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Article

Interconnectedness of financial markets in crises in the case of the enlarged BRICS

Gulnara Romashkina[1], Kirill Andrianov[2,*], Djamilia Skripnuk[3], Yulia Yukhtanova[1]

[1] Tyumen State University, 625003 Tyumen, Russia
[2] Cbonds.ru Ltd, 196006 Saint Petersburg, Russia
[3] Institute of Industrial Management, Peter the Great St. Petersburg Polytechnic University, 195251 Saint Petersburg, Russia
[*] **Corresponding author:** Kirill Andrianov, kirvland@yandex.ru

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Abstract: The article presents a study of the connectivity and integration of sovereign bond and stock markets in 10 BRICS+ countries in the context of crisis instabilities in 2019−2024. Financial markets are becoming more integrated, and an increasing share of public investments are carried out across borders, which increases not only the opportunities for participants, but also the risks of a new crisis. The work used data on central bank rates of the considered countries, yield indices of 10-year government bonds, gold and Brent oil prices. The methods include the analysis of exchange rate dynamics, connectivity estimates based on the multivariate concordance coefficient and two-factor Friedman rank variance analysis, VAR models, Granger predictability and cointegration. The objective of this study is to analyze the interrelationship and cointegration between the sovereign bond and equity markets of selected BRICS+ countries during crisis periods. Our findings indicate that market interrelationship intensifies during crises, which in turn amplifies volatility. Additionally, we observed that none of the economies within the BRICS+ group can be classified as fully integrated or entirely isolated markets. The disruption of the interrelationship in the sovereign bond markets of the group is primarily reflected in the inconsistency of dynamic changes between Russia, China, and India. During the global shock of 2019–2020, the crisis spread from China, followed by Indonesia, and later to the other countries of the group. The financial and debt markets of the sampled countries were able to quickly cope with the severe shocks of the COVID-2019 period. The 2022–2024 crisis, which lasted significantly longer, began in Russia before spreading to countries across Asia and Africa. By 2024, Russia's sovereign bond yields showed a marked decline. The increased market volatility following 2022 disrupted the integration and interrelationship of the stock and debt markets within the BRICS+ countries.

Keywords: institutes; finances; financial market; government debt; crysis; bonds; international integration

1. Introduction

Numerous quantitative studies have confirmed that financial markets not only express the capital allocation process that promotes economic growth, but also reflect expectations about the economic environment and economic fluctuations of a country or region (Li et al., 2024). The interdependence between financial crises and economic downturns has also been proven (Casarin et al., 2023). This issue is highly relevant, as financial markets are becoming increasingly integrated, and a growing share of government investments is being made by foreign investors, thereby increasing risks for economic actors.

In recent years, government institutions have increasingly intervened in economic relations during crises, but the outcomes of these interventions have varied

significantly. It remains unclear whether these differences are driven by political, cultural, economic factors, or behavioral patterns. The fact that the most financially open economies are more susceptible to the economic side effects of financial crises has contributed to the varying spread of crises between markets in Southeast Asia and Latin America (Hegerty, 2012; Rahmayani et al., 2021). García-Herrero attributes the severe negative impact of the Covid-19 pandemic on the Latin American economy to excessive debt burdens and reliance on dollar liquidity, both of which are linked to the region's economic openness (García-Herrero, 2021). In contrast, although the Asian market was also heavily affected by the pandemic, it did not face the same level of economic devastation. The case of Nigeria has shown that poor government policies have exacerbated the negative impact of the COVID-19 pandemic on the economy (Zhang, 2024). In contrast, De Vries et al. demonstrated that in France, labor productivity increased across several sectors during the same period, facilitating a rapid economic recovery after the lifting of restrictions (De Vries et al., 2021). At the same time, asset purchases by global central banks during the Covid-19 crisis offset the effects of rising budget deficits by lowering the expected returns on international bonds, which acted as a strong stabilizing factor (Malliaropulos and Migiakis, 2023). Additionally, there were a number of relatively localized shocks, such as concerns about potential economic failures in the U.S. (Best, 2020; Heymann et al., 2020), tensions between China and the U.S., and the political-driven fragmentation of the global economic landscape (Bonga-Bonga and Mpoha, 2024; Cai et al., 2022； Kireyev and Leonidov, 2021).

Despite the extensive body of research on the interaction between public institutions, stock, and debt markets, new global shocks continue to provide fresh examples. The question remains open as to whether such interactions lead to greater market uncertainty or, conversely, act as a stabilizing factor.

This article presents a case study of the expanding BRICS group of countries. We selected a group of 10 developing economies that have been impacted by external influences and internal instability. The objective of this study is to analyze the interrelationship and cointegration between the sovereign bond and equity markets of selected BRICS+ countries during crisis periods. These include Russia, India, China, South Africa, Indonesia, Malaysia, the Philippines, Egypt, Nigeria, and Kenya for the period from 16 August 2019 to 1 March 2024.

Additionally, the sovereign bond markets of the UAE, Iran, and Ethiopia are not included due to a lack of available data in relevant databases. Indonesia, Malaysia, the Philippines, Kenya, and Nigeria, which participate in the BRICS+ international cooperation format, were added to the sample. The selected period includes two crises—the global one related to COVID-2019, and the introduction of anti-Russian sanctions from 2022.

In this study, we utilize a quantitative approach to analyze the factors influencing the yield structure of 10-year sovereign bonds. Specifically, we examine the impact of national stock market indices, changes in central bank interest rates (CBrates), and fluctuations in Brent crude oil and gold prices as potential determinants. To assess the interconnectedness and integration of sovereign markets, we analyze both domestic and external datasets. In the study we focus on several key categories: sovereign bond

markets, market coherence, interconnection, and integration. Additionally, it examines the impact of instability, which is categorized into global, cross-national, and local effects.

Several approaches for studying market interconnections have been proposed with regression-based and network-based methods being the most prominent, though the line between them has become less distinct.

The most used models for evaluating the effects of external factors on market connectedness are built on vector autoregression (VAR) (Ang and Piazzesi, 2003; Yilmaz, 2010) and its various extensions (Ahmad et al., 2018; Diebold and Yilmaz, 2012). Market networks, analyzed through measures of connectedness, correlation coefficients, covariance matrices, and dynamic Bayesian estimates, have been applied to stock index time series (Almansour et al., 2023). However, there are conflicting views on these methods: while they offer wide-ranging capabilities, their results are often unstable (Capelle-Blancard et al., 2019; Chang and Choi, 2023; Prelorentzos et al., 2024; Wu et al., 2024; Yousfi et al., 2024).

Using the index model (Diebold and Yilmaz, 2012) to examine volatility, spillover effects, and the interconnections between APEC stock markets, Kakran et al. identified the main countries acting as key transmitters of volatility spillovers. They also confirmed that various crisis events after 2020 led to significant increases in spillover effects (Kakran, 2023). Volatility spillovers in sovereign bond markets are just as important; however, it is crucial to remember that, when analyzing bonds, we are dealing with future yields, which heightens the level of uncertainty (Huang et al., 2023; Mai and Wu, 2024).

In our models, we focus on bonds denominated in national currencies, which, as noted by Ballard-Rosa, dominate the market (Ballard-Rosa et al., 2022). Yun's (2023) analysis of international linkages between the U.S. and South Korea utilizes a VAR model, with the two-block structure based on the main components of the yield covariance matrix: level, slope, and curvature.

Most research on sovereign bond markets has concentrated on developed economies, as they tend to be more predictable and offer a larger volume of data. The sources of joint movement in government bond markets have been analyzed primarily in the European context (Gómez-Puig et al., 2014). The impact of the Monetary Union on European debt market integration and the yields of individual countries' government bonds has been categorized into local (country-specific), regional (Eurozone), and global (worldwide) effects (Abad et al., 2014). The shift of systemic risk from West to East in the global stock market data (Cevik et al., 2024), according to our data, is becoming increasingly noticeable in the debt markets of emerging economies. However, the impact of such a shift is not limited to the interaction between the West and the East discussed above. We explore the interaction between East and South within the expanding BRICS group.

