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Income inequality and economic growth in BRICS: insights from non-parametric techniques

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Abstract
The income inequality-economic growth linkage is a topical issue in economics and policy discussions. Both theoretical and empirical results on the impact of income inequality on economic growth have been controversial. One of the criticisms of the existing studies relates to using cross-sectional data and linear estimation techniques for empirical analysis. Capitalising on the limitations in the existing literature, this article employs the novel Quantile-on-Quantile Regression (QQR) approach to examine the relationship between income inequality and economic growth in BRICS. Applying the novel QQR technique helps to model how income inequality distributions affect the distributions of economic growth. The quantile cointegration tests reveal cointegration between income inequality and economic growth. The QQR results indicate that income inequality has a stronger negative effect on the lower and middle tails of economic growth in Brazil while having a stronger positive impact on economic growth in Russia, China and South Africa. For India, income inequality has a stronger negative effect on the lower tail of economic growth and a stronger positive impact on the middle and higher tails of economic growth. These results are consistent with quantile regression results. Further analysis from the Granger causality-in-quantiles shows that at various quantiles, a bidirectional causal relationship between income inequality and economic growth exists in China, while a unidirectional causality runs from income inequality to economic growth in Brazil and India. No causal relationship was found between income inequality and economic growth in Russia and South Africa. The policy implications are discussed.

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1 Introduction

Understanding the income inequality-economic growth nexus is important since reducing income disparity while achieving higher economic growth is at the heart of the efficiency-equity trade-off that shapes policy discussions worldwide (De Dominicis et al. 2008). This study, therefore, seeks to understand the relationship between income inequality and economic growth in Brazil, Russia, India, China, and South Africa (hereafter, BRICS). The BRICS countries occupy an important position in the trajectory of global economic growth. These economies have been and continue to be projected as the main drivers of global economic growth. On average, the global economy experienced a decline in the annual growth rate of 1.7% of Gross National Product (GNP) per capita between 2008 and 2017. However, during the same period, the BRICS economies experienced an average annual GNP growth rate of 5.4% and currently account for 30.4% of global GNP (McKinley 2018; McKinley and Cripps 2017). Despite the projected growth in global GNP per capita by 2.5% annually between 2023 and 2030, BRICS economies are expected to grow by 4.5% within the same period, which is much higher than that of any bloc of developed and other emerging economies (McKinley 2018; McKinley and Cripps 2017). The contribution of the BRICS economies to the global economy is projected to increase to 37.7% (McKinley 2018; McKinley and Cripps 2017).

With BRICS being a driver of global economic growth, income inequality in the bloc has also been rising. Evidence suggests that income inequalities in all BRICS economies have been above the average income inequality in Organisation for Economic Co-operation and Development (OECD) (Ivins 2013). For instance, China, India, Russia, and South Africa experienced a sharp increase in income inequality from the early 1990s to the late 2000s. In BRICS countries, improvements in real household income were concentrated at the top, with the upper quintiles reaching 75% of total income in South Africa (Ivins 2013). The OECD (2011) report revealed that the concentration of increasing real household income in China and India remained closer to the OECD average, ranging between 40–45%. An Oxfam estimation has also revealed that more than a million additional people were pushed into poverty in South Africa between 2010 and 2020. Also, from the early 1990s to the late 2000s, while the income inequality in Brazil was approximately twice as large as the OECD average, it was the only BRICS country that witnessed a decline in income inequality (Ivins 2013). The decline in Brazil's income inequality is attributed to the rapid increase in income of the bottom and middle quintiles relative to the income growth of the upper quintile.

Given that BRICS countries are drivers of global economic growth and have experienced higher income inequality, the question that motivates this study is, "*Does income inequality promote or impede economic growth in BRICS economies?*" Theoretically, the effect of income inequality on economic growth remains debatable in the literature. The literature survey suggests that four main theories, namely, credit-market imperfection, political economy, socio-political unrest, and savings rate, are being used to debate the effect of income inequality on economic growth (Barro 2000; Perotti 1996). Among these theories, the political economy and social unrest theories suggest that income inequality harms economic growth (Alesina and Perotti 1996; Barro 2000; Persson and Tabellini 1994), while

the savings rate theory indicates that income inequality spurs economic growth (Barro 2000; Ezcurra 2007). On the other hand, the credit-market imperfection theory predicts both positive and negative effects of income inequality on economic growth (Barro 2000; Piketty 1997). Like the conflicting theoretical arguments, there is no consensus among the findings of the existing empirical studies. For instance, some empirical studies have reported a negative effect of income inequality on economic growth (Easterly 2007; Ezcurra 2007; Herzer and Vollmer 2012; Keefer and Knack 2002; Mo 2000; Persson and Tabellini 1994) while others have reported a positive effect of income inequality on economic growth (Berg et al. 2018; Bleaney and Nishiyama 2004; Forbes 2000; Li and Zou 1998; Litschig and Lombardi 2019).

Previous empirical studies have contributed significantly to the income inequality-economic growth debate. However, some limitations in these studies need to be addressed. First, the literature survey suggests that the existing empirical studies have mainly employed cross-sectional and panel data approaches to examine the relationship between income inequality and economic growth; however, these methods are argued to lack robustness (Banerjee and Duflo 2003; Ezcurra 2007). In addition, Banerjee and Duflo (2003) contend that applying linear econometric estimators such as OLS, fixed effect, three-stages least-squares etc., in the existing empirical studies has led to bias and inconclusive results. Banerjee and Duflo (2003, p. 268) argue that "when we examine the data without imposing a linear structure, it quickly becomes clear that the data does not support the linear structure that has routinely been imposed on it". This suggests that the complex relationship between income inequality and economic growth is not always linear but could be non-linear (Banerjee and Duflo 2003). Second, we argue that conclusions and policy suggestions from cross-sectional and panel data approaches may not apply to individual-specific countries due to structural differences among countries. Therefore, from a policy perspective, it is imperative to utilise a time-series approach to focus on country-specific analysis. However, there is a paucity of empirical studies that apply time series techniques to conduct country-specific analysis. Third, the existing empirical studies have not explored the causal relationship between income inequality and economic growth. Lastly, existing studies have paid less attention to BRICS countries. However, BRICS countries are vital since they are drivers of global economic growth and have experienced higher income inequality. Therefore, studies focusing on BRICS would contribute significantly to the income inequality-economic growth literature.

In this paper, we contribute to the literature by addressing the above-highlighted limitations. Thus, our study investigates the relationship between income inequality and economic growth in BRICS from 1960 to 2019 using non-parametric time series techniques. Our study is distinct and contributes to the income inequality and economic growth literature and policy discussions in the following directions: First, this study applied the Sim and Zhou (2015) novel Quantile-on-Quantile (QQR) approach, which is an advanced time series technique, to provide new empirical evidence on income inequality and economic growth relationship in the BRICS. The Sim and Zhou (2015) QQR is essential since it combines non-parametric and quantile regression techniques, where a quantile of income inequality is regressed onto the quantile of economic growth. Applying the novel QQR technique helps to model how income inequality distributions affect the distributions of economic growth. Second, this study also uses the Quantile regression (QR) method to test the robustness of the QQR results. Third, this study utilised the Troster (2018) Granger Causality in Quantiles to examine the causal relationship between income inequality and economic growth. Applying the Troster (2018) Granger Causality in Quantiles approach helps to discriminate between causality affecting the median and the tails of the conditional

distribution. This approach provides a sufficient condition for Granger-causality when all quantiles are considered (Troster 2018). Fourth, this study employed the Brock, Dechert and Scheinkman (BDS) test and the Koenker and Xiao (2004) quantile unit-root technique to test the stationarity properties of income inequality and economic growth while using Xiao (2009) quantile cointegration for the cointegration test. Finally, from a policy perspective, the findings from this study will contribute to social equality policy in the BRICS countries.

