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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, their impact on inequality (especially in emerging economies) remains understudied. Thus, the objective of this study is to investigate the impact of technological innovation and financial development on income inequality in BRICS (Brazil, Russia, India, China and South Africa) countries using 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, International Monetary Fund (IMF) and World Bank (1990–2017). The results suggest that technological innovation increases income inequality in the BRICS nations, while financial development has an income reducing effect on inequality. Our results are robust, using alternative estimation with various sub-indicators of financial development (such as financial markets and financial institution), including other measures proxied by access to credit provided by commercial banks. The study's results have important implications for policy and practice in the BRICS countries. By providing a nuanced understanding of the relationship between technological innovation, financial development and inequality, the study will inform the design and implementation of policies aimed at reducing inequality and promoting inclusive growth in these emerging economies.

Keywords: BRICS; PFMOLS; PDOLS; technological innovation; inequality

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1. Introduction

In the last decade, Brazil, Russia, India, China and South Africa—have emerged as significant players in the global economy (Rastogi and Gaikwad 2017). However, this remarkable growth has been accompanied by a surge in inequality, raising concerns about the sustainability of economic progress (Younsi and Bechtini 2018). While technological innovation and financial development have been instrumental in driving economic growth in these countries (Lacasa et al. 2019; Zhang 2021), they also face significant challenges in terms of inequality, particularly with regard to income and wealth distribution. Hence, the impact of these factors on inequality remains largely unclear.

The literature on technological innovation and financial development has produced conflicting evidence on their impact on inequality (e.g., Hasan et al. 2020; Adebayo 2023; Wang and Wu 2023). Some studies suggest that innovation can reduce inequality by creating new opportunities for workers with diverse skills and abilities, while others argue that technological change can exacerbate existing inequalities by favoring highly skilled workers and those already considered to be wealthy (Kharlamova et al. 2018; Aghion et al. 2019; Giri et al. 2021). Similarly, some scholars have argued that financial development can reduce inequality by enabling investment and access to credit for marginalized populations, while others have suggested that even though financialization can lead to the concentration of wealth and exacerbate inequality in the early stages, it tends to eventually reduce it, following an inverted-U pattern (Wang and Wu 2023). When the financial sector of any country starts developing through several channels, namely the banking and financial services sectors, it directly affects the economic growth pattern and, consequently, the distribution in income (Destek et al. 2020). Against this backdrop, this article aims to shed light on the relationship between technological innovation, financial development and inequality in BRICS countries.

The findings of this study are expected to make important contributions to the literature on technological innovation, financial development and inequality. By providing empirical evidence from the BRICS countries, the study will enable policymakers and researchers to gain a better understanding of how these factors interact to shape inequality outcomes in emerging economies. Furthermore, the study will offer insights into how the distributional impact of technological innovation and financial development can be enhanced, particularly with respect to marginalized populations. Overall, this article aims to contribute to our understanding of the complex relationship between technological innovation, financial development, and inequality in the BRICS countries. The study's results have important implications for policy and practice in the BRICS countries. By providing a nuanced understanding of the relationship between technological innovation, financial development, and inequality, the study will inform the design and implementation of policies aimed at reducing inequality and promoting inclusive growth in these emerging 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 the development of the financial sector on income inequality. Section 3 describes the data and the econometric methodology. Section 4 presents the empirical findings. Section 5 draws conclusions and implications of the findings.

2. Literature Review

Technological innovation has been recognized as being a crucial driver of economic growth and development. It involves the use of scientific and engineering knowledge to develop new solutions and applications that meet the needs of businesses, consumers and society (Fayomi et al. 2019; Sobolieva et al. 2021). On the other hand, financial development refers to the process of improving the efficiency and effectiveness of financial systems, institutions and markets (Anginer et al. 2018; Qureshi 2019), while inequality refers to the unequal distribution of resources, opportunities and rewards within a society or between different groups of people and it can take many forms. Undoubtedly, income inequality is one of the paramount threats to societal stability (Kharlamova et al. 2018). Rising inequality can push societies to the brink, especially in developing countries where the majority of the population are already living in poverty. However, the relationship between technological innovation, financial development and inequality remains an important and complex issue (King and Levine 1993; United Nations 2018; Mbona 2022; Biyase and Chisadza 2023).

