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Stock Market TVP-VAR Dynamic Connectedness and VIX Shocks Spillovers: Evidence from a Sectoral Analysis of the Fragile Five

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ABSTRACT

Objective: This study investigates the cross-sectoral spillover effect and the contribution of the volatility index (VIX) in the transmission of shocks in the Fragile Five (Brazil, India, Indonesia, South Africa, and Turkey).

Research Design & Methods: We focused on the role played by the various sectors of the economy (Energy, Financials, Industrials, Basic Materials, and Real Estate) and the VIX in the crisis propagation, *i.e.* whether they act as sources, *transmitters* or *receivers* of financial stress, following the time-varying parameter vector autoregression (TVP-VAR) approach. The study also highlights the dynamic evolution of contagion across time.

Findings: We identified the financial sector (essentially the largest in terms of market value) as a strong *net transmitter*. Another relatively strong *net transmitter* was the industrial sector (medium-sized). Basic Materials (medium-sized) and Real Estate (the smallest in terms of market value) essentially acted as *net receivers*. In all the countries surveyed, Energy (medium-sized sector) and the VIX were identified as *net receivers*. We found that the bidirectional spillover between the VIX and sectoral indices was weak in all countries under investigation. Our observations on the VIX behaviour can be associated with the fundamentals, such as the US/the Fragile Five equity market mutual exposures, but we opted for the neutrality of the relationship between the VIX and sectoral indices. The average Total Connectedness Index (TCI) in the Fragile Five turned out to be relatively low. We also observed that sharp increases in the TCI were associated with market tensions, both country-specific and global.

Implications & Recommendations: Our conclusions can help formulate economic policy goals and increase the efficiency of portfolios with exposures in the Fragile Five countries. *Risk transmitters* such as the financial and industrial sectors should be closely watched by regulators and investors with exposures to *risk takers*, *i.e.* sectors such as Energy, Basic Materials, and Real Estate. Sharp increases in the TCI related to market tensions should be a warning signal when formulating economic policy goals and building investment strategies. Determining the role of fear indices in the spillover mechanism, including the VIX, requires additional in-depth empirical studies.

Contribution & Value Added: Our contribution to the literature is threefold. Primarily, to our knowledge, it is the first study to provide insights into the linkages between the different sectors of the Fragile Five economies and the volatility index. Secondly, unlike the vast majority of previous work focused on sectoral linkages in selected groups of emerging economies taken as a whole, we draw common conclusions for the Fragile Five based on observations of their individual economies, which helped to reduce the number of generalizations. Thirdly, through the inference process, we identified some interesting correlations that could be a starting point for further research.

Article type: research article

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INTRODUCTION

Early studies concerning financial contagion date back to the aftermath of the 1997-1998 Asian financial turmoil. However, the problem of volatility transmission channels has generated a considerable amount of econometric research for the last several decades due to the growing interconnectedness of financial markets and the increased frequency of financial crises. Extreme volatility causes financial instability, which in turn can negatively affect both investment portfolios and the real economy. Due to the scale of macroeconomic consequences, the mechanism of transmission of volatility in equity markets is of particular importance. According to Gunay and Can (2022), equity markets play a crucial role in price discovery and are essential barometers of future economic activity as stock prices incorporate information arrivals and expectations of various market participants. Because equity markets are where foreign direct investment is allocated and economic conditions can force individual and institutional investors to liquidate their stock holdings, equity market sentiment, and economic growth are strongly interconnected (Gunay & Can, 2022).

We investigated the cross-sectoral spillover effect and the contribution of the Chicago Board Options Exchange Volatility Index (CBOE VIX hereinafter referred to as VIX) to the transmission of shocks in the original Fragile Five countries (*i.e.* Brazil, India, Indonesia, South Africa, and Turkey). We aimed to identify the role played by the various sectors of the economy (Energy, Financials, Industrials, Basic Materials, Real Estate) and the VIX in the crisis propagation, *i.e.* whether they act as sources, *transmitters* or *receivers* of financial stress. Furthermore, the study highlights the dynamic evolution of contagion across time in each of the analysed countries, *i.e.* we sought to test whether the roles of *shock transmitters* and *receivers* were constant, as well as whether changes in the Total Connectedness Index (TCI) could have been influenced by an increase in uncertainty in the financial markets triggered by events such as the eurozone crisis, tapering talk, significant depreciation of the local currency, coronavirus pandemic, etc. In both research areas, we looked for common patterns across the Fragile Five countries. We also looked for a potential dependency of the pattern of contagion on the size of the individual sectors.

In this article, we empirically investigated the contagion patterns from September 22, 2009, to December 15, 2021, following the methodology proposed by Diebold and Yilmaz (2014). The method essentially permitted us to test how pervasive risk is throughout a financial market, in response to episodes of price uncertainty from a specific source, *e.g.* whether price variability within a given asset class creates material instabilities that permeate through the rest of the financial market in a non-trivial fashion (Zhang & Broadstock, 2020). According to the literature, employing a TVP-VAR approach results in more precise and unbiased estimates (see Chatziantoniou *et al*., 2022), which gives it an advantage over alternative methods for spillover analysis. The base model incorporates the estimation of coefficients that fluctuate over time, capturing changes in relationships as they occur. This model's flexibility accommodates structural shifts and regime alterations, offering advantages over quantile-based techniques that account for changes in regimes throughout the distribution. In other words, TVP-VAR is all-encompassing making it a key tool in demonstrating the dynamics of financial markets. Its flexible and robust structure is useful in understanding the potential variations over time.

The rationale for choosing the research problem was that the interconnectedness of the financial market exposes not only individual investors to losses, but could also operate as an amplification channel when the initial shock is sufficiently strong, with severe consequences for the macroeconomy. This was evident during episodes of financial contagion over the past several years involving banks, shadow banks, insurance firms, and other financial entities (Franch *et al*., 2022). Therefore, the analysis of financial market linkages can be useful in such areas as 1) determining the principles of effective portfolio management (ways to diversify risk and hedging strategies); 2) determining the principles of effective macroprudential policy (disclosure policy, level of macroprudential buffers and stress testing methodology); and 3) determining the principles of effective macroeconomic policy (tools to achieve the targeted economic growth rate). We decided on the cross-sectoral and VIX analysis of the original Fragile Five countries to bridge the research gap that concerns the transmission patterns of the spillover effect. Existing literature on the subject rarely focuses on cross-sectoral linkages within emerging economies.

To our knowledge, there are no similar studies in the literature on the Fragile Five countries taken as a whole. However, the Fragile Five as a group is an interesting subject of study as their economic situation is strongly influenced by certain common determinants, one of which is the severe pressure of the US dollar on their national currencies due to the large debt in US dollars and the high dependence on foreign flows of portfolio funds held largely in the US dollar. We included the fear index in the cross-sectoral study, because recent studies underline the influence of such indices on the behaviour of sectoral stocks as well as the volatility transmission pattern (Ahmad *et al*., 2021; Bossman *et al*., 2023; Chen & Sun, 2022; Kang *et al*., 2023; Ozcelebi *et al*., 2023; Shahzad *et al*., 2020). Several fear indices are used in scientific research (the Global Macroeconomic Uncertainty Index, the Global Economic Policy Uncertainty Index, the World Uncertainty Index, the VIX, the VXEEM, the VXFXI, VXEWZ, the VSTOXX, *etc.*) but we chose the VIX, because researchers recognize it as a universal proxy for market uncertainty and global risk. This is related to the results of numerous academic studies showing that uncertainty in the US market plays a key role in the uncertainty in the global stock market. A feature of the VIX, then, is widespread acceptance, which allows for the comparison of results with other academic studies. An additional argument in favour of using the VIX as a fear index was the above-mentioned strong links of the group of countries surveyed to the US economy and the US dollar.