Using the non-parametric time series techniques, the quantile cointegration tests revealed cointegration between income inequality and economic growth. The QQR results indicate that income inequality has a stronger negative effect on the lower and middle tails of economic growth in Brazil while having a stronger positive impact on economic growth in Russia, China and South Africa. For India, income inequality has a stronger negative effect on the lower tail of economic growth and a stronger positive impact on the middle and higher tails of economic growth. These results are consistent with quantile regression results. Further analysis from the Granger causality-in-quantiles shows that at various quantiles, a bidirectional causal relationship between income inequality and economic growth exists in China, while a unidirectional causality runs from income inequality to economic growth in Brazil and India. No causal relationship was found between income inequality and economic growth in Russia and South Africa. The policy implications are discussed.

2 Income inequality and economic growth: theory and empirical evidence

In the economics literature, the economic growth effect of income inequality remains ambiguous. This ambiguity stems from the different theoretical lenses used to discuss the possible effect of income inequality on economic growth. Broadly, four main theories, namely, credit-market imperfection, political economy, socio-political unrest and savings rate, are used to discuss the relationship between income inequality and economic growth (Barro 2000; Perotti 1996). Generally, political economy and social unrest theories predict that income inequality harms economic growth, while the savings rate theory indicates that income inequality spurs economic growth. On the other hand, the credit-market imperfection theory predicts both positive and negative effects of income inequality on economic growth.

Based on a political economy (median-voter) model, Persson and Tabellini (1994) argue that in a society where distributional strife is essential, political decisions produce economic policies that tax investment and growth-promoting activities to redistribute income. The authors use the endogenous growth model to reveal that physical capital, human capital, and knowledge accumulation determine economic growth. The incentive to accumulate these productive resources depends on the ability of individuals to reap the fruits of their labour. However, the authors suggested that individuals benefiting from their investments depends on the economy's tax and regulatory policies. The authors highlighted that high-income inequality motivates policies that lead to less private appropriation and accumulation of productive resources, hence less economic growth. In other words, the prevalence of income inequality encourages society to implement redistribution policies such as transfer payments, tax, and other regulatory policies, and given the importance of physical and human capital in the production process; these redistributive policies appropriate the economic gains by the rich reduces the incentive to invest in both physical and human capital and hence less economic growth (Barro 2000; Partridge 1997). It is argued that

the negative effect of income inequality on economic growth, as predicted by the political economy model, mainly applies to developing and newly industrialised economies and not advanced economies (Partridge 1997).

Like the political economy theory, the social-political unrest theory also asserts that income inequality retards economic growth. Thus, income inequality encourages disruptive socio-political activities such as riots, crime, political turnovers, etc. (Alesina and Perotti 1996; Barro 2000; Ezcurra 2007; Perotti 1996). It is argued that engagement of the poor in disruptive social and political activities is a direct waste of productive resource since the time spent on these disruptive activities are not devoted to something productive (Barro 2000). Also, the political instability posed by income inequality deters investment and distorts market activities and labour relations, retarding productivity and economic growth (Ezcurra 2007). Unlike political and social-political unrest arguments, the savings rate theory suggests that income inequality promotes economic growth. The savings rate theory inspired by Keynes assumes that the savings rate increases with an increasing income. If this assumption holds, redistribution of resources from rich to poor reduces the economy's savings rate and capital accumulation (Barro 2000; Ezcurra 2007). Therefore, higher income inequality spurs economic growth.

Another possible relationship between income inequality and economic growth is based on credit-market imperfections. This theory emphasised the linkage between credit constraints, income and wealth distribution, and physical and human capital investment (Ezcurra 2007; Piketty 1997). The credit-market imperfection theory suggests that with limited access to credit, the exploitation of investment opportunities depends on the asset and income of the individuals, and poorer households tend to forgo human-capital investment that offers a relatively high rate of returns (Barro 2000). In this case, distortion-free policies to redistribute income from the rich to the poor increase the amount and productivity of investment. This indicates that reducing income inequality at the initial stage generates a higher economic growth rate during the transition to a steady state (Barro 2000). However, an offsetting force arises if investments require an enormous setup cost. It is argued that investment in human and physical capital benefits the economy if it reaches a certain threshold. Therefore, if the setup cost is large relative to the median income, redistributing income from the rich to the poor will reduce aggregate investment and, thus, impede economic growth (Barro 2000; Ezcurra 2007). Credit imperfections reflect information asymmetry and deficiency in legal institutions; therefore, improving the capital market and legal institutions would be more important in developing economies than in developed economies (Barro 2000). In sum, the credit-market imperfection theory predicts both positive and negative effects of income inequality on economic growth.

The above theoretical discussions suggest that income inequality can affect economic growth through various channels. The conflicting theoretical arguments suggest that empirical research is needed to understand the linkage between income inequality and economic growth. From Table 1, some of the empirical studies have reported a negative effect of income inequality on economic growth (Easterly 2007; Ezcurra 2007; Herzer and Vollmer 2012; Keefer and Knack 2002; Mo 2000; Persson and Tabellini 1994) while others have reported a positive effect of income inequality on economic growth (Bleaney and Nishiyama 2004; Forbes 2000; Li and Zou 1998; Scholl and Klassen 2019). The literature survey suggests that the existing empirical studies have mainly employed cross-sectional and panel data approaches to examine the income inequality and economic growth relationship; however, these methods are argued to lack robustness (Banerjee and Duflo 2003; Ezcurra 2007). Additionally, the existing studies have laid less emphasis on country-specific analysis. However, given the differences among countries, it is important for studies to also

Table 1 Summary of selected empirical studies on the effect of income inequality on economic growth