Economic theory acknowledges that financial development and technological 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 (Stiglingh 2015). 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 Levine (2021), financial development can enhance economic growth by raising the productivity of investments and reducing transaction costs and can thus increase the share of savings channeled 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 and Sahay 2020).

In reality, financial development is always inclusive of technological innovation. One perspective stems from the classical school of thought which proposes that because of technology and economic institutions, labor efficiency is bound to increase, thereby improving economic performance through increased output (Fourie and Burger 2012; Knell 2016). This is known as one aspect of the Solow growth model (Greenhalgh and Rogers 2010) which, to a certain degree, stems 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 and Levine 1993). This argument is supported by Stiglingh (2015, p. 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 industrialization process through the facilitation and mobilization of capital. Demirgüç-Kunt and Levine (2009) and Mbona (2022) also contend that a well-developed financial sector can absorb the impact on household earnings by letting poor people 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 link technologically related economic expansion to underlying forces of inequality in society (Maddison 2001). 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 characterized by high income and wealth inequality that arises from the assumptions that they are based on (Ayres 1953). Hence, technological innovation arising from financial development on the other hand can be regarded as a 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 and Phelps 1966; Schultz 1975) points to the industrial revolution through developments in technology in the early 1900s as having perpetuated social inequality (Krueger 1993; Greenwood et al. 1997; Goldin and 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 the most affected by the 2008 Global Financial Crisis (e.g., Spain and 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 favor educated employees over uneducated and unskilled ones, fueling increased demand by employers for those with higher qualifications and those who are more skilled (Giri et al. 2021). At the same time, those who are unskilled and those who are 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 poor people, who are most likely to be uneducated and unskilled, and rich people, who are more likely to be educated and skilled (Zhu and Trefler 2005; Levine 2012). This viewpoint was in fact predicted in the mid-1930s, where Jerome (1934, p. 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 (Farooqi and Wegerich 2014); what the modern times brought was technological innovation that led to an expansion in commercial agriculture, pushing small-scale farmers out of business, and consequently benefiting the already wealthy (Shah 2010). "In unequal societies, fast wealth accumulation by the elites may put excessive pressure on key natural resources thus affecting the dependent poor population" (Mirza et al. 2019, p. 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 globalization. Mainstream economics has long advocated for the free movement of capital, whether it be financial or otherwise, between countries, as it is believed to bring about greater economic efficiency (Weiss 1999). However, this approach has had a negative impact on developing countries' income distribution, benefiting only those at the top of the social hierarchy, consequently widening the gap between rich and poor countries (Blanchard and Willmann 2011; Sampson 2014). This means that poor countries that do not have innovation capacity and the right institutions take a long time to catch up to their developed counterparts (United Nations 2021). Thus, while technological innovation and financial development hold significant potential for advancing economic development, it is crucial to carefully consider their distributional effects on inequality to ensure inclusive growth. The next subsection looks at the empirical findings on the topic at hand.

2.1. Review of Empirical Literature

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

2.1.1. Technological Innovation and Inequality

Using a model featuring biased heterogeneity, factor proportions and labor 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 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 that are central in the region including the United Kingdom, while countries at the periphery become more affected. Lastly, inequality reactions to technological innovation in countries that already have high income inequality are found to be both positive and negative. 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 poorer people remaining poor, richer people remaining richer and the environment being on a degrading path.

Mirza et al. (2019) conducted a study on technology-driven inequality, poverty and resource depletion in developing countries. Using a stylized social–ecological model, they discovered that technological innovation may feed local inequality by its favorable relationship to wealth, which can lead to resource degradation, a collapse in ecological resources and an unforeseen intensification in poverty. When analyzing the relationship between income inequality and innovation in the US, Aghion et al. (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 of revenue share. Khan and Ulucak (2020) found that the use of green technology has a positive impact on growth by promoting poverty alleviation through reduced costs of renewable energy. Similar findings are also reported by Fernandes et al. (2021).