Our contribution to the literature is threefold. Primarily, to our knowledge, it is the first study to provide insights into the linkages between the different sectors of the Fragile Five economies and the volatility index. Secondly, unlike the vast majority of previous work focused on sectoral linkages in selected groups of emerging economies taken as a whole, we drew common conclusions for the Fragile Five based on observations of their individual economies, which helped to reduce the number of generalizations. Thirdly, through the inference process, we identified some interesting correlations that could be a starting point for further research, such as the relationship between the sector size and its role (*net receiver* or *net transmitter*) in the shock transmission mechanism; the impact of the relative (in relation to the size of the economy) level of energy imports on the behaviour of the energy sector; the impact of the size of mutual (country/region – the US) equity exposures on the role of the VIX in the spillover. Moreover, the conclusions have valuable practical applications, as the identification of key sectors that lead other sectors and shock recipient sectors can help formulate economic policy objectives and increase the efficiency of portfolios with exposures in the Fragile Five countries.

Our article is structured as follows. We will first look at related works on connectedness in the financial markets through returns and volatility spillovers. Based on this literature review, we will identify a research gap and formulate a research hypothesis. In the next section, we will describe the data, data sources, and basic assumptions made in our study, and outline the empirical model used. Then come the results, which we divide into three parts: the results of the sectoral analysis, the results of the bidirectional spillover between the VIX and sectoral indices analysis, and the results of the dynamic total connectedness analysis. When presenting the results, we will also identify areas for further discussion. The last section will conclude our findings.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

The 2008 financial crisis highlighted the importance of financial linkages and challenged pre-crisis financial stability regimes (The World Bank, 2013). Since its outbreak, the connectedness in financial markets through returns and volatility spillovers has been gaining prominence in international finance literature (Bouri *et al*., 2021; Farid *et al*., 2021; Iqbal *et al*., 2022; Nguyen *et al*., 2020). Many authors have analysed various aspects of the spillover effect, but two main research trends can be discerned in the studies devoted to this phenomenon to date. The former is observed in research focusing on the connectedness between international asset classes and stock markets (Bouri *et al*., 2021; Franch *et al*., 2022; Gomez-Gonzalez *et al*., 2022; Hernandez *et al*., 2020; Iqbal *et al*., 2022; Kang *et al*., 2019; Lee & Lee, 2020; Nguyen *et al*., 2020; Shu & Chang, 2019; Singh *et al*., 2019). The second trend is reflected in the group of works looking for effective methods of portfolio management and hedging strategies (Belhassine, 2020; Fang *et al*., 2019; Fasanya *et al*., 2021; Kang *et al*., 2019; Mensi *et al*., 2023; Papathanasiou *et al*., 2022; Samitas *et al*., 2022; Raza *et al*., 2019; Yousaf *et al*., 2022; Lin *et al*., 2021).

The most interesting conclusions of the first group of studies are as follows. Firstly, there is a set of countries – mostly consisting of large, developed or crisis-stricken economies – that plays a critical role in the unfolding of contagion episodes. Emerging economies are mostly *net receivers* of shocks (Franch *et al*., 2022; Hernandez *et al*., 2020; Kang *et al*., 2019). The *primary transmitter* of shocks is the US economy (Kang *et al*., 2019; Lee & Lee, 2020) and the largest developed market spillover *transmitters* are the largest financial institutions from the US (Hernandez *et al*., 2020). Secondly, there is also a group of indices – such as the equity and USD indices – that are the *primary transmitters* of shocks, although, for individual asset classes, the roles of *net transmitter* and *net receiver* may alternate over time (Bouri *et al*., 2021). Thirdly, as Hernandez *et al*. (2020) showed, the spillovers and connectedness among institutions from emerging countries are noticeably smaller than those among institutions from the developed world. The aforementioned authors made this observation by studying banks from emerging and developed America between 2011 and 2019. Interestingly, during the COVID-19 pandemic, the total connectedness of the emerging market bank group was more intensified than its counterpart, which may indicate the particular vulnerability of the developing world to macroeconomic shocks.

For the second type of study, the available literature on the subject concludes that financial turbulences induce changes in the volatility dynamics, so both mean and volatility spillovers between different asset classes are time-varying and heterogeneous. Even if the acquisition of certain asset classes enables effective hedging against some notable market risks and increases portfolio diversification during tranquil periods, this may not be a rule in times of market turbulence. Thus, market participants can achieve better portfolio diversification benefits and increase hedging effectiveness by incorporating the size and direction of the net return spillover information (Belhassine, 2020; Fasanya *et al*., 2021; Kang *et al*., 2019; Papathanasiou *et al*., 2022). Noteworthy, until recently, many authors identified gold as a safe haven against stock market crashes (Baur & Lucey, 2010; Junttila *et al*., 2018), but more contemporary research remains ambiguous in this matter (Yousaf *et al*., 2022; Adekoya *et al*., 2021).

Both types of studies indicate that the total connectedness spikes and the structure of the connectedness networks alters during periods of market turmoil. Nguyen *et al*. (2020), who examined the inter-relationship between green bonds and other asset markets (stocks, commodities, clean energy, and conventional bonds) over 11 years from 2008 to 2019, found strong evidence that most correlation emerged and reached a peak in the aftermath of Global Financial Crisis 2007-2009. According to Kang *et al*. (2019), the total spillover connectedness between eighteen world stock markets, six commodities, two bond indices, and two implied volatility indices (VIX and VSSTOXX) peaked during the periods from 2011 to 2012 and from 2015 to 2016, which coincided with the eurozone crisis, and the Chinese stock market crash and the Brazilian economic crisis, respectively. Analysing data for 2011-2020, Bouri *et al*. (2021) confirmed a significant increase in linkages between various assets with different levels of risk during the COVID-19 pandemic. Papathanasiou *et al*. (2022) presented similar findings. Their research covered the years 2011-2021 including S&P 500 Value Index and six other significant stock S&P 500 indices. According to Papathanasiou *et al*., high levels of volatility spillovers were triggered by the European Sovereign Debt Crisis and the outbreak of the pandemic crisis.