Author	Country	Method	Results
Banerjee and Duflo (2003)	Cross-section data for 45 countries	Kernel regression	Inverted U-shaped relationship
Herzer and Vollmer (2012)	Panel data for 46 countries (1970–995)	DOLS	Negative effect
Persson and Tabellini (1994)	Cross-section data for 9 developed countries	OLS	Negative effect
Li and Zou (1998)	112 developed and developing countries (1947–1994)	Fixed and random effect	Positive effect
Ezcurra (2007)	63 European regions (1993–2002)	Maximum Likelihood estimator	Negative effect
Mo (2000)	Cross-sectional data (1965–1985)	Two-stage least square	Negative effect
Brueckner and Lederman (2015)	Panel data for 104 countries (1970–2010)	Two-stage least square	Negative effect for high and middle-income countries Positive effect for developing countries
Easterly (2007)	Cross-sectional data for 118 countries	Two-stage least square	Negative effect
Castello (2004)	Panel data for 96 countries (1960–1985)	System GMM	Negative effect
Bleaney and Nishiyama (2004)	Cross-sectional data	OLS	Positive effect
Forbes (2000)	Panel data for 45 countries (1966–1995)	Fixed effect, random effects and GMM	Positive effect
Keefer and Knack (2002)	Cross-sectional data	OLS	Negative effect
Knowles (2005)	Cross-sectional data	OLS	Negative effect
Panizza (2002)	Panel data for US states	Fixed effect and System GMM	Negative effect
Voitchovsky (2005)	Panel data for 25 countries (1975–2000)	System GMM	Inequality at the top end of the distribution has a positive effect Inequality at the lower end of the distribution has a negative effect
Berg et al. (2018)	OECD and Non-OECD countries	System GMM	Lower net income inequality promotes faster and durable economic growth
Breunig and Majeed (2020)	Panel data for 152 countries (1956–2011)	System GMM	Income inequality does not affect economic growth unless poverty is included in the model

Table 1 (continued)

Author	Country	Method	Results
Scholl and Klassen (2019)	Panel data for 122 countries (1961–2012)	System GMM and IV-estimation	Positive effect
Marrero and Servén (2021)	Panel data for 158 countries (1960–2010)	System GMM	It can be positive or negative depending on the econometric estimator
Hailemariam and Dzhumashev (2020)	Panel data (1965–2014)	Threshold model	Income inequality has a threshold effect on economic growth
Azam (2019)	13 Asia and the Pacific countries (1996–2008)	Random effect estimator	Negative effect
Akinci (2018)	Panel data for 143 countries (1980–2017)	Two-states least squares	Negative effect
Balcilar et al. (2021)	Panel data for 63 countries (1991–2017)	Semi-Parametric estimator (IV-estimator)	Income inequality has an inverted U-shaped relationship with economic growth

focus on time series analysis to inform country-specific policy. Furthermore, the existing empirical studies have not explored the causal relationship between income inequality and economic growth. Because of these knowledge gaps, our study contributes to the literature by employing novel non-parametric time series techniques to examine the effect of income inequality on economic growth in BRICS. Our study further contributes to the literature by addressing the causal relationship between income inequality and economic growth in BRICS using the Granger causality-in-quantiles approach.

3 Estimation strategy

3.1 Quantile-on-quantile technique

In this study, we follow and apply the Sim and Zhou (2015) QQR estimator to investigate the dependency between income inequality (INEQ) and economic growth (GDP) in BRICS. The QQR technique, an advanced form of the traditional QR estimator, is applied when an investigator is interested in identifying how one variable quantile influences another variable's quantiles. Thus, the Sim and Zhou (2015) QQR technique combines non-parametric and quantile regression techniques, where a quantile of one variable is regressed onto the quantile of another variable.

The application of the QQR technique in applied research involves two phases. In the first phase, the traditional Quantile Regression (QR) approach developed by Koenker and Bassett Jr (1978) is applied to estimate the impact of income inequality on different quantiles of economic growth. Relative to the linear OLS estimator, the QR technique is used to examine the effect of the independent variable at the tail and centre of the dependent, enabling a more thorough examination of the relationship between variables. In the second phase, Cleveland (1979) and Stone (1977) local linear regression is applied to estimate the spatial influence of a single quantile of the independent variables on the dependent variable. The local linear regression helps overcome the "curse of dimensionality" problem inherent in strictly non-parametric techniques. This dimensionality reduction strategy is to construct a linear regression locally around each point of the data in the dataset, offering closer neighbours more weight. Integrating these two modelling phases makes it feasible to estimate the quantile relationship between income inequality and economic growth and yields robust results compared to modelling approaches such as QR and OLS. In a nutshell, the QQR technique has been argued to provide robust results when investigating the influence of the quantiles of X on Y quantiles. As stated in Eq. (1), the QQR method has its root in the QR model:

$$GDP_t = \beta^{\vartheta}\left(INEQ_t\right) + \mu_t^{\theta} \tag{1}$$

where GDP_{2t} and $INEQ_t$ portray the dependent variable (economic growth) in period t and the independent variable (income inequality) in period t. θ stands for θth quantile of economic growth conditional distribution and μ_t^{θ} is an error term in the quantile whose θth conditional quantile is zero (0). The unknown function is illustrated by $\beta^{\vartheta}(\bullet)$ because previous information connecting economic growth and INEQ is unknown. The effect of INEQ on the distribution of economic growth is measured using this QR model, which permits the influence of INEQ to vary across various economic growth quantiles. Since there is no established hypothesis about the functional form of the linkage between INEQ and economic growth, the primary benefit of this specification is its stability. However, one

limitation of the QR method is its inability to capture complete dependency. In this respect, the QR model ignores the probability that the existence of INEQ shocks influences the association between economic growth and INEQ. For instance, the results of big positive INEQ shocks can vary from those of small positive INEQ shocks. Furthermore, negative and positive INEQ shocks will cause economic growth to respond asymmetrically.

Therefore, to examine the relationship between θth the quantile of economic growth and τth of INEQ, represented by INQ^{τ}, the local LR is applied to investigate INQ^{τ} neighbourhood. The unknown function which is depicted by $\beta^{\vartheta}(\bullet)$ can be estimated as a first-order Taylor expansion centred on INQ^{τ} quantile as follows:

$$\beta^{\theta}\left(INEQ_t\right) \approx \beta^{\theta}\left(INEQ^t\right) + \beta^{\theta_1}\left(INEQ^t\right)\left(INEQ^t - INEQ^t\right) \tag{2}$$

where $\beta^{\theta}\left(INEQ_t\right)$ partial derivative concerning INEQ is illustrated by β^{θ_1} which is also recognised as a response and is comparable to the coefficient slope in a LR framework in terms of meaning. The notable feature of Eq. (2) is that $\beta^{\theta}(INEQ^{\tau})$ and $\beta^{\theta_1}(INEQ^{\tau})$ parameters are twice indexed in τ and θ. Given that $\beta^{\theta}(INEQ^{\tau})$ and $\beta^{\theta_1}(INEQ^{\tau})$ are functions of θ and $INEQ^t$ and $INEQ^t$ is a function of τ, it is obvious that $\beta^{\theta_1}(INEQ^{\tau})$ and $\beta^{\theta}(INEQ^{\tau})$ are both functions of τ and θ, respectively. Also, $\beta^{\theta}(INEQ^{\tau})$ and $\beta^{\theta_1}(INEQ^{\tau})$ can be represented as $\beta_0(\theta,\tau)$ and $\beta_1(\theta,\tau)$. Therefore, Eq. (2) can be transformed as follows:

$$\beta^{\theta}\left(INEQ_t\right) \approx \beta_0(\theta,\tau) + \beta_1(\theta,\tau)\left(INEQ_t - INEQ^{\tau}\right) \tag{3}$$

When Eq. (3) is substituted into Eq. (1), Eq. (4) is obtained as follows:

$$GDP_t = \underbrace{\beta_0(\theta,\tau) + \beta_1(\theta,\tau)\left(INEQ_t - INEQ^{\tau}\right)}_{(*)} + \mu_t^{\theta} \tag{4}$$

In Eq. (4), the θth conditional quantile economic growth is depicted by (*). However, contrary to the standard conditional quantile function, this illustration discloses the interconnection between θth of economic growth and τth quantile of INEQ because β_0 and β_1 parameters twice index in θ and τ. These parameters may differ throughout various distinct θth quantiles of economic growth and τth quantiles of INEQ. Furthermore, no linear association between the variable quantiles under analysis is presumed at any point. As a result, Eq. (4) estimates the overall dependency structure between economic growth and INEQ based on the correlation between their different distributions.