Adebayo (2023) explored how technological innovation impacted income inequality in BRICS countries and Turkey for the period from 1992 to 2019. The study results offer diversity in the consequences observed in various nations, which can be classified into three distinct categories: (i) there exists a positive relationship between technological innovation and income inequality, (ii) the distribution of technological innovation has an adverse effect on the distribution of income inequality and (iii) the implications of technological innovation on income distribution are not uniformly dispersed.

Dachs (2018) found that the use of new technologies has led to skills- and employment-biased growth, widening wage inequality in several EU countries. With regard to the auto regressive distributed lag (ARDL) method, Giri et al. (2021) examined 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 Vector Error Correction Model (VECM) conclusions based on the Granger causality method, technological advancement, trade and financial globalization all contribute directly and indirectly to income disparity through inflation and economic growth. A study by Wang and Wu (2023) on financial development, technological innovation and income inequality in China found that urban–rural income disparity is positively impacted by technological innovation, whereas an inverted-U pattern is discernible between financial development and the urban–rural income gap. Additionally, there exists a mutually causal relationship between financial development and the urban–rural income gap.

Chege and Wang (2019) conducted a comprehensive review of the literature pertaining to the impact of technology innovation on job generation in small businesses located in developing countries. The findings indicate that technology innovation has a favorable influence on job creation in small businesses and serves as a catalyst for economic progress, suggesting a positive impact on inequality. Similar findings are reported by Cetin et al. (2021) for Turkey.

2.1.2. Financial Development and Inequality

Kapingura (2017) examined the connection between South Africa's financial industry development and inequality over the years from 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, was considered in the study. The results from the Autoregressive distributed lag (ARDL)approach show that inclusive financial development lowers the level of inequality in South Africa over long- and short-term periods. The decline in inequality was more significant when access to ATMs was expanded than when financial depth was.

Jung and Cha (2021) explored the long-run relationship between economic financial development and income inequality in China and, contrary to the literature, the study observed that the process of financial deepening does not enhance equity; rather, it exacerbates the existing inequality. Consequently, the outcomes suggest that financial development can simultaneously elevate per capita income and amplify income disparity.

Altunbaş and Thornton (2019) used panel data analysis to investigate the impact of financial development on income inequality in 121 countries. The findings suggest that financial development has divergent effects on income inequality across countries with different income levels. While it leads to an increase in income inequality between high- and lower income countries, it contributes to a reduction in income inequality among upper middle income countries. Notably, the adverse influence of financial development on income distribution in lower income countries is mainly mediated by the development in financial markets, as opposed to institutional factors.

Tabash et al. (2022) used panel data analysis to investigate how financial development affects income inequality and poverty in selected Sub-Saharan African countries including South Africa. The research reveals that the pillars of financial development exhibit constructive and notable influences on income inequality. Poverty reduction effects were significant in low- and lower middle income countries, but not in upper middle income countries.

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 seems 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.

Erkişi (2018) found inconclusive findings on whether financial development has an impact on growth in a panel study on BRICS countries and Turkey. Ngo et al. (2022) confirm a bidirectional relationship between financial development and green growth, which plays a significant role in achieving the sustainable development goals in 36 emerging and developed economies from 1996 to 2014. Sharma and Dahiya (2020) reported a non-linear relationship between financial development and income inequality in India, characterized by an inverted U-shape. Additionally, the study suggests that economic development can have a negative impact on income inequality by exacerbating the gap between rich and poor people. The results of a study by Cetin et al. (2021) on Turkey suggest that changes in financial development can influence income inequality and vice versa.