In the study we also classify these effects, but we focus on their impact within the BRICS+ group, exploring multilateral relationships. This brings forth three key methodological challenges. First, expanding the set of countries under study requires a larger data pool. Second, local effects tend to get "diluted" within global models. Third, the relative influence of fundamental variables must be accounted for, which increases the dimensionality of the models.

These issues have emerged in studies of the financial interrelationships of BRICS countries and global sovereign bond markets through generalized VAR frameworks. (Ahmad et al., 2018). Key drivers of financial interconnectedness include public debt, current account deficits, and interest rates. For India and Russia, a causal link was established between currency market pressures and domestic economic policy, while no such link was found for China (Olanipekun et al., 2019). Differences in market impacts and associated risks have also been highlighted in studies of the West African Economic Union (Behanzin et al., 2024).

Many researchers prefer network analysis of bond markets and sovereign risks, citing the significant uncertainty associated with VAR models (Huang and Liu, 2022; Zhuang et al., 2024). However, network analysis itself introduces even greater uncertainty in interpreting influencing factors, as it primarily captures the structure of interactions without providing deeper insights into the causes. To address this, we combine both approaches in this article. While studies on the network effects of volatility in international bond markets between developing and developed countries (Capelle-Blancard et al., 2019; Costantini and Sousa, 2022) have contributed to empirical understanding, the emergence of new events calls for additional research. In line with this, we explore the interaction between the bond markets of developing countries and the influence of fundamental factors.

Research on the COVID-19 pandemic and the events of 2022–2023 (Almansour et al., 2023) revealed that the financial markets of Russia, the U.S., and Ukraine were already highly interconnected before the crises, and the increased volatility of financial indices likely impacted other economies. However, the exclusion of other countries from the model leaves the full extent of this volatility's effects unclear. We hypothesize that the bond and stock markets of BRICS countries have become more interconnected since 2022. By examining the integration and connectedness of BRICS sovereign bond markets, this article expands on previous studies of global financial interconnectedness (Billah et al., 2022; Dahir et al., 2018; Kakran et al., 2023; Li et al., 2022). We focus on monetary policies, oil and gold prices, and stock indices as indicators of the economic environment, using data from 2019 to 2024 to support our analysis.

2. Materials and methods

2.1. Hypotheses

The research problem is that the expansion of the BRICS group introduces additional risks for countries, which are especially significant during periods of crisis[1].

Hypothesis 1: the connectivity and integration of sovereign bond markets of the BRICS+ countries is manifested in the presence of chains of volatility transmission from market to market.

Hypothesis 2: crisis phenomena can increase the effect of connectivity of the sovereign bond markets of the BRICS+ countries.

Hypothesis 3: the policy of central banks can play a stabilizing or corrective role in debt markets.

In order to apply appropriate analytical tools for testing time series, the presence of a unit root in stock market and government bond returns was tested using the

augmented Dickey-Fuller method. The null hypothesis that consider the volatility variables of financial markets are not stationary was rejected.

2.2. Dataset

The data are presented as vector time series, period 16 August 2019–01 March 2024, on business days. Here and throughout, $n \in (1, 10)$, represents the country, and t refers to the current date.

1) $Y = \{Y_{n,t}\}$ aggregate yield indices of 10-year government bonds[2].
2) $BI = \{BI_{n,t}\}$ list of trading platforms[3] and the source data[4];
3) $CR = \{CR_{n,t}\}$ daily refinancing rates of the Central Bank[5];
4) $GR = \{GR_t\}$ daily gold rate, $ USA[6];
5) $BR = \{BR_t\}$ the price of oil (Brent, $ USA)[7].

All prices used in the index calculations are as of the current date.

Selected BRICS+ countries: (Y_01) Russia, (Y_02) India, (Y_03) China, (Y_04) RSA, (Y_05) Indonesia, (Y_06) Malaysia, (Y_07) Philippines, (Y_08) Egypt, (Y_09) Nigeria, (Y_10) Kenya. This sample comprises BRICS countries and nations that have announced their intention to join the group[8].

Rationale for Data Relevance and Limitations

Aggregate yield indices are essential for medium-term macroeconomic analysis and function as endogenous variables in the model (Zhuang et al., 2024). The predictive nature of these indices, which extend up to 10 years, can introduce significant volatility, representing a potential limitation. However, government bond yields are generally homogeneous unless there is a risk of default, making them appropriate for calculating average indices. Stock market indices are even more sensitive to changes (Fiordelisi and Galloppo, 2018), providing a solid basis for broad market forecasts. Gold prices, as a «safe-haven» asset, react to various crises (Ryan et al., 2024; Vieira et al., 2023). Daily refinancing rates serve as a standard indicator reflecting governmental economic policies. Additionally, oil demand is indicative of global economic activity, financial crises, and anticipated economic challenges (Wu and Mai, 2024; Wu et al., 2024).

The primary limitation lies in the fact that fluctuations in the data are influenced by not only fundamental factors but also market participants' expectations and potentially unreliable information. Moreover, our analysis does not account for the possibility that the overall stock market index dynamics may be driven by a single sector, which is beyond the scope of this study. BR factor limitations arise from our focus on public exchange rates, without considering discrepancies in actual contract values. Since our focus is not on the oil market itself, we treat the indicator as primary indicative.

In this context, we analyze the impact of political and economic risks on the interconnectedness of the markets in question. Additionally, we differentiate between two types of crises: the global pandemic of COVID-2019 and the spread of localized crises after March 2022.

2.3. The consistency of distributions check

Since different methods of checking mutual influences in markets imply different effects denoted by outwardly similar terms, we will clarify the terms used below.

We will consider local connectedness as the mutual influence of characteristics of bond yields, stock prices, and refinancing rates of a given country. We will consider interethnic connectedness as the mutual influence of the corresponding indicators between the countries of the group. If the corresponding characteristics are strongly influenced by oil and gold prices, we will designate such influence as global.

The quantitative values of yields differ significantly, making it unproductive to use absolute figures for analyzing deviations. Therefore, we compared the variation in the average annual sovereign bond yields Y_n, (where n represents the country) across countries using normalized yield series, calculated according to the following formula.

$$Yn\_1 = (Y\_n - \text{mean}(Y\_n))/\text{st.dev}(Y\_n) \quad (1)$$

where mean (Y_n) is average values and st.dev (Y_n)—standard deviation of the original value.

For the normalized yield series, we calculated the annual number of observations that fell into the top decile of the distribution for each country (Appendix A). These deciles were computed for the entire period for each country, allowing us to evaluate the occurrence of extreme yield values (shocks) across the sample countries. Normalized values were used due to significant inflation rate differences, which make direct cross-country comparisons of absolute yield dynamics meaningless. The duration of the shock period, expressed as a percentage of the total series length, is denoted as L (10). For example, in China in 2020, 28 observations were in the 10th decile, representing 11% of the total $N = 262$ observations (Appendix A).

Since the time series Y, BI, CR, GR, and BR do not follow a normal distribution, we tested the first differences of their logarithms (reflecting changes in direction): id_Y, id_BI, id_CR, id_GR, and id_BR.

For instance*:*

$$\text{id}\_X_{n,t} = \ln(X_{n,t}) - \ln(X_{n,t-1}) \quad (2)$$

Considering that in the distributions of logarithmic differences the median and arithmetic mean are located around zero, the minimum and maximum of the differences in the logarithms of yields of sovereign bonds, stock indices, characterize the distributions, Appendix B. The degree of agreement of the logarithmic differences demonstrates the spread of crisis phenomena between countries.

The definition of the agreement of variability is obtained by rank tests of multiple concordance. Kendall's coefficient and two-factor Friedman rank variance analysis for related samples check the null hypothesis about the consistency of distributions of features, Appendix C.