Also, $INEQ_t$ and $INEQ^{\tau}$ is replaced by $\widehat{INEQ_t}$ and $\widehat{INEQ^{\tau}}$ when estimating Eq. (4). The parameters b_0 and b_1, which are β_0 and β_1 estimates are gathered by fixing the following issue of minimisation:

$$\min_{b_0,b_1} \sum_{i=1}^{n} \rho\theta\left[GDP_t - b_0 - b_1\left(\widehat{INEQ_t} - \widehat{INEQ^{\tau}}\right)\right] K\left(\frac{F_n\left(\widehat{INEQ_t}\right) \sqcap -\tau}{h}\right) \tag{5}$$

where the quantile loss function is illustrated by $\rho_{\theta}(u)$, and $\rho_{\theta}(u) = u(\theta - I(u < 0)), I$, which is the usual indicator function. The kernel function and h, which is the parameter kernel bandwidth, is depicted by $K(\bullet)$. The Gaussian kernel, which is applied to weight the observations in the $INEQ^{\tau}$ neighbourhood is one of the most common kernel functions in finance and economics research due to its simplicity, computation, and reliability.

Around zero, the Gaussian kernel is symmetric, giving lower observations of weights that are further out. These weights are inversely proportional to the distance between the analytical distribution function of $\widehat{INEQ_t}$, indicated by $F_n\left(\widehat{INEQ_t}\right) = \frac{1}{n}\sum_{k=1}^{n} I\left(\widehat{INEQ_k} > \widehat{INEQ_t}\right)$ and the function of distribution value that aligns with the $INEQ^{\tau}$ is illustrated by τ. When utilising the non-parametric approaches, bandwidth selection is crucial. The bandwidth governs the smoothness of the corresponding approximation since it specifies the scale of the neighbourhood surrounding the target point. A wider bandwidth suggests a higher risk of estimation distortion, while a smaller bandwidth illustrates a higher risk of prediction uncertainty. As a result, a bandwidth must be chosen that provides equilibrium between variance. Following Sim and Zhou's (2015) recommendation, a bandwidth $h=0.05$ parameter was used for the analysis. We further check the validity of the QQR results by comparing the estimated QR parameters with the averaged QQR parameters.

4 Results and discussion

4.1 The description and nature of the data

This study used time-series data ranging from 1960 to 2019 for BRICS. In this study, we used the post-tax/transfer (net) Gini index from the Solt (2016) Standardized World Income Inequality Database (SWIID)[1] to represent income inequality (INEQ). The SWIID inequality data is essential for this study because it combines and standardises inequality data from various inequality databases such as the World Income Inequality Database, Luxembourg Income Studies, World Income Distribution Data, and others (Solt 2016). Previous studies such as Berg et al. (2018) and Acheampong et al. (2021) and Scholl and Klassen (2019) have utilised the SWIID. Also, GDP per capita growth (annual %) is used to measure economic growth. The GDP per capita growth variable was sourced from the World Development Indicator database. The descriptive statistics of the variables for each of the countries are presented in Table 2. Table 2 shows that for the economic growth (GDP) variable, China (6.7949) has the highest mean, followed by India (3.2668), Brazil (2.1138), Russia (0.8950) and South Africa (0.8228). The kurtosis value for all the BRICS countries shows that all the variables are leptokurtic. Furthermore, the skewness value indicates that Brazil, Russia, India, China and South Africa have a negatively skewed GDP. Regarding the income inequality (INEQ) variable, South Africa (62.0258) has the highest average value, followed by Brazil (50.9838), India (India), China (38.8903) and Russia (34.0677). The kurtosis value shows that Russia's inequality is platykurtic, while inequality values for Brazil, India, China, and South Africa are leptokurtic. Moreover, regarding income inequality, the skewness value shows that all the variables are negatively skewed.

After the descriptive statistics, we applied the BDS test developed by Broock et al. (1996) to assess the linearity attributes of the variables. The BDS results are presented in Table 3, and the findings show that the null hypothesis of "linearity" is rejected at a significance level of 1%. This suggests that applying linear econometric techniques such as OLS, fixed effect, three-stages least-squares, etc., to examine the relationship between income inequality and economic growth can lead to biased results (see Banerjee and Duflo 2003).

[1] See Solt (2016) for detailed discussion on the SWIID inequality data.

Table 2 Descriptive statistics

	Economic Growth (GDP)							
Country	Mean	Median	Maximum	Minimum	Std. Dev	Skewness	Kurtosis	Jarque–Bera
Brazil	2.1138	2.1089	11.2938	-6.4787	3.7664	-0.0552	2.9239	0.0442
Russia	0.8950	1.9767	10.4637	-14.6139	6.4593	-0.6826	2.7132	2.4326
India	3.2668	3.7344	7.2994	-7.3881	3.0373	-1.1568	4.5691	19.2113
China	6.7949	7.6084	16.0504	-26.5276	6.6047	-2.5757	12.7764	300.2011
South Africa	0.8228	1.2231	5.2369	-4.5503	2.3819	-0.4101	2.5922	2.0624
	Inequality (INEQ)							
Country	Mean	Median	Maximum	Minimum	Std. Dev	Skewness	Kurtosis	Jarque–Bera
Brazil	50.9838	51.7062	55.0281	46.1281	3.09623	-0.2335	1.42645	13.919
Russia	34.0677	35.7046	37.2312	24.9593	3.66870	-1.47293	3.91382	49.151
India	45.7330	46.5968	49.7078	41.0843	3.37318	-0.17853	1.35966	14.560
China	38.8903	41.1062	43.0156	30.5375	3.86136	-0.70808	2.08913	14.648
South Africa	62.0258	62.3968	63.5156	60.1843	1.11345	-0.28919	1.61606	11.623

The values in this table are the raw values of the variables

Table 3 BDS test

	Z-stat(P-value)	Z-stat(P-value)	Z-stat(P-value)	Z-stat(P-value)	Z-stat(P-value)
Economic growth					
Country	M2	M3	M4	M5	M6
Brazil	21.894*	21.962*	22.259*	22.920*	24.106*
Russia	28.853*	29.589*	30.381*	31.808*	34.268*
India	22.298*	21.752*	22.651*	24.469*	26.790*
China	24.503*	25.179*	26.175*	27.812*	30.280*
South Africa	27.452*	28.520*	29.822*	31.980*	34.961*
Inequality					
Brazil	21.869*	22.375*	22.859*	23.798*	25.221*
China	20.059*	21.227*	22.473*	24.223*	26.542*
Russia	9.4401*	9.6817*	9.8624*	10.211*	10.669*
India	9.6994*	8.8879*	7.7253*	7.0201*	7.0787*
South Africa	23.718*	24.774*	25.615*	27.070*	28.111*

* presents the 1% level of significance

Based on this knowledge, we applied the non-linear econometric approaches to determine the relationship between inequality and economic expansion in the BRICS economies.