Existing literature on the subject rarely focuses on cross-sectoral linkages within countries. However, the number of such works is steadily increasing (Chatziantoniou *et al*., 2022; Chen *et al*., 2022; Collet & Ielpo, 2018; Jiang *et al*., 2020; Laborda & Olmo, 2021; Liu *et al.,* 2021; Wu *et al*., 2019). Many such publications emphasize the important role of the financial sector in the transmission of crises. For example, Chen *et al*. (2022) demonstrated the importance of the overall stock market and the financial sector in driving the other segments (*i.e.* oil, gold, and broad market) volatilities in the US economy after the Global Financial Crisis. Empirical results of Laborda and Olmo (2021) showed that Banking & Insurance are among the main channels through which shocks are transmitted to the rest of the US economy, which was particularly evident between 2007 and 2009. According to Liu *et al*. (2021), who also studied the US market, the financial sector was near the 'universal transmitter' of volatility between 1999 and 2016. Similarly, Wu (2019), who analysed 2009-2018 data for the Chinese economy, found Financials as the top risk contributor.

Among publications focused on sectoral linkages within a single country, studies on emerging markets are rather limited, yet these markets face different conditions and have key structural features that can affect the relevance and efficacy of macroprudential and macroeconomic policies. According to the position of The World Bank, 'because they suffered earlier financial crises, many emerging markets have had greater experiences with macro-prudential and other policies aimed at ensuring financial stability. As such, emerging markets can offer valuable lessons' (The World Bank, 2013). Having identified the aforementioned research gap, we decided to focus on the Fragile Five countries. As far as the spillover study is concerned, we found them interesting, because in some respects they are a homogeneous group, *i.e.* as the Morgan Stanley analysts indicated, these countries relied heavily on a stable US economy to function properly, and their national currencies were under severe pressure from the US dollar (Badkar, 2013; Ozturk *et al*., 2020; Unver & Dogru, 2015; Yenice & Tekindal, 2015). To our knowledge, there are no similar studies in literature. Those that do exist are devoted either to sectoral links within a single country belonging to the group (Chatziantoniou *et al*., 2022; Chen *et al*., 2022; Collet & Ielpo, 2018; Jiang *et al*., 2020; Laborda & Olmo, 2021; Liu *et al*., 2021; Wu *et al*., 2019) or to the price response of broad asset classes issued by the group as a whole (Yildirim, 2016).

In studies on the nature of international and domestic spillover, fear indices are often included. According to Mensi *et al*. (2023), the advent of many crises has increased market uncertainty and made allocating funds more challenging over the past few decades. At the same time, with the regular occurrence of various types of uncertainty, volatility in financial markets has increased significantly. Herein, we should note that uncertainty and fear are similar concepts in terms of reflecting market stress, while the classification of Datta *et al*. (2017) makes a clear distinction between non-asset market-based and asset market-based measures of risk and uncertainty. Our study deals with the impacts of asset market-based indicators on stock indices following the assumption that the interplay between financial markets and such indicators is relatively stronger than the relationship among non-asset market-based measures and variables related to financial market dynamics. Asset market-based indicators have significant transmission effects on financial assets, particularly on stock markets after the 2008-2009 Global Financial Crisis.

Considering recent arguments related to the pricing implication of volatility indices (Das & Kannadhasan, 2020; Dogah & Premaratne, 2018; Kang *et al*., 2019; Ozcelebi, 2020; Tsai, 2014; Yildirim, 2016), we decided to follow that approach and used the VIX as the fear index. The rationale behind choosing the VIX was twofold. Firstly, we were inspired by the findings of Chudik and Fratzscher (2011) who explored the role of risk shocks and liquidity shocks in spreading the crisis, both to advanced economies and to emerging markets before and during the global financial crisis (January 1, 2005-end July 2009). They concluded that emerging economies (which include the Fragile Five – authors' note) were particularly vulnerable to US-specific risk shocks (shocks to the VIX), with equity markets being the most susceptible. Moreover, Smales (2022), who examined the linkages between twelve stock market uncertainty measures over a 20-year sample period (2001-2020), showed that US market uncertainty plays a pivotal role in global stock market uncertainty. Secondly, according to Morgan Stanley analysts, the Fragile Five have strong links to the US economy, so the use of the VIX as a proxy for the level of market stress seemed warranted.

The previous studies and the literature review allowed us to formulate the following research hypothesis:

In the Fragile Five taken as a whole,

H1: There is a common pattern of spillover, with the financial sector being the *primary transmitter* of shocks.

H2: The VIX plays the role of a *net transmitter* and the bidirectional spillover between the VIX and sectoral indices is strong.

H3: The sectoral connectedness is relatively low, although such connectedness rises in times of market stress.

RESEARCH METHODOLOGY

Data Sources and Variable Definitions

We based the analysis on the daily quotations of five sectoral indices in the Fragile Five countries (Brazil, India, Indonesia, South Africa, and Turkey) and one volatility index (stress index) over the period from September 22, 2009 to December 15, 2021. We took VIX as the stress index. The values of the sectoral indices were extracted from the Refinitiv Datastream database. We sourced the volatility index from https://pl.investing.com/indices/volatility-s-p-500-historical-data (December 15, 2021). Our focus on the post-global financial crisis (post-GFC) was motivated by the increasingly relevant argument that after the GFC, there was an increasing connectedness between commodity and equity markets (Kang *et al*., 2019; Gomez-Gonzalez *et al*., 2022; Aboura & Chevallier, 2014) as well as between the different types of commodity markets themselves (Zhang & Broadstock, 2020). The main factor determining the start and end dates of the research data was the availability and completeness of quotations of the selected indices in the two databases mentioned above.

The Fragile Five is a group of emerging countries which possess the following features: high inflation, weakening growth, high and rising current account deficits, large US dollar debt, high dependence on foreign portfolio fund flows, and vulnerable national currencies (Badkar, 2013; Ozturk *et al*., 2020; Unver & Dogru, 2015; Yenice & Tekindal, 2015). The aforementioned characteristics of the group make it particularly susceptible to internal and external shocks and thus to the occurrence of cross-sectoral spillover. The composition of the Fragile Five has been revised several times by various analysts, but we focused on the so-called 'original Fragile Five,' *i.e.* the countries first included in the group by Morgan Stanley in 2013, namely, Brazil, India, Indonesia, South Africa, and Turkey. Although considering changes in the composition of the Fragile Five group is certainly worthy of in-depth scientific analysis on its own, choosing a fixed group has undeniable advantages based on the fact that frequent changes within the sample would make it difficult to draw country-specific conclusions about long-term relationships between sectors of the studied economies.

In the analysis, we used daily logarithmic returns of five total return sectoral indices expressed in local currencies. The sectoral indices were as follows: Energy, Financials, Industrials, Basic Materials, and Real Estate. The choice of the sectoral indices was determined by three factors: 1) the conclusions drawn from the review of the literature on the subject, which underscores the importance of the selected sectors in spillover transmission (Belhassine, 2020; Chen *et al*., 2022; Das & Kannadhasan, 2020; Dogah & Premaratne, 2018; Wu *et al*., 2019); 2) the data availability; and 3) the completeness of the sectoral index time series in the Refinitiv Datastream. We decided to choose the total return versions of the sectoral indices because their informative value is greater in relation to the price indices (total return versions of indices were used to measure spillover among others by Frijns *et al*., 2017; Samitas *et al*., 2022; Tian & Hamori, 2016; Kirschenmann *et al*., 2020). The daily returns of the sectoral indices were computed on a continuous basis as the difference between the natural logarithms of two consecutive levels. Table 1 presents a detailed list of sectoral indices surveyed in the 'original Fragile Five.'