2.4. Vector autoregressive model

The degree of agreement in logarithmic differences illustrates the spread of crisis events across countries. Vector autoregression is used as a tool to assess the speed at which risks spread (Malliaropulos and Migiakis, 2023; Qin et al., 2023). To measure the impact of the study variables, we use a vector autoregression (VAR) model with

exogenous variables. The dimension of the vector, along with k exogenous variables and their lags, is considered. Adding distributed lags for the exogenous variables to the model allows us to capture indirect effects as well as the multiplier effect (joint movement).

Volatility is assessed using the first differences of the logarithms of each vector function.

$$\overline{id\_Y} = a_0 + \sum_{j=1}^{q}\sum_{n=1}^{p} L_n B_{n,j} \times id\_Y_{n,t-j} + \sum_{j=1}^{q}(\sum_{n=1}^{p}(C_{n,j} \times id\_BI_{n,t-j} + D_{n,j} \times id\_CB_{n,t-j}) + \beta_{t-j} \cdot id\_GR_{t-j} + \gamma_{t-j} \cdot id\_BR_{t-j}) + \bar{\varepsilon} \quad (3)$$

where $p = 10$; $q = 5$; n is the country number from the sample[9].

A key limitation of the model lies in its dimensionality. Incorporating only exogenous variables fails to produce stable and meaningful results, while including autoregressive effects enhances significance but risks violating the sufficiency of exogenous variables and increasing heterogeneity. These models extend beyond the scope of historical data description and do not provide accurate forecasts (Ahelegbey et al., 2024). As a result, the findings are interpreted through the lens of Granger causality-based integration.

The autoregressive part of the VAR model is based on the id_Y series, the remaining variables are included in the models as exogenous. Since the models are built for countries with different time periods, zero and first lags were considered to capture the simultaneous precedence of exogenous time series. The model was tested for robustness. Testing the VAR system for the best lags shows the best lag is 1, then the significance gradually decreases, see Appendix C. The robustness of significant relationships was tested using the sliding window method, the shift was made by 5, 10 and 30 days. The structure of the model changed no more than 5% for relationships at the level of $p < 0.05$ (*), relationships with a significance higher than that did not change. Including the following lags in some cases added a set of significant effects (for example, for Russia, China, Malaysia, the autoregressive series was lengthened), but there was no fundamental change in the structure of the results.

2.5. Granger causality testing algorithm

Cointegration refers to the external integration of markets, the explanation of integration is determined by the Granger test. The Granger test shows that if the lag variable $X2$ is included equation for $X1$, but the lag variable $X1$ is absent in the regression equation for $X2$, then there is no information in the process $X1$ to predict $X2$. While there is information in the process $X2$ that allows predicting $X1$. The test indicates the transfer of information from the process $X2$ to the process $X1$. If the market is fully integrated, then the equation for $X1$ should be free of local variables. Similarly, if the market is fully disintegrated, then only country-specific variables are present in the equation for $X1$. If lagged variables are mutually present in the models of $X1$ and $X2$, then there may be a third variable that affects both processes. This effect reflects mutual connectivity.

Next, when adding a lagged value of the exogenous variable, it is determined how this explanation changes. The hypothesis of integration is accepted if the coefficient

of lagged *X* is statistically significant. Accordingly, a market is considered fully integrated if it is only under the influence of factors external to the given market.

The interpretation of results in terms of Granger causality testing suggests that lagged variables exert influence, indicating integration when a significant relationship is present (Almansour et al., 2023; Shahid, and Shahid, 2022; Wu et al., 2024).

To test Hypothesis 1, we used distribution analysis (**Figure 1**–**4**), Granger causality tests for connectedness and integration (**Figures 5**–**6**). To test Hypothesis 2, we used distribution analysis (Appendix A), as well as non-parametric tests for paired samples (Appendix C). Hypothesis 3 was evaluated using VAR models (Appendix D), and additional details provided in Appendix B.

3. Results and discussion

3.1. Dynamics of government bond indices and stock markets

In the first step, we divided the yield on government bonds of each individual country into three effects: local (own country), cross-national effect (government bond and stock markets of a group of countries) and global effect. The time interval was divided into annual periods (Appendixes A and B). Thus, we examined the long-term (annual) changes in yields that spread across the countries in the group. Next, are shown the average annual statistical characteristics, including means, deciles, range, standard deviation. Below, the length of shock periods L (10), calculated as the ratio of observations with extreme (10th decile) values of normalized yields to the total length of the analyzed period (Appendix A). This approach captures not only the increase in absolute bond yield values (see **Figure 1**) but also significant deviations from the trend.

Crisis period 1 (2019–2020 period) and the recovery phase of 2021.

Among the countries under consideration, China (Y_03) has the most developed sovereign bond market, **Figure 1**. As the COVID-19 pandemic began spreading from China, the yields on Chinese sovereign bonds were the first among the countries analyzed to experience a sharp increase in late 2019, continuing until early 2021 (local shock). In 2019 and 2020, extreme values of normalized Chinese sovereign bond yields accounted for L (10) = 0.11 of the total observations, making China the first country in the sample to experience such shocks during this period. In January 2021, the rise in bond yields (Y_03) occurred due to the seasonal surge in infections, with the length of the shock periods L (10) = 0.06. Following this, risk expectations diminished **Figure 1**, and the market stabilized (Appendix A).

Indonesia (Y_05) saw an increase in sovereign bond yields slightly after China but earlier than the other countries in the group. The duration of the shock periods was short, L (10) = 0.06 in 2019 and L (10) = 0.22 in 2020. However, the deviation in normalized yields in Indonesia was lower than in the Philippines(Y_07), where yield fluctuations were more extended but less extreme (Appendix A).

By early 2020, the COVID-19 pandemic had spread worldwide, leading to a sharp rise in bond yield indices (global shock). During this period, yield spreads surged between 100 and 300 basis points. In 2020, average normalized bond yields reached their highest levels in South Africa (L (10) = 0.09, st.dev. = 0.97) and Indonesia (L (10) = 0.22, st.dev. = 1.29) (Appendix A). Short-term yield spikes occurred in China,

South Africa, Indonesia, and Nigeria between 20–23 March 2020 **(Figure 1)**. The smallest yield fluctuations during this period were observed in Russia, India, Malaysia, and Kenya, and markets gradually recovered over the year (Appendix A).

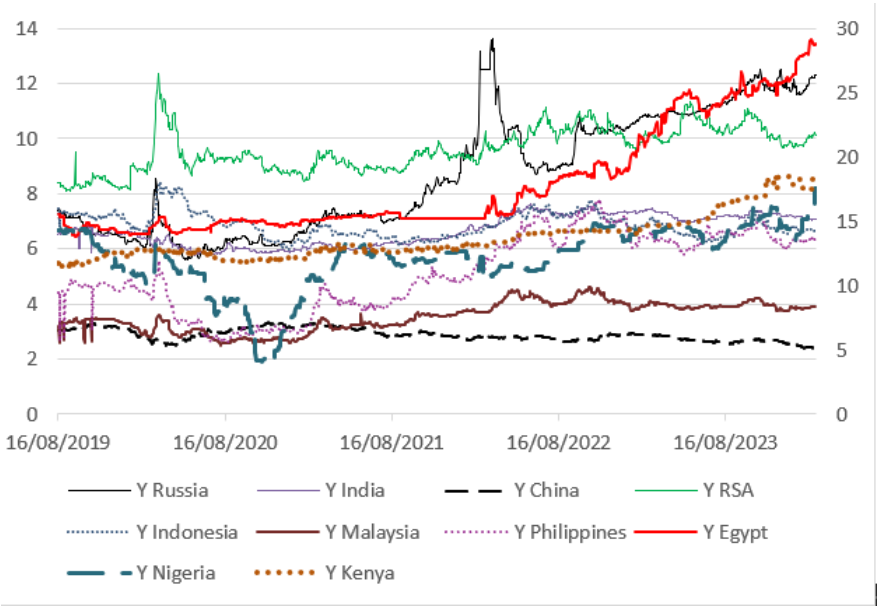

Figure 1. Dynamics of yield indices of sovereign bonds of the sample countries (Egypt, Kenya, Nigeria—right axis; other countries—left axis).
Source: https://cbonds.com/indexes.