After determining the variables' nonlinearity properties, we investigate the stationarity properties of the variables. Therefore, we utilised the quantile unit root test suggested by Koenker and Xiao (2004), an upgraded version of the Augmented Dickey-Fuller (ADF). The quantile unit root test was utilised, considering various disruptions influencing income inequality and economic growth. Prior studies that have employed time series or panel unit root tests, on the other hand, overlooked the impact of these shocks on different quantiles of income inequality and economic growth. The optimal number of lags used in this study

Table 4 Quantile unit root test results

	Economic growth (GDP)									
	Brazil		Russia		India		China		South Africa	
Quantile	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats
0.1	1.028	-1.937	0.933	-1.245	0.992	-1.516	0.926	0.689	0.853	-0.945
0.2	1.028	1.285	0.832	-1.890	1.110	-1.578	1.193	-0.267	1.003	-1.538
0.3	0.972	0.872	0.981	-1.929	1.044	-2.080	1.081	-1.291	0.987	-1.879
0.4	1.001	-1.582	0.961	-2.041	0.998	1.095	0.978	-2.045	0.912	-2.053
0.5	0.989	-1.329	1.002	-2.011	0.972	-2.203	1.001	-1.256	1.005	-1.839
0.6	0.999	-1.780	1.114	-1.900	1.001	-1.929	0.972	-0.458	0.962	-2.115
0.7	1.001	-1.609	0.987	-1.543	0.988	-1.783	1.011	-1.977	1.004	-0.842
0.8	0.958	-2.133	1.082	-1.811	1.017	1.444	1.009	-0.087	0.942	-0.220
0.9	0.991	-2.196	0.989	-0.785	0.995	1.246	1.004	-2.290	1.013	-0.832
	Income inequality (INEQ)									
	Brazil		Russia		India		China		South Africa	
Quantile	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats
0.1	0.791	-2.120	0.877	− 1.324	0.877	− 1.324	0.877	− 1.324	1.011	-1.122
0.2	0.712	-1.521	0.886	− 1.383	0.886	− 1.383	0.886	− 1.383	1.022	-1.420
0.3	0.848	-1.438	0.828	− 1.826	0.828	− 1.826	0.828	− 1.826	0.982	-1.314
0.4	0.856	-2.156	0.814	− 2.159	0.814	− 2.159	0.814	− 2.159	0.922	-1.392
0.5	0.975	-2.221	0.858	− 1.894	0.858	− 1.894	0.858	− 1.894	0.933	-1.921
0.6	0.922	-2.021	0.794	− 2.192	0.794	− 2.192	0.794	− 2.192	0.839	-2.119
0.7	0.938	-1.772	0.855	− 1.822	0.855	− 1.822	0.855	− 1.822	0.829	-2.211
0.8	0.979	-1.736	0.814	− 1.812	0.814	− 1.812	0.814	− 1.812	0.797	-1.341
0.9	0.953	-1.762	0.799	− 2.130	0.799	− 2.130	0.799	− 2.130	0.910	-1.332

Table 4 presents points estimated and t-values at 5%. In the table t-value < CV, we reject the null hypothesis of $\alpha(\tau) = 1$. While Quantiles bold values > CV, which means $\alpha(\tau) \neq 1$ on different quantiles

to overcome the serial correlation problem is 10. The quantile unit root tests are presented in Table 4. Table 4 shows that income inequality and economic growth have unit roots in Brazil, Russia, India, China and South Africa.

4.2 Quantile cointegration results

After determining the stationarity properties of the variables, we determine the cointegration between income inequality and economic growth. It is worth noting that the conventional cointegration test can provide biased results since the variables are nonstationary. Centred on this knowledge, the current study used the quantile cointegration technique developed by Xiao (2009). The advantage of this method is that it can determine the long-run relationship between income inequality and economic growth at all quantiles using a spaced grid of 19 quantiles (0.05–0.95). Table 5 provides the results of the quantile cointegration, and shows evidence of cointegration between inequality and economic growth in all the BRICS countries at various quantiles of both income inequality and economic growth.

Table 5 Quantile cointegration results

Model	Coefficient	$Sup_{\tau}\|V_{\pi}(\tau)\|$	CV1%	CV5%	CV10%
Brazil	β	4282.49	2444.41	1657.78	784.20
	α	667.13	466.10	286.86	161.19
Russia	β	2164.42	1150.60	764.79	2313.61
	α	287.49	127.03	86.27	42.48
India	β	987.49	807.03	607.27	482.48
	α	114.29	83.55	49.69	35.96
China	β	3214.61	2332.70	1441.51	810.80
	α	376.29	202.03	187.28	111.27
South Africa	β	7609.57	5770.19	3792.06	2827.69
	α	703.22	605.94	482.17	326.88

4.3 Quantile-on-quantile regression results

This section presents and discusses the main empirical results from the QQR technique. Figure 1 displays the QQR results. Figure 1a shows the effect of income inequality (INEQ) on Brazil's economic growth (GDP). Figure 1a shows that INEQ significantly impacts all the GDP's tail (0.05–0.95). The INEQ has a stronger negative effect on GDP at the lower and middle tails (0.05–0.6). However, at the higher quantiles (0.60–0.95), the effect of INEQ on GDP is positive and weak. On the other hand, the effect of GDP on INEQ in Brazil is shown in Fig. 1b. From Fig. 1b, GDP has a weak negative impact on INEQ at all the tails (0.1–0.95). These results suggest that in Brazil, income inequality has a more substantial negative effect on economic growth at the lower and middle tails, while economic growth, on the other hand, has an insignificant on income inequality.

The significant negative effect of income inequality on Brazil's economic growth supports the credit-market imperfection, political economy and socio-political unrest theories. Theoretically, it is argued that higher income inequality can impede economic growth by encouraging disruptive socio-political activities such as riots, crime, political turnovers, etc. (Alesina and Perotti 1996; Barro 2000; Ezcurra 2007; Perotti 1996). It is argued that the engagement of the poor in disruptive social and political activities is a direct waste of productive resource since the time spent on these disruptive activities are not devoted to productive ventures (Barro 2000). Also, the political instability posed by income inequality deters investment and distorts market activities and labour relations, retarding productivity and economic growth (Ezcurra 2007). The negative effect of income inequality on Brazil's economic growth aligns with previous studies that revealed that income inequality harms economic growth (Easterly 2007; Ezcurra 2007; Herzer and Vollmer 2012; Keefer and Knack 2002; Mo 2000; Persson and Tabellini 1994).