Table 1. Sectoral indices surveyed

Sector/Country	Brazil	India	Indonesia	South Africa	Turkey
Energy (En)	Brazil – DS[a] Energy	S&P BSE Energy	Indonesia – DS[a] Energy	South Afri – DS[a] Energy	Turkey – DS[a] Energy
Financials (Fin)	Brazil – DS[a] Financials	S&P BSE Finance	Indonesia – DS[a] Financials	FTSE/JSE Financials	Turkey – DS[a] Financials
Industrials (In)	DJGL Brazil Industrials	S&P BSE Industrials	Indonesia – DS[a] Industrials	FTSE/JSE Industrials	Turkey – DS[a] Industrials
Basic Materials (Mat)	Brazil Basic Material (IMAT)	S&P BSE Basic Materials	Indonesia – DS[a] Basic Materials	FTSE/JSE Basic Mats	Turkey – DS[a] Basic Materials
Real Estate (Rea)	Brazil Real Estate Imob Index	India – DS[a] Real Estate	DJGL Indonesia Real Estate	South Afri – DS[a] Real Estate	DJGL Turkey Real Estate

[a] Datastream index.

Source: own study based on the Refinitiv Datastream (2021).

Table 2 presents the relative sizes of the analysed sectors measured by the shares (minimum and maximum) of the average annual market values of the sectoral indices in the sum of the average annual market values of all the indices covered in the Fragile Five during the analysis period.

Table 2. Minimum and maximum shares of average annual market values of sectoral indices in the sum of average annual market values of all indices covered in the Fragile Five during the analysis period (%)

Sector/Country	Brazil	India	Indonesia	South Africa	Turkey
En	12.0-28.0	14.0-20.0	3.0-19.0	1.0-11.0	6.0-17.0
Fin	38.0-62.0	34.0-56.0	41.0-72.0	27.0-42.0	45.0-81.0
In	1.0-12.0	13.0-23.0	11.0-19.0	3.0-11.0	8.0-20.0
Mat	16.0[b]-34.0[b]	11.0-17.0	5.0-25.0	34.0-59.0	4.0-24.0
Rea	2.7[b]-5.3[b]	1.5-7.4	1.3-6.8	2.1-8.1	0.2-2.9

[a]Annual averages calculated from daily observations except [b].
[b]Annual averages calculated from monthly observations.
Source: own study based on market values sourced from the Refinitiv Datastream (2021), BM&FBOVESPA Basic Materials Index (2022), and BM&FBOVESPA Real Estate Index (2022).

As we can see from the data presented in Table 2, in almost all of the countries analysed, except South Africa, the financial sector was the largest compared to the other sectors included in the study. In South Africa, the sector with the largest market value was Basic Materials, while the financial sector was the second largest. The size of the energy, industrial and basic materials sectors varied in each of the countries studied, but they can consistently be considered medium-sized sectors, accounting for up to 1/3 of the market size (the Basic Materials was the largest sector of those analysed only in South Africa). Real Estate was the smallest sector in each of the countries surveyed.

Volatility indices, also referred to as 'investor fear gauges,' are measures of market expectations of stock return volatility (Whaley, 2000). The VIX measures the implied volatility of the S&P 500 index options and represents the market's expectation of stock market volatility over the next 30 days, which is commonly used to measure investor sentiment. In practice, the VIX is also examined to determine whether investors' perceptions of a possible financial recession have intensified (Tsai, 2014). Lower VIX values indicate less market uncertainty, while higher values of the VIX represent more uncertainty or 'fear' in the market (Basher & Sadorsky, 2016). Pessimistic market sentiment further causes the prices of stocks, bonds, funds, and other financial assets of the relevant country to fall (Chen & Sun, 2022).

Stress indices behave somewhat differently than sectoral indices (unlike the latter, stress indices do not show upward trends in the long term and their values change sharply only as a result of specific changes in the economic environment). Ozcelebi and Pérez-Montiel (2023) obtained empirical evidence that raw values of the VIX provide more accurate estimations and forecasts than the transformed ones. Given the above arguments, following an approach widely used in the literature on the subject (Das & Kannadhasan, 2020; Kang *et al*., 2019; Mensi *et al*., 2019; Ozcelebi, 2020; Ozcelebi & Pérez-Montiel, 2023; Tsai, 2014), we used daily observations in the levels ('raw' values) of the VIX.

Empirical Model

In this study, we incorporate the TVP-VAR model, which is an extension of the standard VAR, to take advantage of its strength of flexibility in modelling time-varying relationships. While the parameters are assumed to be constant in the standard VAR model specification, TVP-VAR is particularly useful in economic and financial modelling, where the relationships between variables can change in response to various events, leading to structural breaks or shifts in the relationship between model variables over time. Thus, the TVP-VAR leads to improved forecasting accuracy, better represents macroeconomic and financial dynamics and decreases the risk of misspecification.

We departed from the connectedness approach of Diebold and Yilmaz (2014) and performed the relevant analysis in terms of the TVP-VAR model in line with Antonakakis *et al*. (2020), Antonakakis *et al*. (2021), Balcilar *et al*. (2021) Bouri *et al*. (2021), Chatziantoniou and Gabauer (2021). In this context, Gabauer (2021) defines the TVP-VAR model as presented below. Please bear in mind that

the empirical results are based on TVP-VAR(p) model, while the lag order of the model (*p*) is imposed by the Schwarz information criterion (SC).

$$y_t = \phi_t Z_{t-1} + \epsilon_t \qquad \epsilon_t | I_{t-1} \sim N(0, \Sigma_t) \tag{1}$$

$$vec(\phi_t) = vec(\phi_{t-1}) + \xi_t \qquad \xi_t | I_{t-1} \sim N(0, \Xi_t) \tag{2}$$

More specifically, model variables displayed in Table 1 (En, Fin, In, Mat, Rea, VIX) are contained in the vector y_t. This approach leads to the derivation of the generalized impulse response functions (GIRFs) and generalized forecast error variance decompositions (GFEVDs) in terms of the time-varying coefficient and time-varying variance-covariance matrices computed from the TVP-VAR in terms of each country, namely Brazil, India, Indonesia, South Africa, and Turkey. Accordingly, the vector moving average (VMA) representation via the Wold representation theorem can also be specified as below:

$$y_t = \Gamma'(\Upsilon_t(Z_{t-2} + \zeta_{t-1}) + \zeta_t \tag{3}$$

$$= \Gamma'(\Upsilon_t(\Upsilon_t(Z_{t-3} + \zeta_{t-2}) + \zeta_{t-1}) + \zeta_t) \tag{4}$$

$$= \Gamma'(\Upsilon_t^{k-1} Z_{t-k-1} + \textstyle\sum_{j=0}^{k} \Upsilon_t^j \zeta_{t-j} \tag{5}$$

in which p is the lag length of the model and m refers to the number of variables in the model. Accordingly, Υ_t denotes an $mp \times mp$ dimensional matrix, ζ_t represents a vector with an $mp \times 1$ dimension, and the matrix Γ has $mp \times m$ dimensions. Taking the limit as k approaches ∞ results in Eq. (6).