The next global yield spike occurred in March–April 2021. Although China and Malaysia had the lowest average yields (**Figure 1**, Appendix B), their sovereign bonds showed higher risk in terms of variation (Appendix A). Yields continued to rise across all markets until February 2022.

In February 2022, there were sharp spikes in bond yields (local shocks). The largest annual variations in normalized yields for 2022 were observed in Russia, with the shock period length at L (10) = 0.11. This was followed by a smaller, but more prolonged, rise in yield variation in Indonesia (L (10) = 0.28), Malaysia, and the Philippines (L (10) = 0.45), and India (L (10) = 0.11). This indicates a gradual spread of local shocks across the sovereign bond markets of BRICS countries, particularly in Asian nations. By the summer and fall of 2022, the crisis had reached African countries, affecting the bond yields in South Africa and Nigeria, Appendix A. In 2023, shock periods were concentrated in Russia, South Africa, Egypt, and Kenya. By 2024 (up to March), shock periods remained localized in Egypt and Kenya, where the entire period was marked by extreme yields, as well as in Nigeria and Russia.

Note that while the expected yield on bonds grows with an increase in expected risks, the growth of stock indices, on the contrary, reflects a positive economic trend. Stock indices collapsed almost synchronously in March 2020 (the first global shock). Then, until June 2020, there was a fairly rapid synchronous recovery of indices, **Figure 2**. The second and third shocks associated with seasonal surges in COVID-2019 cases were much smaller both in depth and duration. During this period, stock indices reflect a general upward trend. The exception is the dynamics of the stock indices of China and Russia. The Chinese stock market grew sharply in the period 2019–2021,

subsequently overheating was replaced by a decline in stock indices until the end of 2023. Russian stock indices grew until the fall of 2021, then there was a gradual decline.

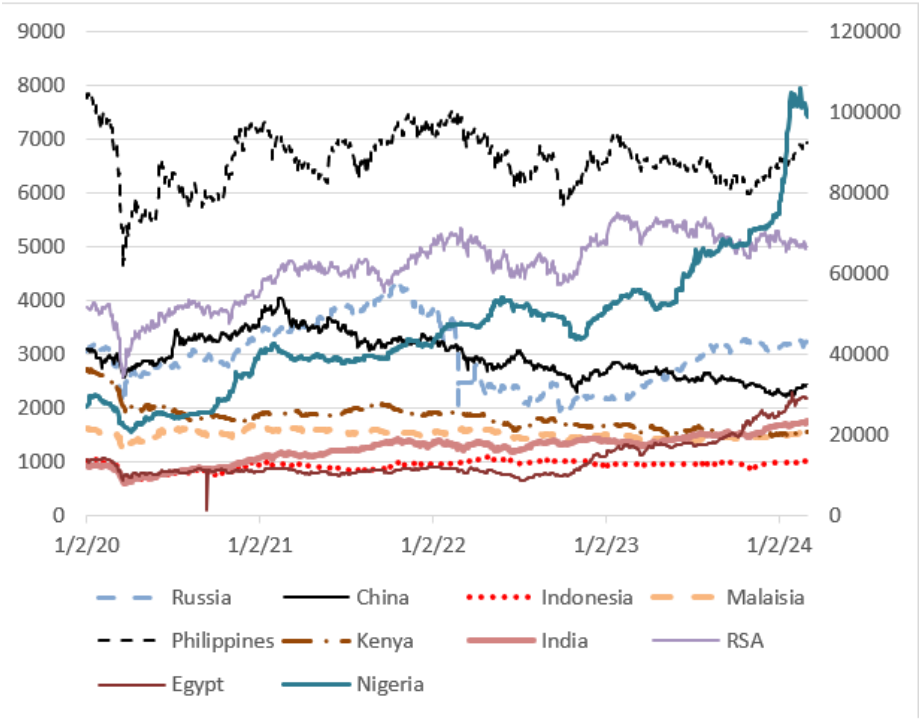

Figure 2. Dynamics of stock indices (BI_N) of sample countries, right axis Nigeria, South Africa, Kenya, Egypt, India; other countries—left axis.
Source: https://cbonds.com/indexes.

To test the global connectivity of the markets, the methodology for assessing the consistency of variability using multiple concordance rank tests *W* was used, Appendix C. In the first crisis period (2019–2020), corresponding to the spread of the COVID-2019 epidemic, the null hypothesis is accepted about the consistency of the sample distributions for the logarithmic differences of sovereign bonds, stock markets, policies of national regulators of the considered countries, gold and oil rates (each of the markets was considered separately for all 10 countries as a whole). In 2021, debt markets significantly reduced global volatility, which led to the fact that global connectivity was violated. The hypothesis about the connectivity of gold and oil rates, policies of national regulators is also rejected. Stock markets retained global connectivity in their volatility.

Crisis period 2 (2022–2024)

The second crisis in the study period is linked to the sanctions imposed on Russia and the escalation of localized conflicts. This period spans from March 2022 to 2024. The excess and asymmetry of the differences in the logarithms of the indices of yields on Russian sovereign bonds in 2023 reached 11.2 and 1.7, in China 13.2 and 0.4, see Appendix B. Then, in 2024, volatility increased, spreading to the yields of sovereign bonds of all the countries considered. The volatility of stock market indices increased in 2024 in almost all countries of the group, not affecting only Indonesia and Malaysia. In the period 2022–2024, the global connectivity of the volatility of gold and oil rates,

and the yields of 10-year sovereign bonds remains. The volatility of stock markets ceased to be globally connected in 2023–2024. Thus, it should be concluded that the global connectivity of income volatility distributions increases during crisis periods. After global crises have passed, local factors and/or mutual influences of national markets become more significant in the markets.

While the rapid global shock in the first period was followed by a gradual recovery in 2021 and 2022, the second period shows strong multidirectional volatility in sovereign bond yields with an upward trend. The exception is the Chinese market, which has seen a steady downward trend in sovereign bond and stock indices, which is not typical for a free market. The latter means that China's budget can borrow cheaper on international markets against the backdrop of rising borrowing costs for other countries. However, China's stock market is subject to fundamental trends that cause asset prices to decline. Monetary authorities in all countries in the sample behaved similarly during this period, gradually reducing refinancing rates, thereby trying to keep the economy in a relatively stable situation until March 2022. The only country in the sample where monetary authorities began raising rates earlier, already in April 2021, is Russia, **Figure 3**.

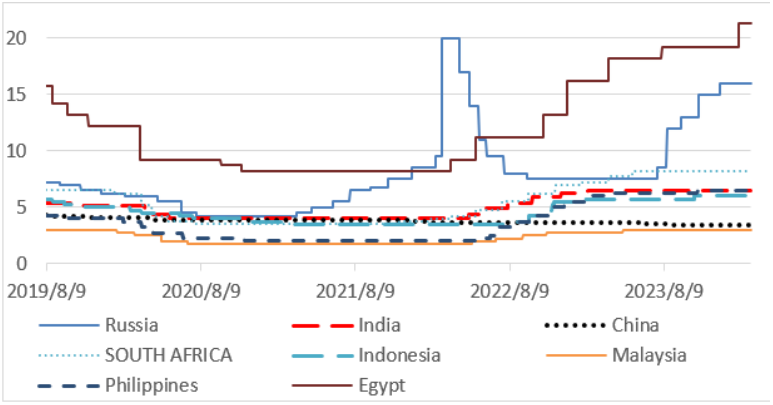

Figure 3. CB rates of countries under consideration.

Source: https://cbonds.com/central-bank-rates.

Note that in different periods, the gold rate acts as an alternative to the oil rate (until 2021), then during 2022–2023, the variables varied in the same direction. After February 2022, the gold and oil rates again began to vary in opposite directions, **Figure 4**. It can be assumed that in a period of strong volatility, gold plays the role of a reserve currency, compensating for the fall in stock market returns. Oil can rise in price for both fundamental and political reasons.