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 affect 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 was reduced; after a certain point, a rise in financial depth caused income inequality to worsen. Similarly, Mncube and Kaulihowa (2022) found mixed results when investigating the relationship between financial innovation and income inequality in South Africa, Brazil, China and Turkey between 1986 and 2020. Specifically, financial innovation (when using bank credit extended to the private sector and the ratio of broad money to narrow money as indicators) demonstrates a U-shaped relationship with income inequality. However, they found evidence of a negative association with income inequality when measuring financial innovation specifically through the use of ATMs, suggesting that increased ATM usage was associated with decreased income inequality.

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. Brei et al. (2018) support the U-shaped relationship, while Nguyen et al. (2019) confirm the existence of an inverted U-shaped relationship in 21 emerging economies. Therefore, it is crucial to develop, introduce new ideas and expand the range of mechanisms, programs and financing tools, as they have a significant impact in promoting economic and social progress in emerging economies (Kooli et al. 2022).

To fill the gap in the literature, this study adopts 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 of 1990–2018. This also implies that our data are recent and updated. Thirdly, we use different techniques (panel fully modified least square, and for the 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

This section outlines the model specification and offers some description of the key variables and data in order to fulfill the objectives of the study: to establish whether there is any relationship between technological innovation, financial development and income inequality in BRICS countries.

Data and Model Specification

Guided by the extant literature, this study incorporates gross domestic product per capita, technical innovation, the overall financial development index and its sub-components to examine their influences on income inequality for Brazil, Russia, India, China and South Africa (BRICS) from 1990 to 2017. The baseline model, regresses income inequality on technical innovation, overall financial development index and explanatory variables (GDP per capita) are expressed in Equation (1):

$$lnIE = f(lnTI, lnFD\ , lnGDPpc,) \tag{1}$$

The Equation (1) variables were 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:

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

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 via 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 USD, 2015) was used to capture the impact of economic development on income inequality. The Financial Development Index database was obtained from the IMF while GDP per capita was sourced from the world development indicators (WDI) of the World Bank.

For robustness, this study substituted 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:

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

There is a possibility of the cross-sectional dependence among these sampled of countries in this study due to some level of interdependence in these countries. In view of this, this study conducts a specification test of the validity of cross-sectional dependence among the BRICS nations. In keeping with the extant literature, this study estimates the above models by using the dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS) models. The estimators were chosen 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 et al. (2022), FMOLS and DOLS are expressed through Equation (4) and Equations (4) and (5), respectively.

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

where $\widehat{\triangle}_{\varepsilon\mu}$ signifies the serial correlation of the 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:

$$Y_{it} = \alpha_i + x_{it}\delta\sum_{j=q1}^{j=q2} x_{it}\Delta x_{it+j} + \nu_{it} \tag{5}$$

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

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

where Z_{it}= $(x_{it}-\bar{x}_i,\ \Delta x_{it+q})$ is 2(q + 1), where X1 represents the independent variables.

The empirical analysis comprised the following steps. The first step was to test whether there was the presence of a unit root in the variables. The second step involved testing for any cointegrated relationships in the variables. The third step involved conducting some specification tests of the validity of cross-sectional dependence among the BRICS nations. The final step was to carry out estimates concerning the long-run relationship between the variables described above.

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 mimics 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 presents a mixed trend. Figure 3 shows some interesting trends in 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 from 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 and 2008 and a downward trend was subsequently displayed.