$$y_t = \textstyle\sum_{j=0}^{\infty} \Lambda_{jt} \epsilon_{t-j} \tag{6}$$

in which $\Lambda_0 = I_K$ and ϵ_t is a vector of white noise shocks with a $K \times K$ time-varying covariance matrix $E(\varepsilon_t \varepsilon_t{}') = \Sigma_t$. Thus, we considered the generalized connectedness approach (Diebold & Yılmaz, 2012; Diebold & Yilmaz, 2014) on the basis of the K-step-ahead GFEVD introduced by Koop *et al*. (1996) and Pesaran and Shin (1998). In this context, Eq. (7) defines the K-step forecast error.

$$\xi_t(K) = y_{t+K} - E(y_{t+K} | y_t, y_{t-1}, \dots) \tag{7}$$

In this context, the responses of all the model variables to the shock in variable i are included in the GIRFs. Equation (8) shows the differences between a K-step-ahead forecast where once variable i is shocked, and once where it is not shocked.

$$GIRF_t(K, \iota_{i,t}, I_{t-1}) = E(y_{t+K} | \varepsilon_{i,t} = \iota_{i,t}, I_{t-1}) - E(y_{t+K} | I_{t-1}) \tag{8}$$

in which I_{t-1} has the information available until t – 1. Thus, we computed the GFEVD that denotes the forecast error variance share of one variable on others. All model variables together explain 100% of the forecast error variance of i, while the NET total directional connectedness (which corresponds to the total net spillover) was calculated by subtracting the total directional connectedness TO others from the total directional connectedness FROM others as in Equation (8). Moreover, the approach defined above helps to derive the Total Connectedness Index (TCI) in line with Gabauer (2021).

Tables 11-15 in the Appendix show that most series had positive average returns except Real Estate in Brazil, India, and Indonesia. No single sectoral time series had consistently the highest or lowest standard deviation. We observe that most of the series were significantly left-skewed whereas VIX was right-skewed. Interestingly, we found that all series were leptokurtic. According to the Jarque and Bera normality test, the data series were significantly non-normally distributed. As shown in Tables 11-15 in the Appendix, the augmented Dickey–Fuller (ADF) and Philips–Perron (PP) tests suggested that we may describe all the series as stationary at levels.

RESULTS AND DISCUSSION

Directions of Shock Transmission

Using the TVP-VAR model, we first examined the directional spillover between the time series included in our network. We provide detailed calculations and net total connectedness measures in Tables 3-7 and Figures 1-5 in the Appendix, while a summary of the results obtained for all the Fragile Five countries is presented in Table 8.

Table 3. Averaged connectedness: Brazil

Index	En	Fin	In	Mat	Rea	VIX	FROM
En	42.65	17.58	11.15	12.99	13.90	1.74	57.35
Fin	15.34	36.67	15.23	11.27	19.99	1.49	63.33
In	10.75	16.67	40.60	13.64	16.18	2.16	59.40
Mat	13.23	12.88	14.89	46.09	10.33	2.57	53.91
Rea	12.90	21.23	15.60	9.70	39.04	1.53	60.96
VIX	2.95	3.02	3.92	4.07	2.92	83.13	16.87
TO	55.17	71.39	60.79	51.67	63.31	9.50	311.83
Inc. Own	97.82	108.06	101.38	97.76	102.35	92.62	
NET	-2.18	8.06	1.38	-2.24	2.35	-7.38	TCI
NPDC	2.00	5.00	3.00	1.00	4.00	0.00	51.97

Note: in Brazil, Energy, Financials, Industrials, Basic Materials, and Real Estate are strongly influenced by respectively: Financials (17.58%) and Real Estate (13.90%), Real Estate (19.99%) and Energy (15.34%), Financials (16.67%) and Real Estate (16.18%), Industrials (14.89%) and Energy (13.23%), Financials (21.23%) and Industrials (15.60%). Contribution *to others* is strongest in the case of (in descending order): Financials (71.39%), Real Estate (63.31%) and Industrials (60.79%). *Net transmitters* of shocks are Financials, Real Estate and Industrials. Basic Materials, Energy and the VIX should be considered as *net receivers*.
Source: own study.

Table 4. Averaged connectedness: India

Index	En	Fin	In	Mat	Rea	VIX	FROM
En	40.54	15.38	16.67	16.27	10.49	0.66	59.46
Fin	12.51	32.42	21.28	18.89	14.04	0.87	67.58
In	12.74	20.24	30.32	21.52	14.33	0.85	69.68
Mat	12.99	18.52	22.24	31.35	13.98	0.92	68.65
Rea	10.05	16.45	17.67	16.78	38.20	0.85	61.80
VIX	1.20	1.90	2.16	2.25	1.58	90.91	9.09
TO	49.49	72.48	80.02	75.71	54.43	4.14	336.27
Inc. Own	90.03	104.90	110.34	107.06	92.62	95.04	
NET	-9.97	4.90	10.34	7.06	-7.38	-4.96	TCI
NPDC	1.00	3.00	5.00	4.00	2.00	0.00	56.04

Note: in India, Energy, Financials, Industrials, Basic Materials, and Real Estate are strongly influenced by respectively: Industrials (16.67%) and Basic Materials (16.27%), Industrials (21.28%) and Basic Materials (18.89%), Basic Materials (21.52%) and Financials (20.24%), Industrials (22.24%) and Financials (18.52%), Industrials (17.67%) and Basic Materials (16.78%). Contribution *to others* is strongest in the case of (in descending order): industrials (80.02%), Basic Materials (75.71%) and Financials (72.48%). *Net transmitters* of shocks are (in descending order) Industrials, Basic Materials and Financials. *Net receivers* are Energy, Real Estate and the VIX.
Source: own study.

Table 5. Averaged connectedness: Indonesia

index	En	Fin	In	Mat	Rea	VIX	FROM
En	46.27	7.41	9.60	29.28	6.77	0.67	53.73
Fin	7.44	44.22	19.42	9.56	18.68	0.68	55.78
In	9.47	19.18	43.05	12.03	15.62	0.65	56.95
Mat	27.68	9.07	11.65	42.52	8.40	0.69	57.48
Rea	7.17	19.71	16.68	9.35	46.34	0.75	53.66
VIX	1.00	1.18	1.22	1.13	1.32	94.15	5.85
TO	52.76	56.54	58.56	61.36	50.79	3.44	283.45
Inc. Own	99.03	100.77	101.61	103.87	97.12	97.59	
NET	-0.97	0.77	1.61	3.87	-2.88	-2.41	TC
NPDC	3.00	2.00	4.00	5.00	1.00	0.00	47.24

Note: in Indonesia, Energy, Financials, Industrials, Basic Materials, and Real Estate are strongly influenced by respectively: Basic Materials (29.28%) and Industrials (9.60%), Industrials (19.42%) and Real Estate (18.68%), Financials (19.18%) and Real Estate (15.62%), Energy (27.68%) and Industrials (11.65%), Financials (19.71%) and Industrials (16.68%). Contribution *to others* is strongest in the case of (in descending order): Basic Materials, Industrials, Financials. *Net transmitters* of shocks are Basic Materials, Industrials and Financials. Real Estate, Energy and the VIX are *net receivers*.
Source: own study.

