and income disparity. In 180 advanced and emerging market economies, Čihák and Sahay (2020) investigated the empirical relationships between income inequality and financial depth, financial inclusion and financial stability. According to their analysis, financial depth is initially linked to lower inequality, but only up to a certain degree, beyond which inequality rises. They discovered that lower inequality is related to increased financial inclusion. Finally, credit growth is typically higher when inequality is rising. Svirydzenka (2016), Brei, Ferri, and Gambacorta (2018), Nguyen, Vu, Vo, and Ha all support the U-shaped relationship (2019).

To fill the gap in the literature, we adopt a multifaceted financial development index which is a holistic indicator which accurately captures not only dimensions of financial institutions, and financial markets but also three sub-dimensions: access, depth, and efficiency to examine their influences on income inequality in BRICS, thus providing a more comprehensive evaluation than any proxy used in the above-mentioned empirical studies. Second, this study disaggregates the BRICS data into upper-middle income countries (South Africa, China, Russia and Brazil) and lower-middle income countries (India) for the period 1990-2018. This also implies that our data is recent and updated. Thirdly, we use different techniques (Panel Fully Modified Least Square, for robustness check we use Panel Dynamic Least Squares) compared to other empirical studies. The next section of the article looks at the methodological processes followed in the study.

3. Methodology

3.1. Data and model specification

Guided by the extant literature, we incorporate GDP per capita, technical innovation, overall financial development index and its sub-components to examine their influences on the income inequality for Brazil, Russia, India, China and South Africa (BRICS) from 1990 to 2018. The baseline model, regresses income inequality on technical innovation, overall financial development index and explanatory variables (GDP per capita) expressed in Equation 1:

$$lnIE = f(lnTI, lnFD\ , lnGDPpc,) \qquad (1)$$

Equation 1 variables are transformed into natural-log form for empirical analysis. Thus, the empirical equation of the technological innovation and financial development-inequality nexus is shown as follows:

$$lnIE = \lambda + \Phi lnTI_{it} + \Psi lnFD_{it} + \Omega lnGDPpc_{it} + \mu_{it} \qquad (2)$$

Where $lnIE$ is the log of income inequality captured by the "estimate of Gini index of inequality in equivalized (square root scale) household disposable (post-tax, post-transfer)" from the Standardized World Income Inequality Database (SWIID, 2017 developed by Solt, (2020). $lnTI$ is technological innovation measured by Patent, one of the frequently used proxies for technological innovation (Manhaes Marins, 2008); $lnFD$ is the holistic indicator of financial development which accurately captures not only dimensions of financial institutions, and financial markets but also three sub-dimensions: access, depth, and efficiency while, $lnGDPpc$ GDP per capita (constant \$2015 US), used to capture the impact of economic development on income inequality. Financial Development Index database is obtained from the IMF while GDP per capita is sourced from World development indicators (WDI) of the World Bank.

For robustness we substitute financial development with an alternative measure (Domestic credit to private sector by banks (% of GDP) in order to examine the influence of financial development and technological innovation on income inequality specified as follows:

$$lnIE = \lambda + \Phi lnTI_{it} + \Psi lnCR_{it} + \Omega lnGDPpc_{it} + \mu_{it} \qquad (3)$$

We can't rule out the possibility of the cross-sectional dependence among these sample of countries in this study due to some level of interdependence in these countries. In view of that we conduct some specification test of the validity of cross-sectional dependence among the BRICS nations. In keeping extant literature, we estimate the above models by using the Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS). We chose these estimators for a number of reasons. First these estimators are able to cope with correlation and the endogeneity issues inherent in the panel data setting, thereby providing reliable long-run estimations. Individually DOLS is able to handle issues of endogeneity and serial correlation via differenced leads and lags. Following Zhang, Wang, Tian and Yang (2022) FMOLS and DOLS are expressed through Eq. (4) and Eq. (4) &(5), respectively.