Also, Fig. 1c displays the effect of INEQ on GDP in Russia. Figure 1c shows that at all quantiles (0.-0.90) of INEQ and lower tails (0.05–0.35) of GDP, INEQ has a significant positive effect on GDP. Furthermore, in the middle and higher tails (0.40–0.90) of GDP and all quantiles (0.1–0.90) of INEQ, the positive effect of INEQ on GDP is dominant, though the magnitude of the coefficient decreases. Also, the effect of GDP on INEQ in Russia is shown in Fig. 1d, and the results revealed interesting findings. For instance, at the lower tails (0.05–0.2) of INEQ and all quantiles (0.05–0.9) of GDP, the effect of GDP on INEQ is positive. Furthermore, in the lower tails (0.05–0.30) of GDP and INEQ, the impact of GDP on INEQ is weak and negative. In addition, in the middle tails (0.40–0.90)

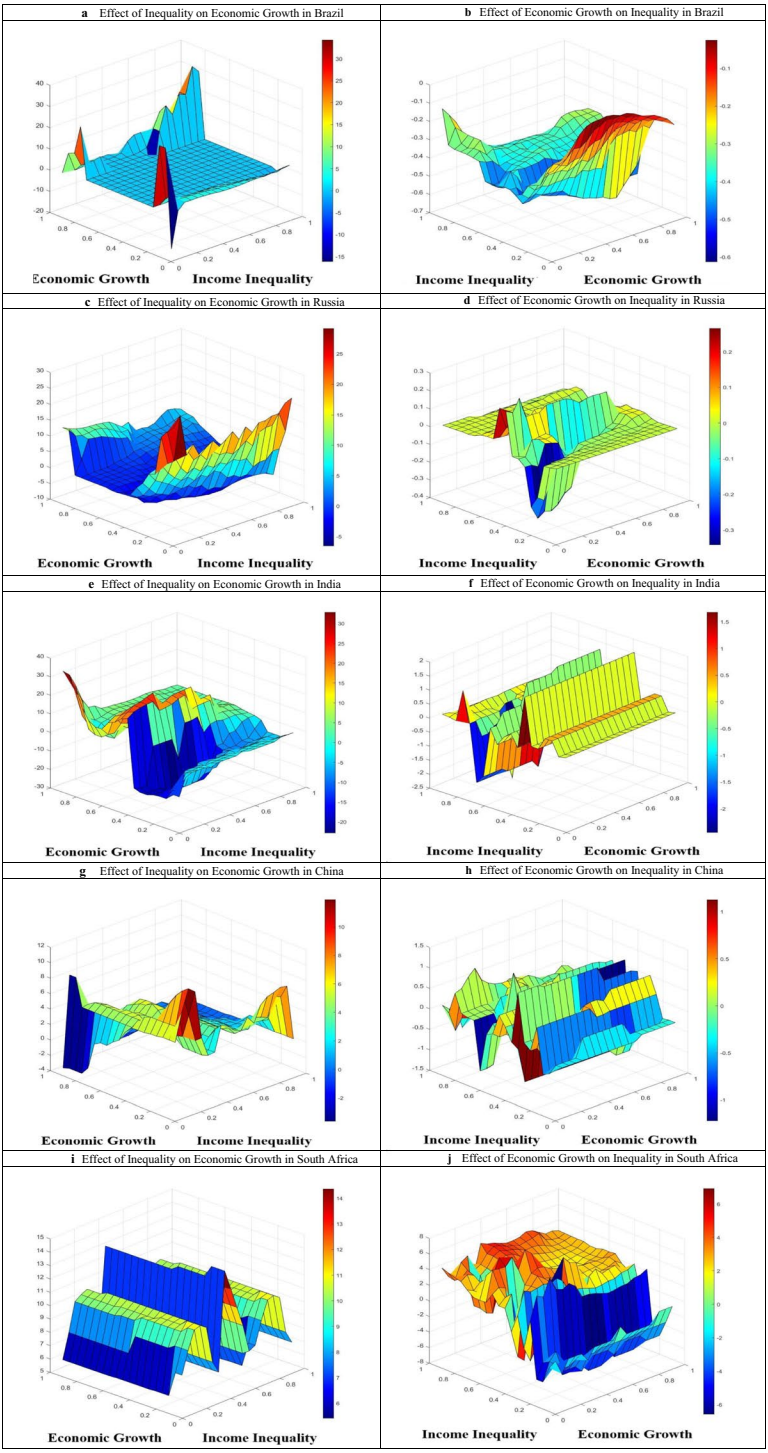

Fig. 1 Quantile-on-Quantile (QQ) estimates of the slope coefficient

of both GDP and INEQ, the effect of GDP on INEQ is positive. In summary, in most quantiles, economic growth drives income inequality in Russia. These results suggest that economic growth has widened income inequality in Russia by increasing the income of the middle and upper classes. At the same time, income inequality has contributed substantially to Russia's economic growth. The positive effect of the middle and higher quantile of income inequality on Russia's economic growth reflects the theoretical argument that higher income inequality stimulates economic growth by encouraging savings, investment, innovations and efficiency. These results affirm Voitchovsky's (2005) findings that inequality at the top end of income distribution positively affects economic growth.

Figure 1e displays the effect of INEQ on GDP at all tails (0.05–0.95) in India. Figure 1e suggests that for India, most of the quantile of INEQ has a significant negative effect on GDP at the lower tails (0.05–0.40) of GDP. However, at the middle and higher tails (0.45–0.90) of GDP and INEQ, the effect of INEQ on GDP is positive. This result suggests that an increase in income inequality has contributed to India's economic growth. In summary, the positive effect of INEQ on GDP is dominant. On the other hand, Fig. 1f shows that the lower tails (0.05–0.45) of GDP have a weak negative effect on INEQ at all quantiles (0.05–0.90). Furthermore, the middle and higher quantiles (0.50–0.90) of GDP have a positive and dominant effect on INEQ. Thus, the effect of GDP on INEQ is positive, suggesting that GDP drives INEQ positively in India. The implication is that higher economic growth has contributed significantly to the rise of income inequality in India. At the same time, income inequality has an asymmetric effect on economic growth in India. Thus, for India, income inequality has a stronger negative effect on the lower tails of economic growth while having a stronger positive impact on the middle and higher tails of economic growth. The distinctive negative effect of income inequality on reducing the lower tails of economic growth in India reflects the credit constraint, social unrest and reduced effort argument in the literature (Barro 2000; Perotti 1996). Contrarily, the positive effect of income inequality on the middle and higher tails of economic growth reflects the theoretical argument that higher income inequality stimulates economic growth by encouraging savings, investment, innovations and efficiency. The asymmetric effect of income inequality on economic growth in India affirms the inverted U-shaped relationship found by Banerjee and Duflo (2003).

Figure 1g displays the effect of INEQ on GDP in China. At most INEQ and GDP quantiles (0.05–0.90), INEQ has a positive and dominant impact on GDP, suggesting that income inequality promotes economic growth. On the flip side (see Fig. 1h), the positive effect of GDP on INEQ is dominant. These outcomes suggest that both INEQ and GDP impact each other positively. Lastly, Fig. 1i presents the effect of INEQ on GDP across all quantiles (0.05–0.95) in South Africa. At all quantiles (0.05–0.95) of both INEQ and GDP, INEQ has a positive and dominant effect on GDP in South Africa. On the other hand (see Fig. 1j), irrespective of the quantiles, GDP has a stronger negative effect on the lower tails (0.05–0.30) of INEQ and a positive effect on the middle and higher quantiles of INEQ. These results suggest that in India, economic growth has been widening income inequality by reducing the poor's income while enhancing the richer people's income.