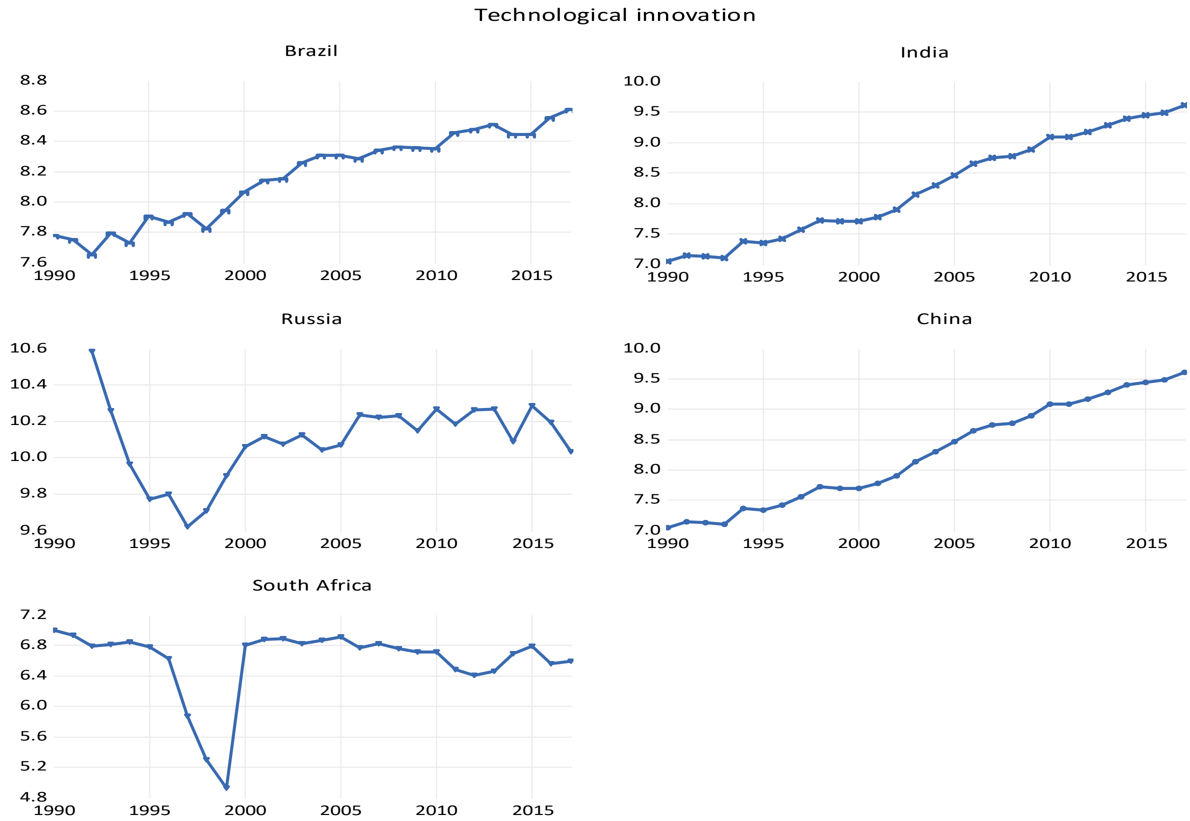

Figure 1. Trends in technological innovation.