$$\hat{\varphi}_{FM} = \left(\sum_{t=1}^{N} \sum_{t=1}^{T} (x_{it} - \bar{x}_i)^1 \right)^1 \left(\sum_{t=1}^{N} \sum_{t=1}^{T} (x_{it} - \bar{x}_i)\hat{y}_{it}^* + T.\widehat{\triangle}_{\varepsilon\mu}\right) \quad (4)$$

where $\widehat{\triangle}_{\varepsilon\mu}$ signifies the serial correlation of correction term, while $\hat{y}_{it}^*$ denotes endogeneity correction. DOLS estimator has also been used to correct for serial correlation as well as endogeneity. Panel DOLS on the other hand can be expressed as follows:

$$Y_{it} = \alpha_i + x_{it}\delta \sum_{j=q1}^{j=q2} x_{it}\Delta x_{it+j} + v_{it} \quad (5)$$

where cij is the coefficient of a lead or lag of first differenced explanatory variables. The estimated coefficient of DOLS is given by

$$\hat{\varphi}_{DOLS} = \sum_{t=1}^{N} \left(\sum_{t=1}^{T} Z_{it}Z_{it}^1\right)\left(\sum_{t=1}^{T} Z_{it}\hat{y}_{it}^*\right) \quad (6)$$

Where Z_{it}=($x_{it} - \bar{x}_i,\ \Delta x_{it+q}$) is 2(q+1)

Where X1 represent the independent variables

4. Empirical analysis

Before embarking into the discussion of the empirical findings obtained through implementing the PFMOLS and PDOLS estimation techniques, we commence the analysis by describing some statistical features of the variables used. We start our discussion by describing some basic trends of three indicators (i.e., technological innovation, financial depth and Gini coefficient (used in this study as a proxy for income inequality). The evidence depicted in Figure 1 is interesting: technological innovation seems to exhibit an increasing trend for Brazil, India and China for the period under investigation. On the other hand, technological innovation for countries such as Russia and South Africa display some miscellaneous episodes during the same period. Russia reveals a declining trend in technological innovation during the 1990s and a multifarious trend thereafter. South Africa mimic the same trend and structure to those displayed by Russia. In Figure 2, the results of financial depth reveal an upward movement for countries such as Brazil, India, China, and South Africa, while Russia present some mixed trend. Figure 3 shows some interesting trends of income inequality within the BRICS nations. Income inequality has been on the downward trend for countries such as Brazil and Russia, more so during the years 1995 to 2015. However, a sharp upward trend is observed for India and China, while a sharp upward movement was observed for South Africa between 1990 to 2008 and a downward trend was subsequently displayed.