Table 6. Averaged connectedness: South Africa

Index	En	Fin	In	Mat	Rea	VIX	FROM
En	51.13	11.20	10.66	22.16	3.33	1.53	48.87
Fin	9.22	40.41	25.50	8.38	14.96	1.53	59.59
In	9.30	26.88	42.70	8.66	10.86	1.60	57.30
Mat	22.73	10.15	9.99	52.56	2.91	1.66	47.44
Rea	4.00	19.98	13.84	3.38	57.26	1.55	42.74
VIX	2.31	3.09	3.05	2.60	2.69	86.26	13.74
TO	47.57	71.30	63.04	45.17	34.74	7.87	269.69
Inc. Own	98.69	111.71	105.74	97.73	92.00	94.13	
NET	-1.31	11.71	5.74	-2.27	-8.00	-5.87	TCI
NPDC	3.00	5.00	4.00	2.00	1.00	0.00	44.95

Note: in South Africa, Energy, Financials, Industrials, Basic Materials, and Real Estate are strongly influenced by respectively: Basic Materials (22.16%) and Financials (11.20%), Industrials (25.50%) and Real Estate (14.96%), Financials (26.88%) and Real Estate (10.86%), Energy (22.73%) and Financials (10.15%), Financials (19.98%) and Industrials (13.84%). Contribution *to others* is strongest in the case of (in descending order): Financials (71.30%), Industrials (63.04%) and Energy (47.57%). *Net transmitters* of shocks are (in descending order) Financials and Industrials. *Net receivers* are Real Estate, Basic Materials, Energy, and the VIX.
Source: own study.

Table 7. Averaged connectedness: Turkey

Index	En	Fin	In	Mat	Rea	VIX	FROM
En	45.16	16.18	12.75	12.01	12.96	0.95	54.84
Fin	14.10	40.72	12.91	12.67	18.85	0.75	59.28
In	12.67	14.84	45.09	12.39	14.07	0.94	54.91
Mat	12.22	14.84	12.54	45.85	13.37	1.19	54.15
Rea	12.04	20.03	13.02	12.22	41.77	0.92	58.23
VIX	1.91	1.71	1.75	2.10	1.86	90.67	9.33
TO	52.94	67.60	52.97	51.39	61.11	4.74	290.74
Inc. Own	98.09	108.32	98.06	97.24	102.88	95.41	
NET	-1.91	8.32	-1.94	-2.76	2.88	-4.59	TCI
NPDC	2.00	5.00	3.00	1.00	4.00	0.00	48.46

Note: in Turkey, Energy, Financials, Industrials, Basic Materials, and Real Estate are strongly influenced by respectively: Financials (16.18%) and Real Estate (12.96%), Real estate (18.85%) and Energy (14.10%), Financials (14.84%) and Real Estate (14.07%), Financials (14.84%) and Real Estate (13.37%), Financials (20.03%) and Industrials (13.02%). Contribution *to others* is strongest in the case of (in descending order): Financials, Real Estate and Industrials. *Net transmitters* of shocks are Financials and Real Estate. Basic Materials, Industrials, Energy, and the VIX should be considered as *net receivers*.
Source: own study.

Table 8. *Net transmitters* and *net receivers*: Summary

Index/Country	Brazil	India	Indonesia	South Africa	Turkey
En	R (B)	R (P)	R (B)	R (B)	R (B)
Fin	T (P)	T (P)	T (B)	T (P)	T (B)
In	T (B)	T (P)	T (B)	T (P)	R (B)
Mat	R (B)	T (P)	T (B)	R (B)	R (B)
Rea	T (B)	R (P)	R (B)	R (B)	T (B)
VIX	R (P)	R (P)	R (P)	R (P)	R (P)

Note: symbols used are as follows: T – *net transmitter*, R – *net receiver*, P – persistent, B – both roles.
Source: own study.

As the summary in Table 8 shows, all the analysed countries shared the strong *net transmitter* role played by the financial sector. That sector has the highest market value compared to the other sectors surveyed in all the Fragile Five countries except South Africa (in South Africa the financial sector is the second largest). Based on the information provided in Tables 3-7 and Figures 1-5 in the Appendix, we can further conclude that:

- in three (Brazil, India, and South Africa) of the five countries, the financial sector acts as a *net transmitter* on a continuous basis;
- in Turkey, the financial sector was a *net transmitter* for most of the research period, but its role changed to that of a *net receiver* in the second half of 2018;
- in Indonesia, the role of the financial sector is the least homogeneous and clearly bidirectional.

It follows that in the Fragile Five, the financial sector can be treated as an almost *universal shock transmitter*. Our results support claims that the financial sector contributes the most to the overall risk in the market. Moreover, the results are consistent with the related literature on the subject of the role of the financial sector in transmitting crises (Chen *et al*., 2022; Laborda & Olmo, 2021; Liu *et al*., 2021; Wu, 2019).

Similar to Financials, albeit weaker, is the role of Industrials as a *net transmitter* in almost all of the Fragile Five countries except Turkey (although in Turkey the unidirectional impact of Industrials on other sectors is relatively strong). Based on the information provided in Table 2 on the market value of the analysed indices, we categorized Industrials as a medium-sized sector. In India and South Africa, the industrial sector is a constant *net transmitter*. In Brazil, Indonesia, and Turkey, the role of Industrials is clearly heterogeneous over time. The importance of the industrial sector in spillover was previously confirmed by Wu (2019) as well as Wu *et al*. (2019) in relation to the Chinese financial market. While according to Wu, the industrial sector is the second (after the financial sector) most important source of systemic risk in China, Wu *et al*. (2019) went a bit further. Their results show that the industrial sector plays a central role in volatility transmission and should thus be considered the most systemically important sector in the Chinese stock market.[1] Although we classified the industrial sector as one of medium size in the Fragile Five, we can explain its importance in the risk transmission process by the fact that China, Brazil, India, Indonesia, South Africa, and Turkey are among the ten newly industrialized countries (NICs).[2] A common feature of these countries is above-average economic growth resulting from, among others, industrial development. The belief that this growth must take place predominantly in the industrial sector is now considered outdated. However, the industrial sector is still one of the main pillars of economic development and one of the biggest contributors to the NICs' GDP.