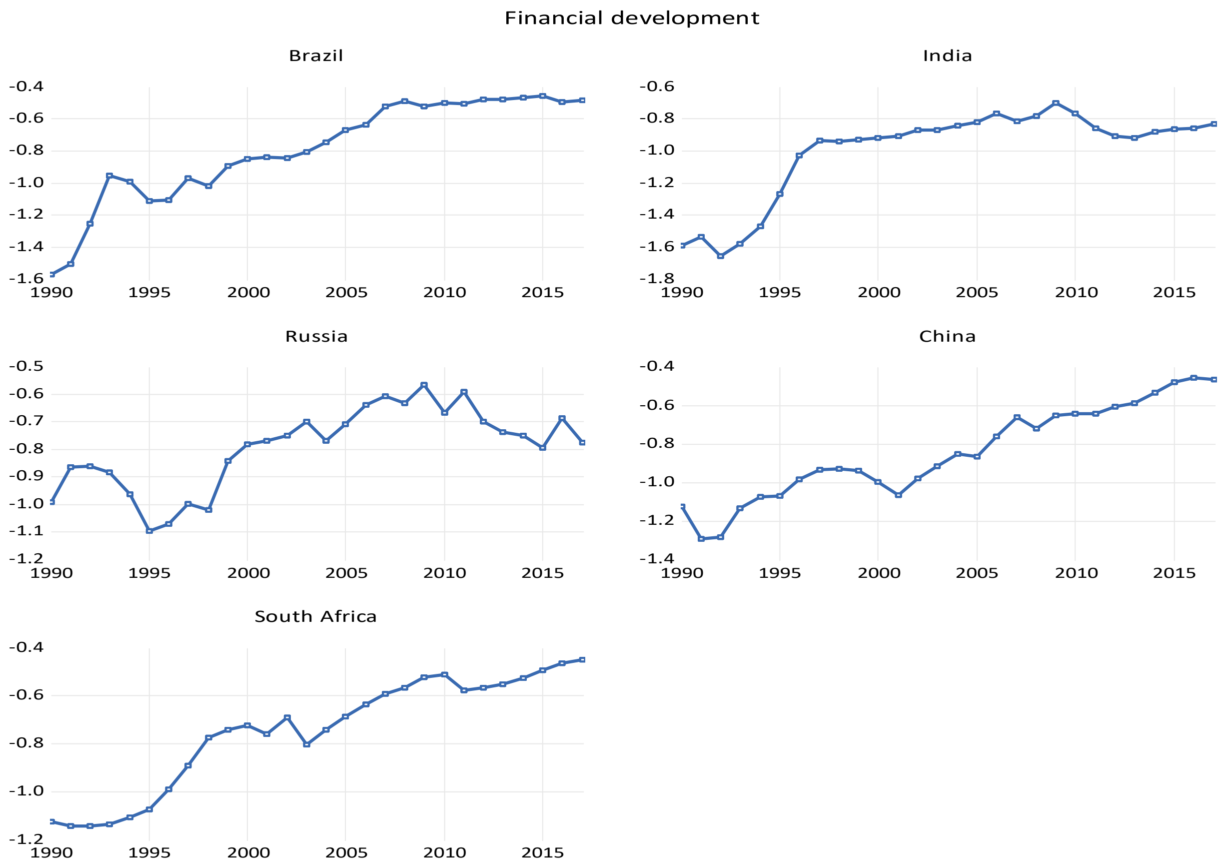

Figure 2. Trends in financial development in BRICS countries.