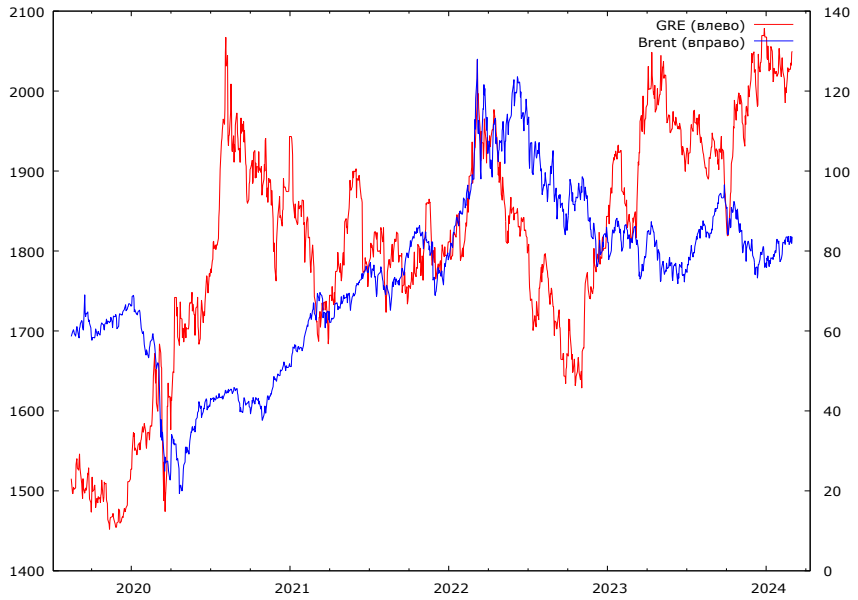

Figure 4. Interaction between the gold rate (GRE) and the oil price (BRENT).
Source: https://cbonds.com/indexes/224/, https://cbonds.com/indexes/624/.

An examination of gold and oil price volatility distributions shows a disruption in their alignment only in 2021, when gold price volatility was notably higher than that of oil. In all other periods, the fluctuations in oil and gold prices remained correlated.

During the first crisis period, financial market integration increased. In 2019–2020, the hypothesis of connectedness was confirmed for all financial market indicators analyzed, with refinancing rates also showing connectedness. However, in 2021, the null hypothesis was rejected for sovereign bond yields and refinancing rates, while stock indices remained interconnected. In 2022, the null hypothesis was accepted for all financial indicators except local refinancing rates. By 2023–2024, the null hypothesis of global connectedness was rejected for sovereign bond yields, stock indices, and refinancing rates (Appendix C).

Thus, during crisis periods, the global connectedness of financial market indicators strengthens. In the stock market, crises tend to start earlier and last longer. Refinancing rate connectedness was only observed in 2019–2020, after which the null hypothesis was rejected (Appendix D). As the crisis subsides, the level of connectedness declines, revealing the influence of local factors. Further analysis using shorter six-month and quarterly periods did not yield additional insights.

3.2. Cointegration and connectivity of the sovereign bond market

Let us consider the structure of the VAR model, incorporating both local and global instruments (Appendix D). When interpreting VAR model results, note that the diagonal elements of the covariance matrix reflect the contribution of autoregression, while the off-diagonal elements represent coefficients typically interpreted as a distributed multiplier. Our primary focus was to study short-term transitions (up to 5 days), which provide valuable insights into the main factors driving shock transmission. In model (2–3), all lags from 1 to 5 were included for the variables. Only the significant terms are shown in Appendix D, with the minimum significant lag for

the model (in business days) indicated in parentheses. The absence of parentheses signifies a lag of 1, meaning the effect is, on average, significant by the next business day.

Key estimates for the full model: autoregressive lag order of 5, observations from 2020.01.10 to 2024.03.01; T = 1081; Akaike criterion AIC= −60.3; Schwarz criterion BIC= −55.6; Hannan-Quinn criterion HQC = −58.5; Portmanteau test LB (48) = 4638, degrees of freedom = 4300 [0.0002]. To ensure the robustness of the results, we conducted a sample shift. The final characteristics of the reduced model were: autoregressive lag order of 5, observations from 2021.01.04 to 2024.03.01; T = 849; AIC = −59.3; BIC = −53.5; HQC = −57; LB (48) = 4556.

It is worth noting that while the structure of the dependencies remained consistent, the values of specific coefficients varied. For example, the coefficient for id_Y_01 was 0.17*** for the full model and 0.21*** for the reduced model. We did not analyze the magnitude and direction of influence but instead focused on examining the structure and Granger-connectedness of the Y markets, accounting for external influencing variables.

The results of the vector autoregression (VAR) can only be interpreted on average, given the length of the time series and the limitations on dimensionality. The models consistently show that markets have information to forecast their own dynamics, indicating that there are no fully integrated markets within the group. Likewise, no market is entirely local, as all are influenced by external factors.

The Granger effect of mutual connectivity in Y markets was observed in the sovereign bond markets between Russia and South Africa, Russia and Nigeria, India and Malaysia, South Africa and Indonesia, Indonesia and Malaysia, Indonesia and Egypt, and Malaysia and the Philippines. This suggests that in these countries, the interaction of debt markets is significantly influenced by external factors.

China stands out as the only country showing a lagged influence spillover to other debt markets. While China's Y market receives signals from and influences other markets, it does not exhibit mutual connectivity with them (Appendix A).

The local effect of the behavior of its monetary authorities (factor CR) can be seen in the dynamics of the Y markets of Russia, South Africa, the Philippines, Nigeria, and Kenya. In Indonesia and Egypt, the model does not reflect a significant influence of regulatory mechanisms. In India and Malaysia, the reaction to external influences is more significant than to the influence of domestic currency rates. This is probably due to the more significant participation of external investors in the market.

The local effect of the stock market (factor BI) is noticeable in Russia, China, South Africa, Indonesia, and the Philippines. The mutual influence effect through stock market volatility is evident in the Y markets of India and Malaysia; China and Indonesia; Indonesia and Nigeria; the Philippines and Egypt. The sovereign bond markets of Russia, China, South Africa, Indonesia, the Philippines, and Kenya are most locally linked. In these countries, the impact of the local sovereign bond market and the stock market is significant.

The mutual connections between the markets can be schematically reflected in **Figure 5**. The connectivity of the sovereign bond markets is reflected through the solid arrow, the interrelations between local markets through the mutual influence of stock markets through the dotted arrow, the mutual influence of regulators is reflected

through the double arrow. In **Figure 5** and Appendix C, it can be seen that the markets of Malaysia, South Africa, and the Philippines are most integrated into international interactions within the group. The Chinese sovereign bond market is locally connected, the influence on other markets is significant through the debt, stock market, and monetary policies. The model for Kenya is not significant due to the weak development of the market.

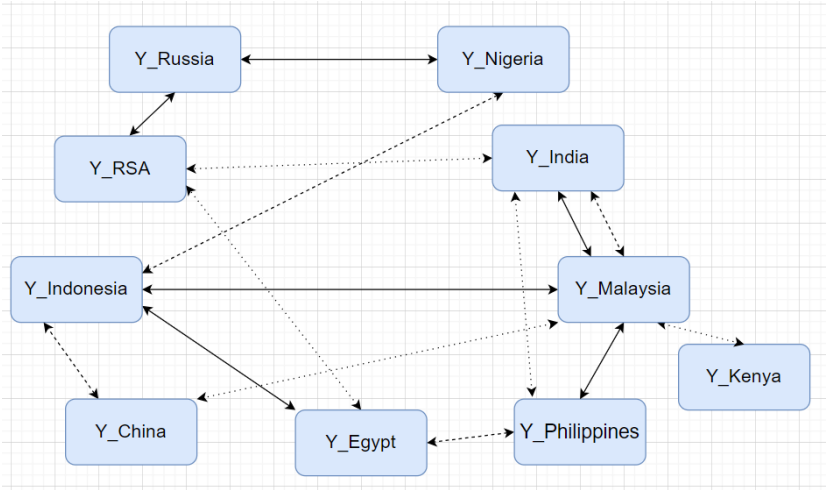

Figure 5. Cross-linkages in sovereign bond markets*.