FIGURE 1. TRENDS IN TECHNOLOGICAL INNOVATION

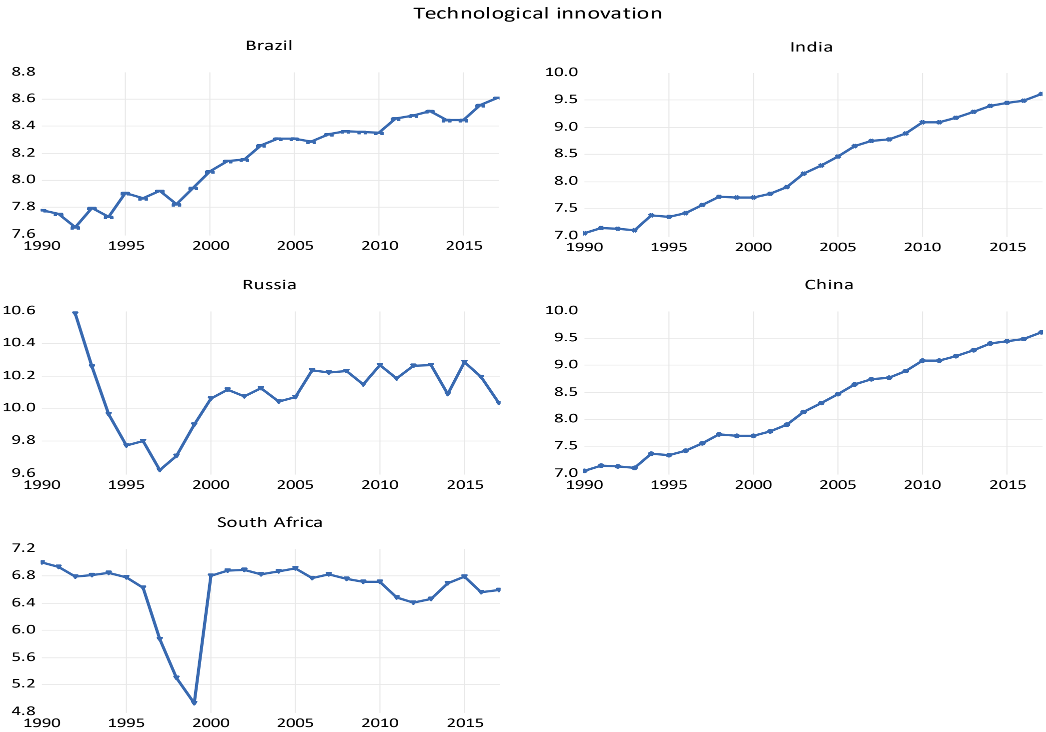

FIGURE 2. TRENDS IN FINANCIAL DEVELOPMENT IN BRICS COUNTRIES

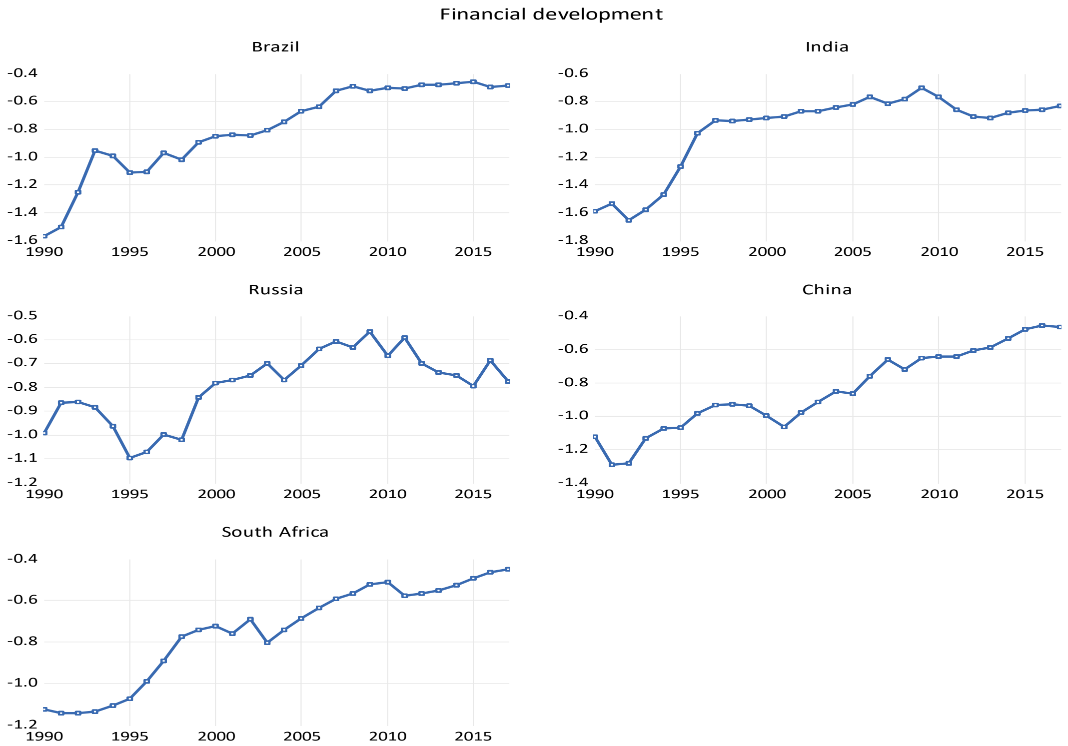

FIGURE 3. TRENDS IN INCOME INEQUALITY IN BRICS COUNTRIES

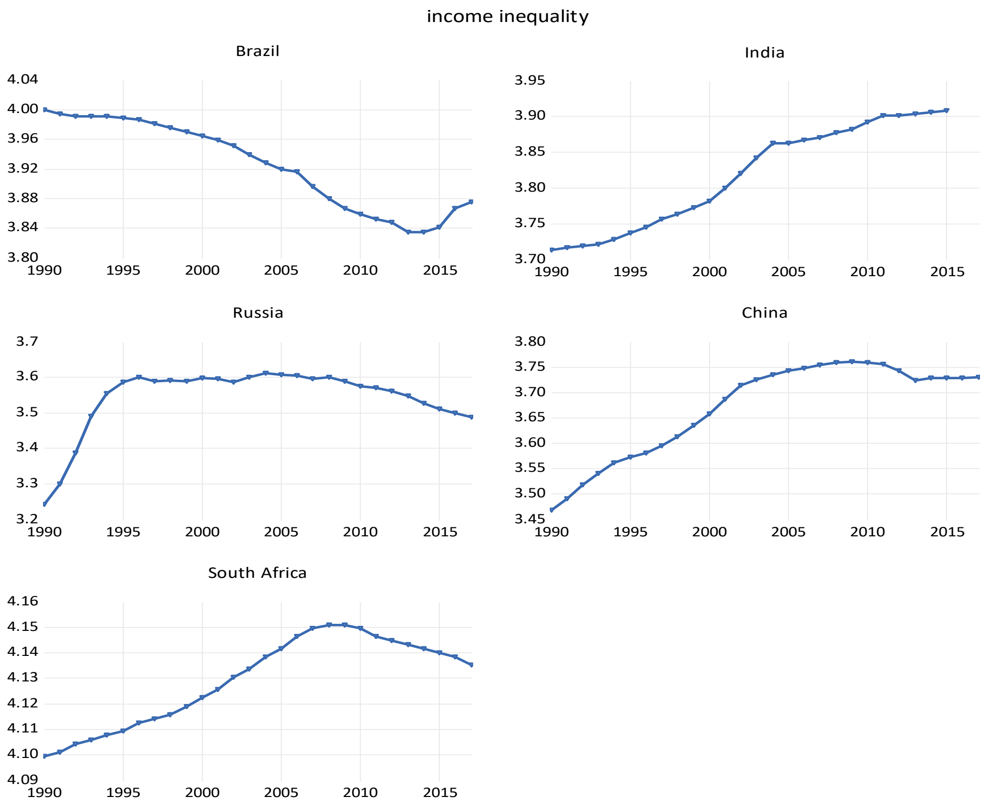

Table 1 below reports the descriptive statistics for all for all the selected variables. We observe that the mean value of income inequality (LGINI) is 3.825, ranging from minimum of 3.388 to maximum of 4.151. The average value of technical innovation (LTI) is 8.232, with a minimum of 4.927 and a maximum of 10.584. The mean value of GDP per capita (LGDPpc) is 8.341, with a minimum and a maximum of 6.355 to 9.392. Financial development (LFD) ranges from a minimum and a maximum of -1.654 to -0.449 and a mean of -0.835. Finally, the remaining variables (financial institution and financial markets components of financial development) show means that are in the negative territory: LFI variable with a mean of -0.866 and LFM with a mean of -0.906 respectively, ranging from the maximum -0.301to minimum of -1.638; and -0.371 to 2.085 respectively.