Basic Materials and Real Estate are *net transmitters* or *net receivers* depending on the country, but both sectors are *net receivers* in three of the five countries included in the analysis (Basic Materials in Brazil, South Africa and Turkey, while Real Estate in India, Indonesia, and South Africa). Based on the information in Table 2, Basic Materials was classified as medium when Real Estate was the smallest sector in terms of market value. Regardless of the dominant effect (a *net transmitter* or a *net receiver*), the role of Basic Materials is generally variable over time. Only in India, is Basic Materials a persistent *net transmitter*. Moreover, only in India, is Real Estate a persistent *net receiver*. In Indonesia and South Africa, Real Estate is essentially a *net receiver*, but occasionally it acts as a *net transmitter*. In Brazil and Turkey, Real Estate is a *net transmitter* or a *net receiver* depending on the period. Although the first role is dominant, the real estate sector is an occasional *net receiver* in Brazil and Turkey. Approaching the Fragile Five holistically, it can be said that in this group, the basic materials and real estate sectors essentially act as *net receivers*. A potential reason for the status of Basic Materials is that it is the basis of production and is strongly influenced by the situation in the industrial sector, which is particularly important in the case of NICs. Our results on the role of the real estate sector are consistent with those of Wu *et al*. (2019) as well as Jiang *et al*. (2020) regarding China's financial market. They are also in line with fundamentals, because if: 1) real estate is an asset of imperfect nature (this type of asset is indivisible, illiquid, requires the involvement of huge capital, and offers no short sales during recession; Wachter, 2015; Duca *et al*., 2019; Chiang & Chen, 2022); 2) for most households, real estate is probably the most important and expensive asset to obtain (Lin & Lin, 2011); and 3) purchases in the real estate market are very often financed through loans or other bank products (Cocconcelli & Medda, 2013),

[1] The differences in the results obtained may be due to the fact that the authors of the two cited publications used slightly different periods and different research methods. Wu (2019) formulated conclusions based on marginal expected shortfall (MES) and component expected shortfall (CES) analysis for the period January 5, 2009 – August 24, 2018. Wu *et al*. (2019) used a vector autoregressive (VAR) model for the period 7 January 2000 – 10 May 2018.

[2] The list of emerging markets sourced from WorldData.info (2022) and World Population Review (2022).

the real estate sector must be strongly influenced by overall economic conditions (*e.g.* economic growth, inflation, interest rates, employment, financial crisis) (Lin & Lin, 2011) and the situation in other sectors. In this context, it is not surprising that the real estate sector is a permanent *net receiver* in India, which is struggling with the problem of overpopulation. It could be that Real Estate acts as a *risk receiver* also due to the sector's relatively small size. As the data in Table 2 shows, it was the smallest sector in each of the countries studied. However, such a thesis requires further research into the nature of the relationship between the size of the sector and its role in the spillover effect.

In all the countries covered by the study, *net receivers* are Energy (medium-sized sector, see Table 2) and the VIX, but the persistent *net receiver* function is performed by the VIX (in Brazil, India, Indonesia, South Africa, and Turkey). Energy is a persistent *net receiver* only in India. In other countries, that sector acts as a *net transmitter* or a *net receiver* depending on the period, although the second role is dominant. We can explain the fact that the energy sector is a *net receiver* in the Fragile Five countries by the high energy intensity of the analysed economies. In 2021, all the countries mentioned were among the top primary energy consumers, ranking as follows:[3]

- India – third place, 6.0% of global primary energy consumption (GPEC);
- Brazil – eighth place, 2.1% of GPEC;
- Indonesia – thirteenth place, 1.4% of GPEC;
- Turkey – sixteenth place, 1.1% of GPEC;
- South Africa – twenty-first place, 0.8% of GPEC.

All of the Fragile Five were also importers, if not of all, then of a subset of energy resources (Brazil imports, *i.a*. crude oil and natural gas, Indonesia – oil, India and Turkey – natural gas and hard coal, South Africa – natural gas). The role of Energy as a potential *net receiver* was confirmed by Wu *et al*. (2019) for China, while directly opposite results were obtained by Collet and Ielpo (2018) for the US financial market. Interestingly, both of these countries are among the world's largest primary energy consumers (China ranks first, the US second)[4] and importers[5] of fossil fuels. However, it may be that the volume of energy imports in relation to the size of the economy plays a key role in the risk transmission process, which requires further research.

The VIX has been identified as a *net receiver* in a number of publications on the transmission mechanism. Singh *et al*. (2019) found this by analysing the MSCI-Emerging Market, MSCI-BRIC, S&P-GSCI, Bloomberg Commodity Index, VIX, and US bond futures index. Kang *et al*. (2019) came to similar conclusions by examining the connectedness between eighteen world stock markets (the sample included both developed and developing markets), six commodities, two bond indices, VIX and VSTOXX. Our results are also in line with Chen *et al*. (2022) who studied commodity and equity indices as well as the VIX and OFR financial stress index in the US. However, Shu and Chang (2019), who analysed three volatility indices (VIX, VSTOXX and VKOSPI) and ten global equity market indices, came to quite the opposite conclusion and found the VIX as a *net transmitter*. The results of their study may have been influenced by the composition of the research group (mainly US, European, and Asian indices) and the analysis period (January 2, 2004 to June 30, 2014), since, as they state, 'the effects of spillovers are more pronounced during economic and financial crises' (Shu & Chang, 2019).

The Bidirectional Spillover Between the VIX and Sectoral Indices

As we mentioned, the VIX has been identified as a *net receiver*. The data presented in Tables 3-7 show that in all the countries covered by the analysis, the bidirectional spillover between the VIX and sectoral indices was weak (the bidirectional contribution to the forecast variance did not exceed 4.07% in Brazil, 2.25% in India, 1.32% in Indonesia, 3.09% in South Africa and 3.09% in Turkey). However, we also observed that in all countries surveyed, the impact of sectoral indices on the VIX (2.92%-4.07% in Brazil, 1.20%-2.25% in India, 1.00%-1.32% in Indonesia, 2.31%-3.09% in South Africa and 1.71%-2.10% in Turkey) is stronger than the impact of the VIX on sectoral indices (1.49%-2.57%, 0.66%-0.87%,

[3] Distribution of primary energy consumption worldwide in 2021 sourced from Statista (a) (2022).
[4] Data on primary energy consumption worldwide in 2021 sourced from Statista (b) (2022).
[5] Data on imports of fossil fuel sourced from NationMaster (2022).

0.65%-0.75%, 1.53%-1.66% and 0.75%-1.19% respectively). Similar in direction, although even stronger was the relationship between the VIX and both the MSCI-Emerging Market and MSCI-BRIC found by Singh *et al*. (2019). Shu and Chang (2019) as well as Kang *et al*. (2019) generally indicate the opposite (they agree that changes in the VIX impact stock returns much more than stock returns impact the VIX changes for all stock markets surveyed), while the findings of Chen *et al*. (2022) seem ambiguous in this respect. The possible explanation for such a diversity of results is the equity exposure of different countries to US equity markets and vice versa (see Singh *et al*., 2019). Our results may be related to the fact that US exposure to the Fragile Five may be higher than the exposure of the Fragile Five to the US market. As we found that the bidirectional spillover between the VIX and sectoral indices is generally weak, it is also highly likely that this relationship is neutral. Since the results of global surveys in this area are rather divergent, drawing conclusions about the interaction of the VIX and sectoral indices requires further investigation. Simultaneously, it is noticeable that in India, Indonesia, and Turkey, the connectedness between sectoral indices and the VIX is comparable. The effect seems to be a little bit stronger in South Africa and the strongest in Brazil.

Total Connectedness Index

In the surveyed Fragile Five countries, the average Total Connectedness Index (TCI; see Tables 3-7) ranged from 44.95% (South Africa) to 56.04% (India). Such values indicate that between 45% and 56% of the total variance of the forecast error can be attributed to cross-sectoral interactions within considered networks. They also imply that between 44% and 55% of the total variance can be attributed to the own-variable effect within the Fragile Five. The TCI level mentioned can be considered relatively low, as evidenced by data on TCI levels for China, Europe and the US taken from the literature on the subject and included for comparison purposes in Table 9.