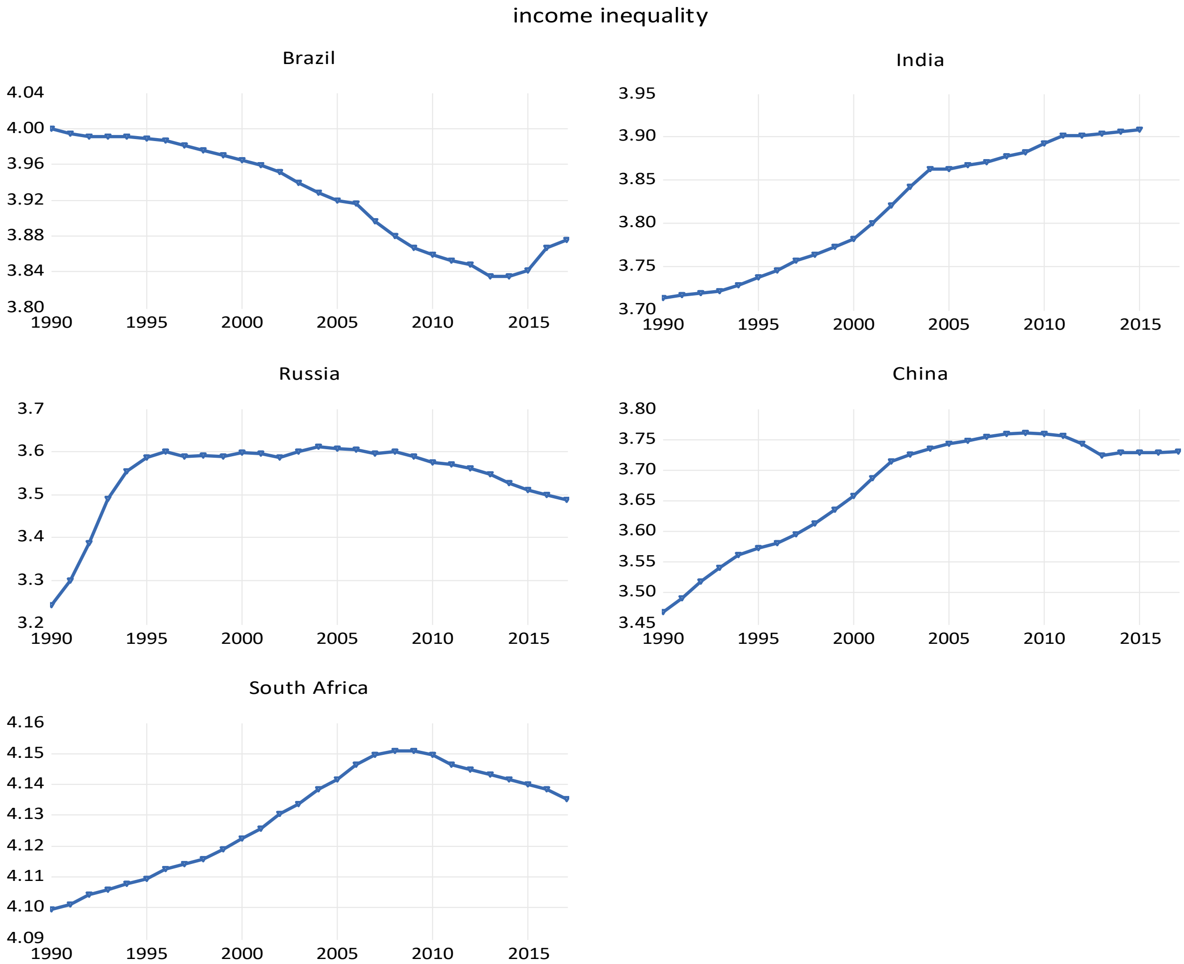

Figure 3. Trends in income inequality in BRICS countries.

Table 1 below reports the descriptive statistics for all of the selected variables. We observe that the mean value of income inequality (LGINI) is 3.825, ranging from a minimum of 3.388 to a maximum of 4.151. Inequality is fairly high in these countries. This is to be expected since some of the member countries have very high inequality, especially South Africa which is seen by many as the most unequal society in the world (based on its higher Gini-coefficient index). 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 and 9.392. Financial development (LFD) ranges from a minimum and a maximum of −1.654 and −0.449 and a mean of −0.835. Finally, the remaining variables (financial institution and financial market components of financial development) show means that are in the negative territory: the LFI variable has a mean of −0.866 and LFM has a mean of −0.906, respectively, ranging from the maximum of −0.301 to the minimum of −1.638, and from −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

5. 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 test 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 was 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 Lagrange Multiplier, Pesaran scaled Lagrange Multiplier, bias-corrected scaled Lagrange Multiplier and Pesaran CD tests that were 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 of 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 ***

Note: ** denote 5% significance level, *** denote 1% significance level.

Since the conventional unit root tests were not appropriate in the presence of cross-sectional dependence, we then applied cross-sectional Im–Pesaran–Shi tests which accounted 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 the first difference, indicating that we can safely apply the cointegration test in order to establish whether 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 a null hypothesis of no cointegration among variables), regarding the long-run relationship between the variables. The test results appear to mostly reject the hypothesis of no cointegration.

Table 3. Panel unit root test.

Variables	Level	First 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 ***

Note: *** and ** denote 1% and 5% significance levels.

Table 4. Panel Pedron cointegration tests.

Alternative Hypothesis: Common AR Coefs. (Within Dimension)				
			Weighted	
	Statistic	Prob.	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		

While the graphical depictions of these are shown above and the descriptive statistics present some interesting insights into the behavior of these variables, these assessments do not authorize us to conclude on the statistical significance of these variables regarding income inequality. Therefore, the discussion should be seen as suggestive in nature. The following section discusses the empirical findings obtained through implementing PFMOLS and PDOLS functions, whose coefficients are displayed in Tables 5 and 6.

Table 5. FMOLS and DOLS estimates of the impact of IT and 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			−0.16197
			(−6.661735)			(−4.99779)

Note: numbers in ( ) denote t-statistics. Source: computed by the authors.