The positive effect of income inequality on economic growth in China and South Africa reflects income inequality's positive role in driving economic growth, as identified in the theoretical literature. Theoretically, Aghion et al. (1999) argue that income inequality can spur economic growth since richer people have a higher marginal propensity to save (MPS) than poorer people. Therefore, the higher savings rate of the wealthier people stimulates investment and economic growth. It is also argued that income inequality generates higher economic growth because if economic output depends on the work effort of agents, any redistributive policies to reduce income inequality might discourage economic

agents (investors) from making any additional effort and thus reduce the efficiency of the production system (De Dominicis et al. 2008; Mirrlees 1971). The empirical findings for India, China and South Africa are consistent with previous results suggesting that income inequality spurs economic growth. (Bleaney and Nishiyama 2004; Forbes 2000; Li and Zou 1998).

4.4 Robustness check using quantile regression (QR)

In this section, we present the results from the QR technique. We applied the QR technique to determine the consistency of the QQR results. The graphical comparison of both QQR and QR results is presented in Fig. 2 (a-j). Figure 2(a–j) demonstrates that irrespective of the quantile used, the mean QQR estimates of the slope coefficient are identical to the QR estimates. Thus, the result presented in Fig. 2(a–j) suggests that the QR estimates are consistent with the QQR estimates.

For instance, Fig. 2 validates the QQR results. For example, Fig. 2a shows that in Brazil, INEQ has a significant negative effect on GDP in both lower and middle tails (0.05–0.60), while in the higher tails, the effect is positive and weak. Also, Fig. 2b shows that GDP has a weak negative effect on INEQ in Brazil. Furthermore, Fig. 2c also shows that INEQ has a significant positive effect on the tails (0.05–0.95) of GDP in Russia. In addition, Fig. 2d shows that GDP has a weak positive effect on INEQ in Russia. Also, Fig. 2e validates the QQR estimates for India, suggesting that for all tails (0.1–0.95), INEQ has a stronger positive effect on GDP. In addition, Fig. 2f shows that in India, GDP has a negative effect on the lower and higher tails (0.05–0.25 and 0.7–0.95) of INEQ, but at the middle tails of INEQ (0.3–0.65), the impact of GDP is positive. Furthermore, Fig. 2g confirms the QQR results for China, indicating that at all quantiles (0.1–0.95), INEQ has a significant positive effect on GDP. Figure 2h further confirms QQR results, suggesting that GDP has a weak positive effect on INEQ in China. Figure 2i also validates the QQR estimates for South Africa, showing that at all tails (0.1–0.95), INEQ has a significant positive on GDP, while Fig. 2j suggests that GDP has a positive effect on INEQ.

The consistency of the QQR and QR results suggests that our findings are reliable for informing policies geared towards improving income inequality and economic growth in BRICS countries.

4.5 Granger causality in quantiles results

This section presents the causal relationship between income inequality and economic growth. We apply the Troster (2018) Granger Causality in Quantiles to examine the causal relationship between income inequality and economic growth. Using the Troster (2018) Granger Causality in Quantiles approach helps to discriminate between causality affecting the median and the tails of the conditional distribution. This approach provides a sufficient condition for Granger-causality when all quantiles are considered (Troster 2018).

The Troster (2018) Granger causality in quantiles results are presented in Table 6, and the findings are as follows: For Brazil, considering all quantiles, changes in GDP do not Granger-cause changes in INEQ at all quantiles. However, in the middle quantiles (0.50–0.65), the null hypothesis of "no causality" from INEQ to GDP is dismissed at a 5% significance level. Therefore, there is unidirectional causality from INEQ to GDP in Brazil but at different quantiles. For China, at the lower (0.20–40) and higher (0.70–0.95)