TABLE 1. DESCRIPTIVE STATISTICS

	LIE	**LTI**	**LGDPpc**	**LFD**	**LFI**	**LFM**
Mean	3.825	8.232	8.341	-0.835	-0.866	-0.906
Median	3.835	8.149	8.721	-0.805	-0.782	-0.797
Maximum	4.151	10.584	9.392	-0.449	-0.301	-0.371
Minimum	3.388	4.927	6.355	-1.654	-1.638	-2.085
Std. Dev.	0.208	1.250	0.954	0.268	0.359	0.427
Skewness	0.078	0.065	-0.799	-0.866	-0.301	-1.170
Kurtosis	1.882	2.228	2.126	3.711	2.026	3.347
Jarque-Bera	7.215	3.474	18.806	19.873	7.438	31.694
Probability	0.027	0.176	0.000	0.000	0.024	0.000
Observations	136	136	136	136	136	136

4.1 Results of cross-sectional dependence and panel unit root tests

We start this section by inspecting the presence of cross-sectional dependence or independence among the variables. The literature suggests that the results from a conventional unit root tests can be misleading if variables are found to have cross-sectional dependence. To circumvent this issue, we then implemented the cross-sectional dependence test promulgated by Pesaran (2004). The null hypothesis of cross-sectional independence is tested against the alternative hypothesis of cross-sectional dependence consistent within the literature (Ummalla et al., 2019; Faisal et al., 2020). Table 2 shows the results of the Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM and Pesaran CD tests, that are implemented to detect any presence of cross-sectional dependency in the analysis. The estimates appear to confirm a strong presence of cross-sectional dependency in all the variables at the 1 percent level of significance.

TABLE 2. CROSS-SECTIONAL DEPENDENCE TEST

Variables	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
LIE	165.855***	34.850***	34.758***	2.568**
LTI	96.708***	19.388***	19.296***	7.773***

GDPpc	228.296***	48.812***	48.720***	15.046***
LFD	177.127***	37.371***	37.278***	13.171***
LFI	190.308***	40.318***	40.225***	13.627***
LFM	117.239***	23.979***	23.887***	7.859***
LFIA	180.253***	38.070***	37.977***	13.103***
LFID	132.025***	27.286***	27.193***	10.710***
LFIE	88.081***	17.459***	17.367***	2.847***
LFMA	73.542***	14.209***	14.116***	7.836***
LFMD	141.015***	29.296***	29.203***	10.822***
LFME	72.985***	14.084***	13.991***	4.542***

Notes: ***, **, and * denote 1%, 5%, and 10% significance levels, respectively.

Since the conventional unit root tests are not appropriate in the presence of cross-sectional dependence, we then applied cross-sectional Im-Pesaran-Shi tests which account for cross-sectional dependence consistent with the work of Ummalla et al. (2019). Perhaps reassuringly, Table 3 below reveals that the data series are all stationary at first difference, indicating that we can safely apply cointegration test in order to establish if there is a long run cointegrated association between the variables used in this analysis. Table 4 produces the results of Pedroni (1999) cointegration tests (based on the null hypothesis of no cointegration among variables), regarding the long-run relationship of the variables. The test results appear to mostly reject the hypothesis of no cointegration.

TABLE 3: PANEL UNIT ROOT TEST

Variables	Level	1st difference
LIE	-2.35518	-2.08581**
LTI	-1.01444	-3.18422***
GDPpc	-1.18865	-3.35261***
LFD	-3.10462***	-3.69644***
LFI	-1.92061	-5.81213***
LFM	-2.01697	-3.75861***
LFIA	-1.93827	-3.79056***
LFID	-3.93349***	-3.2067***
LFIE	-1.30072	-3.77653***
LFMA	-2.116	-3.38511***
LFMD	-1.71778	-3.71317***
LFME	0.03154	-3.81207***

While the graphical depictions of these shown above and descriptive statistics presents some interesting insight on the behaviour of these variables, these assessments does not authorise us to conclude on the statistical significance of these variables income inequality. Therefore, the discussion should be seen as suggestive in nature. The following section then discusses the empirical findings obtained through implementing PFMOLS and PDOLS functions whose coefficients are displayed from Table (5) to (9).