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)

Empirical Results: FMOLS and DOLS Estimates

Tables 5 and 6 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 were all converted into logarithmic form and also added in a stepwise manner for robustness analysis. The Table 5 Model (1) to (6) regressed Gini coefficients (used in this study as a proxy for income inequality) on financial development and 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; it enters positively and significantly at the 1% level of significance across the models. Specifically, the results show that a 1% rise in GDP per capita results in a 0.063%, 0.136% and 0.087% increase in income inequality, respectively. Our findings are similar to those of Shinhye et al. (2015) for the United States, Nemati and Raisi (2015) for 28 developing countries and Constanza (2017) for 146 countries. The literature (see, for example, Aghion et al. 2019) attributes this to the fact that the distribution of income has a tendency to worsen in the early stages of a country's development, and vice versa.

Similarly, technological innovation enters the model positively with a statistically significant coefficient across Models (1) to (3), suggesting that technological innovation facilitates an inequality-widening effect in the BRICS nations, consistent with Mnif (2016), who found evidence to suggest that technological innovation increased 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 the US. Our findings are also consistent with the theoretical foundation laid out in the preceding sections (see, for example, Aghion et al. 2019). For example, according to Bogliacino (2014), this comes about because of 'skills-based technological change' which implies that technological innovation may favor educated employees over uneducated and unskilled ones, fueling increased demand by employers for those with higher qualifications and those who are more skilled (Giri et al. 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 Čihák and Sahay (2020), who found that financial depth reduced within-country inequality up until a certain point, and beyond which it began 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 institution components. Thus, to further examine the effect of financial development on inequality in South Africa, we incorporated these two measures into the analysis in Table 5. Reassuringly, the addition of financial markets (Model 1) and financial institution dimensions (Model 2) both carry the expected negative sign and this is strongly significant, consistent with the 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 institution dimensions have an inequality-narrowing effect, the influence of financial institutions is found to be higher than financial markets—financial markets have less of an inequality-narrowing effect than financial institutions. These results are corroborated by the work of Chisadza and 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 and 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 the 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 matter in explaining income inequality—this enters with negative and statistically significant coefficients, consistent with the results of the PFMOLS estimator. Therefore, the conclusions advanced earlier also apply here.

In Table 6, we adopted a different measure of financial development such as access to credit provided by the commercial bank. Consistent with previous findings, GDP per capita still matters in explaining income inequality within the BRICS countries—it enters positively and is statistically related to income inequality when implementing the PFMOLS model (see also, Aghion et al. 2019). Likewise, technological innovation presents positive but insignificant coefficients, while the traditional measure of financial development enters with negative and statistically significant coefficients. Interestingly, the results from the PDOLS are 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 implementing the PDOLS model.

6. Conclusions

The driving objective of this study was 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) models 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. It also expands upon the current literature by disaggregating the analysis into upper middle income countries (South Africa, China, Russia and Brazil) and lower middle income countries (India) and employing novel financial development measures, including the sub-indicators of financial depth such as financial markets and financial institution to confirm 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 an 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 institution components. Thus, to further examine the effect of financial development on inequality in South Africa, we incorporated these two measures into the analysis in Table 5. Reassuringly, the addition of financial markets (Model 1) and financial institution dimensions (Model 2) both carry the expected negative sign and this is strongly significant, consistent with the 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 institution dimensions have an inequality-narrowing effect, the influence of financial institutions is found to be higher than financial markets—financial markets have less of an inequality-narrowing effect than financial institutions. The study's results have important implications for policy and practice in the BRICS countries. By providing a nuanced understanding of the relationship between technological innovation, financial development and inequality, the study will inform the design and implementation of policies aimed at reducing inequality and promoting inclusive growth in these emerging economies. Future studies can extend the existing debate on this issue by considering the possibility that there might be a non-linear relationship between these variables. The limitation of this study is that data were not available for the period prior to 1980 and that it did not account for a non-linear relationship between variables.

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