* The relationships are two-way.

Oil remains a significant factor in the long term, increasing the yield of sovereign bonds in the markets of India, China, South Africa, and Malaysia. Gold remains a significant factor, reducing the yield of sovereign bonds in China, South Africa, Indonesia, Malaysia, and the Philippines.

4. Conclusion

Hypothesis 1 is confirmed. The sovereign bond markets of the BRICS+ countries are involved in the chain of transmission of effects, **Figure 6**. China, within the framework of international cross-border influences of sovereign debt instability, has a significant impact on the markets of the Russian Federation, India, Egypt, and Kenya. For its part, the Chinese debt market is influenced by instabilities and receives information from the debt markets of South Africa, the Philippines, and Nigeria. Large interconnected sovereign bond markets within the considered group are primarily represented by the pairs Russia-South Africa, India-Malaysia; Malaysia-Indonesia; Malaysia-Philippines; South Africa-Indonesia. The Russian debt market influences the sovereign debt markets of Indonesia, Malaysia, the Philippines, Egypt, and Nigeria. The impact of volatility in the Indian debt market is transmitted to the Russian debt market, see **Figure 6**.

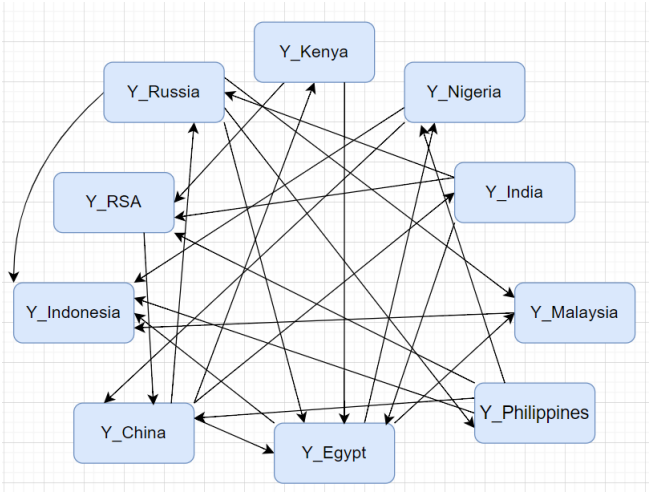

Figure 6. Integration of sovereign bond markets*.

* The relationships are one-way.

Hypothesis 2 is confirmed. During periods of crisis, the consistency of the variation of the debt markets of the BRICS countries increases. Having considered the dynamics of instability risk spread, it should be noted that, first of all, the external connectivity of stock indices increases, which collapse almost simultaneously. During the recovery period, markets become less connected, but local connectivity increases for markets within the country, see Appendixes A and B. Debt markets are significantly less volatile than stock markets. The growth of integration in debt markets occurs during the crisis, both in 2020 and in 2022. It can be concluded that the increase in the consistency of index variability can act as a signal of an increase in crisis phenomena in the corresponding markets. Market integration acts as a signal that a multiplier effect of the influence of instability of markets in other countries is observed in a given country. Examples of such integration are the debt markets of Malaysia, Indonesia, the Philippines, South Africa, and Nigeria.

Hypothesis 3 is partially confirmed. Central bank policies play an important stabilizing or corrective role in all debt markets. The interconnectedness of central bank policies was maintained in the period under review only in 2019–2020. Further, the monetary policies of the countries under review are not interconnected and not correlated. Some debt markets are subject to both local and global influence of monetary policies, for example, the Russian Federation, South Africa, and the Philippines. In less developed debt markets (for example, Indonesia and Egypt), no significant influence of regulatory mechanisms was formed.

The countries in the sample are subject to both external (global and cross-national) and local influences. The breakdown in connectedness is most apparent in the disruption of index variation correlations between Russia, China, and India. The Chinese bond market is marked by predictability and connectivity yet displays atypical behavior where both stock and bond indices decline simultaneously.

Theoretical Implications. Our study provides updated insights into the behavior of financial markets in emerging economies, with a focus on the BRICS+ group. Historically, research on BRIC countries has concentrated on Brazil, Russia, India, and China. While the BRICS nations are not geographically connected, they share common economic and political interests. Previous studies have demonstrated their

dependence on global markets (Ahmad et al., 2018) and mutual interconnectedness (Dahir et al., 2018; Yarygina, 2020). However, with the expansion to BRICS+, and in light of rising Russian sovereign bond yields due to sanctions and declining yields in China, we now observe the formation of two loosely connected centers—Russia and China—along with distinct dynamics in India and South Africa.

Our findings support the conclusion that, during crises, market interconnectedness increases, leading to heightened volatility (Ahelegbey et al., 2022). The novelty of our research lies in examining both the long-term and short-term effects of crises on sovereign bond yields, focusing on two distinct crisis periods. The increased interconnectedness during crises can be explained by the initial, uniform responses of national governments. For instance, in response to a global rise in interest rates, many governments typically react by raising central bank rates. As crisis management strategies evolve, however, local markets begin to diverge in behavior. Our analysis confirms this pattern, interconnectedness tends to weaken as more time passes from the initial crisis event.

During the global shock of 2019–2020, the crisis originated in China, followed by Indonesia, before spreading to the rest of the BRICS+ countries. The financial and debt markets in the sample were able to quickly recover from the severe shocks caused by COVID-19. However, the 2022–2024 crisis, which was more prolonged, began in Russia and later spread to countries in Asia and Africa. By 2024, Russia's sovereign bond yields had started to decline. The volatility observed after 2022, driven by political factors, had a more sustained impact, ultimately disrupting the interconnectedness and integration of the stock and debt markets within the BRICS group.

Our findings challenge previous conclusions by Olanipekun et al. (2019), which identified Russia, followed by South Africa, as the primary sources of shocks within BRICS. For instance, despite strong cross-border trade and direct investment ties, China and India show weak financial interconnectedness. We also disagree with those who argued that South Africa, India, and Russia form a unique high-yield cluster in the network structure of the sovereign bond market (Zhuang et al., 2024).

First, high sovereign bond yields typically indicate economic crises, making borrowing more difficult for governments and creating systemic risks. Second, African countries such as Egypt, Kenya, and Nigeria have joined the high-yield group, contributing to additional shocks in the markets. In contrast, larger economies like China, India, South Africa, and Russia saw their bond yields decline after brief spikes, as macroeconomic risks decreased. Sovereign bond yields, like financial markets overall, respond to divergence (Miyakoshi and Shimada, 2022). However, in the absence of additional negative signals, the driving factors behind yield movements tend to shift toward domestic influences. The case of Nigeria, a mono-economy with a strong dependence on crude oil (Zhang et al., 2024), demonstrates the influence of government policies and sovereign bond markets of related countries (Russia, Philippines, Egypt) on the growth of expected sovereign bond yields (Appendix D). However, our models did not show a direct impact of the oil price.

BRICS represents a heterogeneous market group that attracts a significant portion of global capital inflows (Billah et al., 2022). This heterogeneity is the evident not only in the market interconnections but also in the key drivers of sovereign bond yield

growth. The group includes two major oil importers (China and India) and one of the leading producers and exporters (Russia), which accounts for the differences in market behavior. Sovereign bonds of oil-importing countries tend to respond positively to rising oil prices, while Russian bonds are more influenced by political factors and stock market signals. China stands as a distinct player within the BRICS+ group, with its dynamics being the least affected by external shocks, likely due to its strong resilience and ability to pursue policies independent of external pressures.