TABLE 4: PANEL PEDRON COINTEGRATION TESTS

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	-1.784405	0.9628	-2.057926	0.9802
Panel rho-Statistic	-0.062532	0.4751	0.282503	0.6112
Panel PP-Statistic	-1.800677	0.0359	-1.159556	0.1231
Panel ADF-Statistic	-2.073806	0.0190	-1.639674	0.0505
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	1.022071	0.8466		
Group PP-Statistic	-1.263227	0.1033		
Group ADF-Statistic	-1.893584	0.0291		

4.2 Empirical results: FMOLS and DOLS estimates

Table 5 to Table 9 present the empirical results carried out using both the panel fully modified least squares and the panel dynamic least square models as discussed in the methodology section. Our variables are all converted into logarithmic form and also added in a stepwise manner for robustness analysis. Table 5 Model (1) to (6) regresses Gini coefficient (used in this study as a proxy for income inequality) on financial development, technological innovation, including other control variables. What stands out from Models (1) to (3) using panel fully modified least squares is that GDP per capita is one of the key factors influencing income inequality — enters positively and significantly at 1% level of significance across the models. Specifically, the results show that a 1% rise in GDP per capita will results to 0.063%, 0.136% and 0.087% increase in income inequality respectively. Our findings are similar to those of Shinhye et al. (2015) for United States, Nemati and Raisi (2015) for 28 developing countries and Constanza (2017) for 146 countries. The literature (see for example, Banerjee and Dufo, 2003; Aghion et al., 2019; Topuz, 2022 attributes this to the fact that the distribution of income tends to worsen in the early stages of a country's development, vice versa.

Similarly, technological innovation enters the model positively with a statistically significant coefficient across Models (1) to (3), suggesting that technological innovation facilitates inequality-widening effect in the BRICS nations, consistent with Mnif (2016), who found evidence to suggest that technological innovation increases income inequality for 19 developing countries. Similarly, other important scholars in this field such as Aghion et al. (2019) have reported a positive effect of technological innovation on income inequality for US. Our findings are also consistent with the theoretical foundation laid out in the preceding sections. For example, according to Bogliacino (2014) this comes about because ‘skill based technological change’ which implies that technological innovation may favour educated employees over uneducated and unskilled ones, fuelling increased demand by employers for those with higher qualifications and those more skilled (Giri, Pandey & Mohapatra, 2021).

Financial depth enters with the expected negative and statistically significant coefficient, indicating that an increase in financial depth reduces income inequality. The inverse relationship between financial depth and inequality is consistent with Kapingura (2017). However, these results are dissimilar to Cihak and Sahay (2020), who found that financial depth, reduced within-country inequality up until certain point, and beyond which it begins to increase inequality.

While the overall financial development measure is important, in explaining income inequality, further insights can be gleaned from other dimensions of financial development such as financial markets and financial institutions components. Thus, to further examine the effect financial development on inequality in South Africa we incorporate these two measures into the analysis in Table 5. Reassuringly, adding financial markets (model 1) and financial institutions dimensions (model 2) both carry the expected negative sign and is strongly significant, consistent with inequality-narrowing hypothesis of financial development, while rebuffing the inequality-widening hypothesis of financial development. It is interesting to note that although both financial markets and financial institutions dimensions have inequalities-narrowing effect, the influence of financial institutions is found to be higher than financial markets-–financial markets has less inequalities-narrowing effect than financial institutions. These results are collaborated by the work of Chisadza & Biyase (2022) who found evidence to suggest that increased development in the financial institutions for developing nations, such as the banking sector, has a relatively larger income inequality reducing effect than expansion in the financial markets. In driving the point home Chisadza & Biyase (2022) write "Access to banking credit through easing constraints for borrowing, lowering insurance premiums or increasing the availability of ATMs or bank branches in remote areas allows poor people easier access to finance, whereas trading in stocks or international securities may not be as affordable or easy to access for the lower income groups."