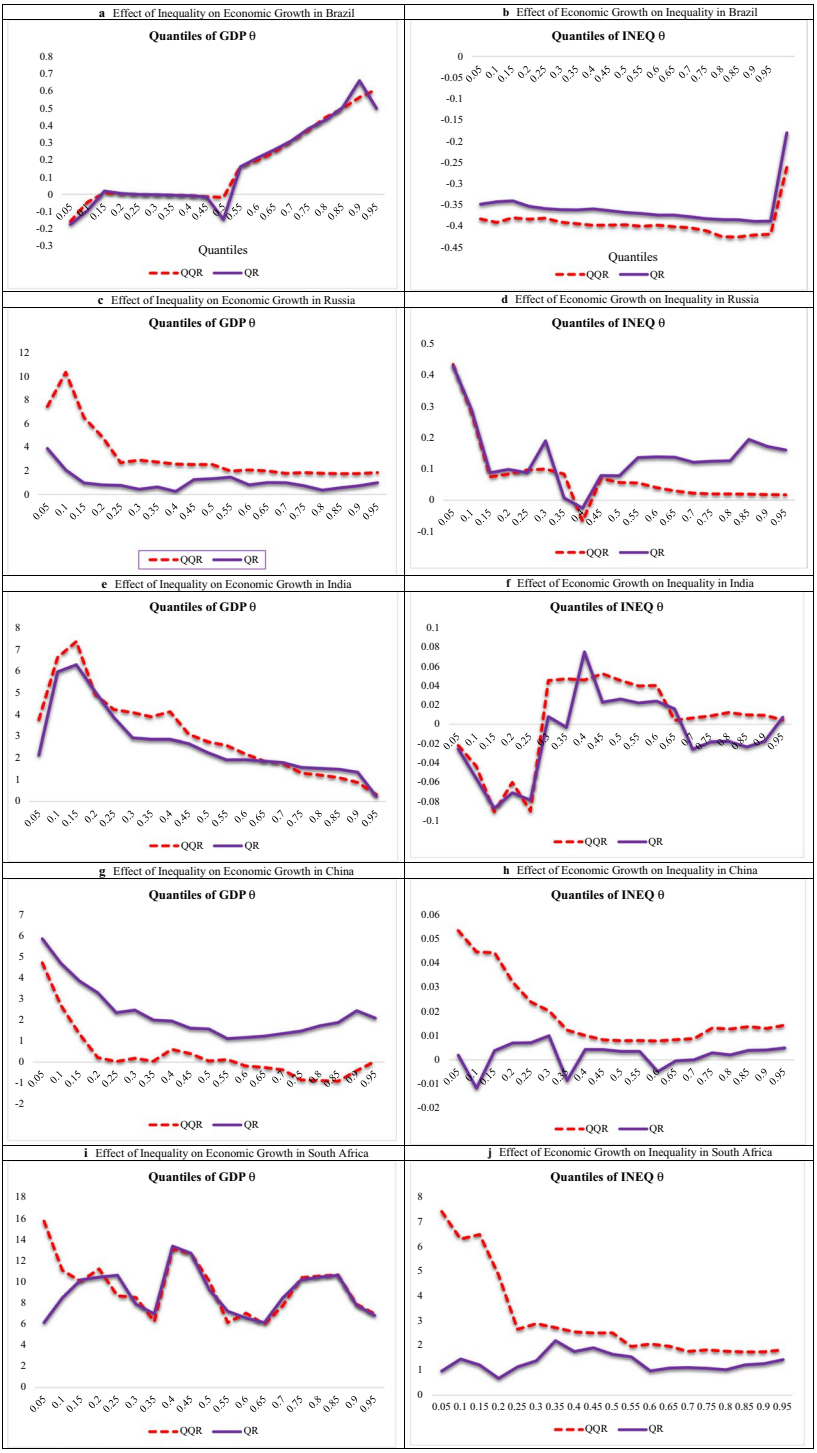

Fig. 2 Comparison of quantile regression and quantile-on-quantile estimate

Table 6 Troster (2018) granger causality in quantiles

Quantiles	Brazil		Russia		India		China		South Africa	
	Δ GDP⇨Δ INEQ	Δ INEQ⇨Δ GDP	Δ GDP⇨Δ INEQ	Δ INEQ⇨Δ GDP	Δ GDP⇨Δ INEQ	Δ INEQ⇨Δ GDP	Δ GDP⇨Δ INEQ	Δ INEQ⇨Δ GDP	Δ GDP⇨Δ INEQ	Δ INEQ⇨Δ GDP
Overall	0.298	0.369	0.833	0.274	0.083	0.071	**0.012**	**0.012**	0.250	0.631
0.05	0.214	0.214	0.893	0.833	0.083	0.083	0.810	0.563	0.417	0.060
0.10	0.214	0.226	0.893	0.833	0.083	0.083	0.202	**0.012**	0.440	0.083
0.15	0.214	0.262	0.905	0.833	0.083	0.083	0.429	**0.012**	0.452	0.262
0.20	0.214	0.357	0.917	0.071	0.083	0.083	**0.012**	**0.012**	0.464	0.429
0.25	0.226	0.393	0.917	0.214	0.083	0.083	**0.012**	**0.012**	0.476	0.655
0.30	0.250	0.619	0.917	0.357	0.083	0.083	**0.012**	**0.012**	0.476	0.762
0.35	0.214	0.655	0.917	0.417	0.083	0.083	**0.012**	**0.012**	0.476	0.345
0.40	0.190	0.810	0.917	0.226	0.083	0.083	0.357	**0.012**	0.881	0.262
0.45	0.202	0.429	0.917	0.321	0.083	0.083	0.202	0.786	0.167	0.833
0.50	0.202	**0.036**	0.833	0.226	0.083	0.083	0.500	0.940	0.357	0.929
0.55	0.119	**0.036**	0.833	0.226	0.083	0.083	0.917	0.048	0.238	0.881
0.60	0.357	**0.036**	0.833	0.250	0.083	**0.036**	0.345	0.238	0.214	0.607
0.65	0.417	**0.036**	0.833	0.238	0.083	**0.036**	0.167	**0.012**	0.202	0.655
0.70	0.429	0.190	0.833	0.369	0.083	**0.036**	**0.012**	**0.012**	0.190	0.655
0.75	0.167	0.274	0.833	0.881	0.083	**0.036**	**0.012**	**0.012**	0.167	0.464
0.80	0.048	0.274	0.833	0.833	0.083	**0.036**	**0.012**	**0.012**	0.036	0.619
0.85	0.726	0.250	0.595	0.262	0.083	**0.036**	**0.012**	**0.012**	0.036	0.595
0.90	0.667	0.214	0.417	0.143	0.083	**0.036**	**0.012**	**0.012**	0.262	0.560
0.95	0.774	0.214	0.298	0.012	0.083	**0.036**	0.643	0.821	0.238	0.417

The rejection of the null hypothesis of "non-Granger causality" at significance levels of 1% and 5% are illustrated by the bold values

quantiles, changes in GDP Granger-cause changes in INEQ at various quantiles while at different quantiles (0.25–0.40 and 0.70–0.95), changes in INEQ Granger-cause changes in GDP. Therefore, there is proof of a two-way causal connection between GDP and INEQ in China at 1% and 5% significance levels, respectively. For Russia, considering all quantiles, changes in GDP do not Granger-cause changes in INEQ, while at all quantiles, changes in INEQ do not Granger-cause GDP. Therefore, there is no causality between GDP and INEQ in Russia. Also, in India, considering all quantiles, changes in GDP do not Granger-cause changes in INEQ, while at 0.6–0.95 quantiles, changes in INEQ Granger-cause changes in GDP, suggesting unidirectional causality from INEQ to GDP in India. Lastly, in South Africa, changes in GDP do not Granger-cause changes in INEQ, while changes in INEQ do not Granger-cause GDP. These causality results suggest that while policies to address income inequality can affect economic growth, any growth-enhancing policy or strategy would also affect income inequality in BRICS.

5 Conclusion and policy implications

The income inequality-economic growth linkage is a topical issue in economics and policy discussions. Both theoretical and empirical results on the impact of income inequality on economic growth have been controversial. The main criticisms of the existing studies relate to using cross-sectional data and linear estimation techniques for empirical analysis. To address the limitations in the existing literature, this article employs the novel Quantile-on-Quantile Regression (QQR) approach to examine the relationship between income inequality and economic growth in BRICS. The application of the QQR technique helps to model how income inequality affects the distributions of economic growth.

From the empirical analysis, the quantile cointegration tests reveal cointegration between income inequality and economic growth. Using the non-parametric time series techniques, the quantile cointegration tests revealed cointegration between income inequality and economic growth. The QQR results indicate that income inequality has a stronger negative effect on the lower and middle tails of economic growth in Brazil while having a stronger positive impact on economic growth in Russia, China and South Africa. For India, income inequality has a stronger negative effect on the lower tail of economic growth and a stronger positive impact on the middle and higher tails of economic growth. These results are consistent with quantile regression results. Further analysis from the Granger causality-in-quantiles shows that at various quantiles, a bidirectional causal relationship between income inequality and economic growth exists in China, while a unidirectional causality runs from income inequality to economic growth in Brazil and India. No causal relationship was found between income inequality and economic growth in Russia and South Africa. The policy implications are discussed.

From a policy perspective, this study's established relationship between income inequality and economic growth is essential for designing and implementing equality and efficiency policies in BRICS. Our study has highlighted that income inequality can positively and negatively affect economic growth. However, such an effect is contextual, and policymakers should be cautious when designing and implementing equality and efficiency policies across the globe in the face of contentious theoretical debates surrounding the economic growth effect of income inequality. Our findings clearly show that income inequality hinders economic growth in Brazil. This finding suggests that policymakers can use redistributive policies to achieve higher economic growth in Brazil. Contrarily, our analysis

clearly shows the trade-off between income inequality and economic growth in Russia, India, China and South Africa. The policy implication is that reducing income inequality using redistributive policies can hinder economic growth in these countries. However, policymakers in these economies should be circumspect since it cannot be overlooked that higher income inequality can impede economic growth by encouraging disruptive socio-political activities such as riots, crime, political turnovers, etc. (Alesina and Perotti 1996; Barro 2000; Ezcurra 2007; Perotti 1996). Finally, our causality analysis suggests that while policies to address income inequality can affect economic growth, any growth-enhancing policies and strategies would also affect income inequality in BRICS.

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Declarations

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