The limitations of this study stem from the inclusion of a large number of parameters and long data series, as outlined in Section 2.2. To account for these factors, we used a sequential approach, incorporating dynamic analysis, volatility assessments, non-parametric multidimensional connectivity indices, the VAR model, and Granger causality analysis. The initial analyses were conducted on annual data to maintain control over the dataset, while the VAR models were constructed over a shorter period to validate the results and evaluate the transmission of shocks. Although we did not specifically analyze the direct impact of the oil market on sovereign bond yields, oil and gold prices were included in the model as signaling variables, reflecting their relative influence within the broader factor structure.

Future Research Perspectives. We see the extension of our approach through the application of GARCH models for a more in-depth analysis of the influence of external and internal factors on forecasting sovereign bond market volatility. Additionally, greater focus should be placed on the sectoral structure of the bond market, as sovereign debt does not exist in isolation from the broader sectors of the economy.

Practical and Policy Implications. The impact of the 2019–2020 and 2022–2024 crises on markets varied significantly due to different underlying factors. During the first crisis, the sovereign bond yields of BRICS+ countries were largely influenced by external economic conditions, such as the drop in oil prices caused by reduced consumption and the surge in gold prices as a «safe-haven asset» for inflation protection and value preservation. Sovereign bond markets in oil-importing countries like India, China, South Africa, and Malaysia became integrated and heavily dependent on lower oil prices. Similarly, the rise in gold prices drove investor interest in sovereign bonds from China, South Africa, Indonesia, Malaysia, and the Philippines. Despite the complexities and uncertainties, global economic recovery was relatively swift, aided by government and central bank support measures.

From a policy perspective, greater convergence and predictability in monetary policies could enhance the integration of BRICS countries. Existing financial initiatives, such as the New Development Bank, the use of national currencies, and the establishment of national payment systems for international transactions, aim to promote economic convergence and reduce financial market risks during crises.

Considering the secondary effects of debt and equity markets is essential for fostering economic growth, making informed decisions, diversifying portfolios, and managing risks. Assessing the interconnectedness of BRICS countries' debt and stock markets, along with the response of sovereign bond yield volatility to global and local financial crises and commodity price fluctuations, offers valuable insights. This deepens our understanding of the growing economic interdependence within the BRICS+ group and supports the ongoing integration process, despite the economic and political diversity of the member countries.

Author contributions: Conceptualization, KA and GR; methodology, GR; validation, DS; formal analysis, GR; investigation, KA and GR; resources, data curation, KA; writing—original draft preparation, GR and YY; writing—review and editing, KA and DS; visualization, KA and GR; supervision, DS; project administration, GR; funding acquisition, GR. All authors have read and agreed to the published version of the manuscript.

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Notes

1 From BRICS to BRICS Plus: Old Partners and New Stakeholders. BRICS PORTAL. (https://infobrics.org/post/40924/date 10.04.2024)

2 https://cbonds.com/indexes/24431 (/24243; /86859; /24297; /24245; /24259; /24281; /24229; /24275; /24255; /24215; /24265)

3 MSCI, BSE Sensex, Shanghai 50, JSE 40, LQ45 (Indonesia), FKLCI^KLSE (Malaysia), PSEi (Philippines), Egypt EGX 30, NSE-All Share, Nairobi 20, IGPA, IPC Mexico

4 https://cbonds.com/indexes/216 (/27049; /38811; /39563; /59895; /31399; /36969; /29553; /36203; /33853; /32823; /35331)

5 https://cbonds.com/central-bank-rates/

6 https://cbonds.com/indexes/224/

7 https://cbonds.com/indexes/624/

8 Kommersant (https://www.kommersant.ru/doc/6560225 date of application 7.03.2024). RIA (https://ria.ru/20160621/1449483710.html date of application 7.03.2024)

9 Calculations were performed in Gretl

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Appendix A

Table A1. Descriptive statistics of normalized sovereign bond yields (Y1_1–Y10_1).

		Russia	India	China	RSA	Indonesia	Malaysia	Philippines	Egypt	Nigeria	Kenya
Date		**Y01_1**	**Y02_1**	**Y03_1**	**Y04_1**	**Y05_1**	**Y06_1**	**Y07_1**	**Y08_1**	**Y09_1**	**Y10_1**
	mean	−0.86	−0.11	1.25	−1.60	0.81	−0.34	−0.39	−0.79	0.42	−0.99
	st.dev.	0.14	0.28	0.37	0.30	0.21	0.36	0.24	0.09	0.65	0.22
2019	min	−1.05	−1.39	0.55	−1.96	−0.14	−1.82	−1.80	−0.96	−3.22	−1.26
	max	−0.58	0.23	1.90	−0.15	1.41	−0.09	−0.16	−0.56	0.94	−0.57
	N	98	98	98	98	98	98	98	98	98	98
	mean	−1.11	−1.07	0.30	−0.33	0.46	−1.24	−1.15	−0.77	−1.19	−0.78
	st.dev.	0.20	0.45	1.08	0.97	1.29	0.49	0.55	0.10	1.05	0.20
2020	min	−1.43	−1.57	−1.69	−1.83	−1.90	−2.01	−1.80	−0.91	−3.30	−1.09
	max	−0.05	0.05	1.90	3.60	3.39	0.10	0.34	−0.58	0.49	−0.46
	N	262	262	262	262	262	262	262	262	262	262
	mean	−0.62	−0.92	0.71	−0.65	−0.93	−0.55	−0.68	−0.61	−0.18	−0.56
	st.dev.	0.26	0.28	0.69	0.41	0.41	0.52	0.43	0.05	0.57	0.16
2021	min	−1.14	−1.39	−0.34	−1.57	−1.90	−1.82	−1.59	−0.75	−1.96	−0.97
	max	−0.03	−0.31	1.90	0.37	0.08	0.29	0.19	−0.49	0.53	−0.28
	N	261	261	261	261	261	261	261	261	261	261
	mean	0.62	0.90	−0.50	0.63	0.56	1.08	0.91	−0.14	0.13	0.08
	st.dev.	0.52	0.51	0.34	0.65	0.76	0.51	0.58	0.35	0.51	0.27
2022	min	−0.16	−0.31	−1.24	−0.67	−1.02	0.10	−0.23	−0.63	−0.69	−0.46
	max	2.28	1.67	0.11	1.92	2.07	2.01	1.91	0.44	1.10	0.35
	N	260	260	260	260	260	260	260	260	260	260
	mean	1.19	0.99	−0.66	0.89	−0.34	0.75	0.93	1.42	0.89	1.20
	st.dev.	0.25	0.23	0.51	0.53	0.58	0.22	0.22	0.46	0.30	0.76
2023	min	0.73	0.59	−1.69	−0.15	−1.46	0.29	0.48	0.20	0.20	0.12
	max	1.77	1.49	0.11	2.18	0.97	1.24	1.48	2.08	1.63	2.83
	N	260	260	260	260	260	260	260	260	260	260
	mean	1.49	0.85	−1.89	0.36	−0.34	0.57	0.84	2.35	1.15	2.50
	st.dev.	0.10	0.10	0.31	0.20	0.12	0.10	0.05	0.24	0.47	0.22
2024	min	1.34	0.59	−2.58	0.11	−0.58	0.48	0.69	1.92	0.53	2.19
	max	1.68	0.95	−1.24	0.76	−0.14	0.67	0.91	2.68	2.24	2.83
	N	45	45	45	45	45	45	45	45	45	45
	mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	st.dev.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Всего	min	−1.43	−1.57	−2.58	−1.96	−1.90	−2.01	−1.80	−0.96	−3.30	−1.26
	max	2.28	1.67	1.90	3.60	3.39	2.01	1.91	2.68	2.24	2.83
	N	1186	1186	1186	1186	1186	1186	1186	1186	1186	1186

L(10)—the length of the shock period, calculated as the percentage of observations that fall into the 10th decile of the distribution. The deciles were computed by dividing the range of normalized yields into 10 equal intervals for the entire period for each country.

Appendix B

Table B1. Minimum and maximum differences in the logarithms of average annual yields of sovereign bonds (id_Y_01-id_Y_10) and stock indices (id_BI_01-id_BI_10).