From Model (4) to (6), we reproduce the analysis by using an alternative estimation technique, the PDOLS for robustness check. The model produced qualitatively similar results to those produced when implementing PFMOLS estimator. For instance, GDP per capita still enters with positive and statistically significant coefficients, reinforcing the results of the PFMOLS model. Although the coefficient of technological innovation is still positively correlated with income inequality, the impact is not consistent across Models. Likewise, the results hold after using PDOLS: such as financial markets and financial institutions and financial depth still matters in explaining income inequality — enters with negative and statistically significant coefficients, consistent with the results of the PFMOLS estimator. Therefore, the conclusions advanced earlier also apply here.

TABLE 5. FMOLS AND DOLS ESTIMATES OF THE IMPACT OF IT, FD (FM, FI) ON IE

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Variable	FMOLS	FMOLS	FMOLS	DOLS	DOLS	DOLS
LGDPpc	0.063557	0.136283	0.087178	0.080515	0.121946	0.132695
	-3.945118	-6.30602	-5.099509	-2.12853	-2.794	-3.08062
LTI	0.026348	0.021643	0.028882	0.012413	0.032821	0.010997
	-2.58501	-1.90179	-2.880528	-0.50979	-1.49421	-0.39096
LFD	-0.076125			-0.14539		
	(-4.267533)			(-3.461030)		
LFM		-0.02106			-0.04166	
		(-2.192593)			(-2.218460)	

LFI	-0.156106 (-6.661735)	-0.16197 (-4.99779)

Note: numbers in () denotes t-statistics
Source: Computed by the authors

In Table 6, we adopted a different measure of financial development such as access to credit provided by commercial bank. Consistent with previous findings, GDP per capita still matters in explain income inequality within the BRICS countries — enters positive and statistically related to income inequality when implementing PFMOLS model. Likewise, technological innovation present positive but insignificant coefficients, while the traditional measure of financial development enters with negative and statistically significant coefficients. Interestingly, the results from the PDOLS is similar in the direction of the impact to those of the PFMOLS estimator. The only difference is that the coefficient of technological innovation is insignificant when implement the PDOLS model.

TABLE 6. FMOLS AND DOLS ESTIMATES OF THE RELATIONSHIP BETWEEN TI, FD_CRED AND IE

	Model 1	Model 2
Variable	FMOLS	DOLS
LGDPPC	0.690018	0.155521
	(2572.807)	(2.575152)
LTI	0.728064	0.001012
	(370.2441)	(0.132285)
LFD_CRE	-0.151436	-0.023617
	(-132.9438)	(-2.142315)

5. Conclusion

The driving objective of this study is to empirically investigate the causal impact of technological innovation and financial development on inequality in the BRICS countries. This study employs cutting-edge econometric techniques, including cross-sectional dependence, second-generation stationary methods, panel fully modified ordinary least square (FMOLS) and panel Dynamic Ordinary Least Squares (PDOLS) with annual data sourced from the Standardized World Income Inequality Database, IMF and World Bank (1990-2017) to investigate the empirical relationship between technological innovation and income inequality in BRICS countries. We expand on the current literature by disaggregated the analysis into upper-middle income countries (South Africa, China, Russia and Brazil) and lower-middle income countries (India) and employing novel financial development measure, including its sub-indicators of financial depth such as financial markets, financial institution to confirm whether the robustness of our results.

Two key findings emerge from the study: technological innovation enters the model positively with a statistically significant coefficient across Models, suggesting that technological innovation facilitates inequality-widening effect in the BRICS nations. While the overall financial development measure is important, in explaining income inequality, further insights can be gleaned from other dimensions of financial development such as financial markets and financial institutions components. Thus, to further examine the effect financial development on inequality in South Africa we incorporate these two measures into the analysis in Table 5. Reassuringly, adding financial markets (model 1) and financial institutions dimensions (model 2) both carry the expected negative sign and is strongly significant, consistent with inequality-narrowing hypothesis of financial development, while rebuffing the inequality-widening hypothesis of financial development. It is interesting to note that although both financial markets and financial institutions dimensions have inequalities-narrowing effect, the influence of financial institutions is found to be higher than financial markets—financial markets has less inequalities-narrowing effect than financial institutions.

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