		Russia	India	China	RSA	Indonesia	Malaysia	Philippines	Egypt	Nigeria	Kenya
	id_Y										
Min	2019	−0.01	−0.14	−0.03	−0.14	−0.07	−0.3	−0.53	−0.03	−1.19	−0.03
	2020	−0.1	−0.03	−0.04	−0.09	−0.04	−0.06	−0.1	−0.04	−0.21	−0.03
	2021	−0.03	−0.03	−0.04	−0.02	−0.03	−0.09	−0.09	−0.02	−0.14	−0.05
	2022	−0.08	−0.06	−0.04	−0.1	−0.03	−0.05	−0.17	−0.64	−0.42	−0.34
	2023	0.08	0.03	0.15	0.04	0.03	0.05	0.05	0.04	0.14	0.02
	2024	−0.02	−0.01	−0.3	−0.01	−0.07	−0.03	−0.02	−0.04	−0.07	−0.06
Max	2019	0.02	0.14	0.03	0.12	0.08	0.3	0.53	0.05	1.21	0.03
	2020	0.07	0.03	0.07	0.06	0.05	0.06	0.16	0.05	0.21	0.04
	2021	0.02	0.02	0.04	0.02	0.02	0.09	0.06	0.02	0.05	0.05
	2022	0.08	0.03	0.15	0.04	0.03	0.05	0.05	0.04	0.14	0.02
	2023	0.03	0.01	0.04	0.03	0.03	0.05	0.07	0.05	0.11	0.04
	2024	0.51	0.09	0.04	0.21	0.02	0.17	0.34	0.71	0.42	0.38
	id_BI										
Min	2020	−0.07	−0.08	−0.07	−0.08	−0.14	−0.07	−0.07	−2.09	−0.06	−0.02
	2021	−0.03	−0.04	−0.04	−0.03	−0.04	−0.02	−0.05	−0.03	−0.03	−0.01
	2022	−0.18	−0.29	−0.05	−0.05	−0.03	−0.04	−0.04	−0.92	−0.74	−0.02
	2023	−0.03	−0.02	−0.03	−0.04	−0.02	−0.01	−0.04	−0.05	−0.05	−0.02
	2024	−0.02	−0.02	−0.25	−0.02	−0.02	−0.03	−0.11	−0.05	−0.04	−0.55
Max	2020	0.09	0.14	0.07	0.1	0.09	0.05	0.14	2.09	0.05	0.05
	2021	0.04	0.04	0.04	0.03	0.03	0.02	0.04	0.04	0.02	0.03
	2022	0.4	0.05	0.26	0.04	0.06	0.03	0.06	0.06	0.03	0.22
	2023	0.03	0.02	0.03	0.03	0.03	0.02	0.03	0.06	0.03	0.02
	2024	0.07	0.62	0.02	0.25	0.01	0.01	0.01	0.73	1.31	0.01

Appendix C

Table C1. Results of tests of nonparametric criteria for related samples.

Null hypothesis (H0)	Periods years	Friedman test statistics	W concordance	Signifi-cance*	Solution (1) and (2)**
Volatility distributions of GRE and BRENT are aligned.	2019–2020	0.1	0.0001	0.75	Hypothesis H0 is accepted
	2021	5.8	0.022	0.016	Hypothesis H0 is rejected
	2022	0.32	0.001	0.575	Hypothesis H0 is accepted
	2023–2024	0.56	0.002	0.454	Hypothesis H0 is accepted
Volatility distributions of Y_01–Y 12 are aligned.	2019–2020	17.67	0.029	0.418	Hypothesis H0 is accepted
	2021	37.4	0.013	0.0001	Hypothesis H0 is rejected
	2022	2.27	0.001	0.99	Hypothesis H0 is accepted
	2023–2024	34.8	0.011	0.0001	Hypothesis H0 is accepted
Volatility distributions of BI_01–BI 12 are aligned.	2019–2020	11.68	0.004	0.307	Hypothesis H0 is accepted
	2021	9.7	0.004	0.466	Hypothesis H0 is accepted
	2022	7.3	0.003	0.702	Hypothesis H0 is accepted
	2023–2024	28.2	0.009	0.002	Hypothesis H0 is rejected
Volatility distributions of CR_01-CR 12 are aligned.	2019–2020	6.3	0.002	0.707	Hypothesis H0 is accepted
	2021	31.7	0.013	0.0001	Hypothesis H0 is rejected
	2022	28.1	0.012	0.001	Hypothesis H0 is rejected
	2023–2024	24.7	0.009	0.003	Hypothesis H0 is rejected

(1) Coefficient of concordance for related samples. (2) Friedman's two-way rank analysis of variance for related samples. *two-sided asymptotic significance (probability of the null hypothesis being true). ** The significance level boundary is 0.05.

Appendix D

Table D1. VAR structure for 10-year sovereign bond yield indices (Y_1—Y10) considering exogenous variables.

	Endogenous variables Y_1-Y10**									
	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y10
Autoregressive part and exogenous variables	Y_1 (1) Y_2 (3) Y_3 (2) Y_4 (3) Y_9 (2) CB_1 CB_3 CB_4 (1) CB_7 CB_8 (1) BI_1 (1) BI_2 BI_7	Y_2 (1) Y_3 (2) Y_6 (3) Y_7 (3) Y_8 (1) Y10 (3) CB_4 CB_6 CB_7 BI_6 (1) BR	Y_3 (1) Y_4 (1) Y_7 (2) Y_9 (5) CB_4 CB_6 CB_8 (1) BI_3 BI_5 BI_8 (1) GR (1) BR (1)	Y_1 (4) Y_2 (4) Y_4 (2) Y_5 (3) Y_7 (1) Y10 (4) CB_2 (1) CB_3 (1) CB_4 BI_1 (1) BI_2 BI_4 BI_7 GR (1) BR (1)	Y_1 (1) Y_4 (1) Y_5 (2) Y_6 (1) Y_6 (1) Y_8 (2) BI_1 (1) BI_2 (1) BI_3 (1) BI_5 (1) BI_7 BI_9 GR (1)	Y_1 (1) Y_2 (1) Y_5 (1) Y_6 (1) Y_7 (1) Y_7 (4) Y_8 (1) Y_9 (4) CB_3 (1) CB_8 (1) CB10 (1) BI_1 (1) BI_2 BI_5 (1) BI_9 GR (1) BR (1)	Y_1 (4) Y_5 (2) Y_6 (1) Y_7 (1) CB_4 (1) CB_5 (1) CB_6 (1) CB_7 (1) BI_5 (1) BI_6 BI_7 (1) BI_8 (1) GR (1)	Y_1 (2) Y_3 (1) Y_5 (5) Y_8 (1) Y10 (3) BI7 (1) BI9 (1)	Y_1 (4) Y_7 (4) Y_8 (1) Y_9 (2) CB_4 (1) CB_8 (1) CB_9 CB_10 (1) BI_1 BI_5 (1) BI_7	Y_3 (3) Y_6 (4) Y_9 (3) Y10 (1) CB_4 (1) CB_6 CB_10 BI_3 (1) BI_6
Max	3	3	3	4	5	5	3	5	4	4
R^2	0.44	0.18	0.177	0.29	0.17	0.17	0.18	0.08	0.14	0.18
F	7.8	13.3	12.5	1.8	5.5	2.2	6.7	2.4	3.6	0.45
p (F)	0	0	0	0.09	0.000	0.05	0	0.03	0.002	0.92
prho	0.002	0.0003	0.008	−0.01	−0.02	−0.02	0.004	0.001	0.002	0.014
D-U	1.99	1.99	1.97	2.03	2.03	1.99	1.98	2	1.85	1.97

Max-Maximum significant lag of auto-recession. * The number of the variable corresponds to the country. The minimum effective lag is indicated in brackets, the first lag is not indicated. Calculations were carried out on the series of logarithmic differences id, which are omitted in the notation. DU-Durbin-Watson coefficient. Source: compiled by the authors.