Table 9. TCI and the range of TCI fluctuations in selected countries according to different authors

Authors	Country	Period of analysis	Subject of analysis	TCI (%)	approximate TCI range (%)
Chen *et al*. (2022)	US	July 1, 2011-June 9, 2021	financial market indices, commodity market indices, VIX and FSI	64.52	55-85
Collet and Ielpo (2018)	US	January 3, 1996-March 31, 2017	sectoral bond indices	76.93	50-90
Jiang *et al*. (2020)	China	October 8, 2003-April 30, 2018	sectoral indices	80.70	60-85
Laborda and Olmo (2021)	US	July 20, 2003-December 31, 2020	sectoral indices	71.19	40-85
Liu *et al*. (2021)	US	January 1999-December 2016	commodity market indices, sectoral indices	43.57[a] (51.69)[b]	30-70
Mensi *et al*. (2022)	Europe	September 17, 2010-December 24, 2020	22 subindices of the STOXX 600 index, gold futures and Brent crude oil futures	87.70[c] (85.70[d], 89.00[e])	n.a.

n.a. – not available; [a] Static connectedness; [b] Dynamic connectedness; [c] The full sample period; [d] The positive-returns-based subsample; [e] The negative-returns-based subsample.
Source: own study based on the review of the literature on the subject.

However, an analysis of Figure 6 in the Appendix, leads to the conclusion that in all countries surveyed, the TCI index fluctuated significantly, periodically exceeding the level of 60% (all countries) or even 70% (Brazil). Evidently, in the surveyed countries, the TCI varies over time, which is indicative of the fact that all the analysed networks are quite sensitive to time-specific developments and events. Table 10 summarizes developments and events (in Table 10 we included only periods with the TCI exceeding or approaching 60%).

As shown in Table 10, sharp increases in the TCI can occur both during periods of external shocks (such as the eurozone crisis, tapering talk or oil price plunge) and internal turmoil (such as the failure of the N. Modi government reforms and demonetization in India). Interestingly, the highest frequency of

exceedances of 60% was recorded for India, which in 2021 and 2022 was the sixth (IMF 2021) and fifth (IMF 2022) largest economy in the world in terms of nominal GDP, respectively. The observed responses are in line with the literature and confirm increased connectedness in times of market stress.

Table 10. Time-specific developments and events in the Fragile Five during the research period

Country	Periods of TCI growth above 60% or close to 60%	Number of periods	Determinant events for TCI to rise above 60%
Brazil	The end of 2010	3	Eurozone crisis (before a surge of capital inflows from Europe to Brazil was observed)
	From the end of 2011 to second half of 2012		
	From late 2020 to early 2021		Coronavirus pandemic
India	The second half of 2010	6	Eurozone crisis (a damper on India's export to Europe as well as capital inflows into the Indian equity and debt markets)
	From the second half of 2011 to first half of 2012		
	mid-2013		Sharp depreciation of Indian rupee and tapering talk in 2013
	From the second half of 2015 to end of 2016		A number of events such as the oil price plunge of 2014-2016, problems of the N. Modi government with the implementation of internal reforms in 2015, continuing rural crisis and the effects of demonetization in November 2016
	Mid-2018		Depreciation of the Indian rupee as a result of severe capital outflows, growing concerns over tightening of global financial conditions (in 2018 Federal Reserve continued to raise interest rates to tighten the global financial environment)
	From the late 2020 to early 2021		Coronavirus pandemic
Indonesia	The second half of 2010	3	Eurozone crisis (this external shock was rather moderate and had a predominantly financial impact, as Europe is not the country's main export destination, while foreign investors play a crucial role in the financial market)
	From the late 2011 to early 2012		
	The late 2020-early 2021		Coronavirus pandemic
South Africa	From the late 2011 to early 2012	2	Eurozone crisis (the negative effects of the crisis were significant as a result of the capital outflow, the depreciation of the national currency and the decline in exports to Europe being a relevant target market)
	Mid-2020		Coronavirus pandemic
Turkey	Mid-2010	4	Eurozone crisis (effects of the crisis remained limited, because Turkish exports are diversified in terms of product and market, and the Turkish financial sector is not strongly reliant on the European financial sector)
	From the late 2011 to early 2012		
	The second half of 2013		Tapering talk
	The second half of 2020		Coronavirus pandemic

Source: own study.

CONCLUSIONS

We aimed to identify the role played by the various sectors of the economy (Energy, Financials, Industrials, Basic Materials, and Real Estate) and the VIX in crisis propagation in the Fragile Five countries taken as a whole. We also sought to test whether the roles of Shock *transmitters* and *receivers* were constant, as well as whether changes in the TCI could have been influenced by an increase in uncertainty in financial markets in the surveyed group of economies. Furthermore, we looked for potential dependencies between the pattern of contagion and the size of the individual sectors.

The results of our empirical study led us to accept hypothesis 1 (H1). We found a common contagion pattern for the Fragile Five and identified the financial sector (the largest in all countries considered apart from South Africa) as a strong and essentially permanent *net transmitter*. Such an observation provides additional arguments in favour of the position often presented in the literature that the financial sector should be treated as a *universal shock transmitter*, *i.e.* it accounts for the largest share of the overall market risk, not only in developed, but also in emerging economies.

In the Fragile Five countries, the industrial sector played a relatively strong (although weaker than in the case of Financials) *net transmitter* role. Although we classified the industrial sector as one of medium size, we can explain its importance in the risk transmission process by the fact that all the economies surveyed are NICs, that is countries with above-average growth resulting from *i.a*. industrial development. Even though the main source of such impressive growth is not necessarily industrial development, the industrial sector is still one of the biggest contributors to the NICs' GDP.

Looking at the Fragile Five holistically, we can state that in this group, the basic materials (medium-sized) and real estate (the smallest in terms of market value) sectors essentially acted as *net receivers*. Interestingly, this was also the case in South Africa, where Basic Materials was the sector with the highest market value. We associate the status of Basic Materials with its strong dependence on production and the situation in the industrial sector that is strategic for the development of NICs. Our results on the role of the real estate sector are in line with both literature and fundamentals. The fundamental premises follow distinctive features of real estate as an asset class: 1) real estate is an asset of imperfect nature (indivisible, illiquid, requiring the involvement of huge capital, and offering no short sales during the recession); 2) for most households, real estate is probably the most important and expensive asset to obtain; and 3) purchases in the real estate market are very often financed through loans or other bank products. The fundamental premises indicated make the real estate sector particularly susceptible to overall economic conditions and help to explain the *net receiver* role played by the real estate sector in India, a country struggling with the problem of overpopulation. It could be that Real Estate acted as a Risk *receiver* also because it was the smallest sector in each of the countries studied, but this claim needs further examination to be confirmed.

In all countries surveyed, we identified Energy (medium-sized sector) and the VIX as *net receivers*. We associate the status of the energy sector with the high energy intensity of the analysed economies. In 2021, all the Fragile Five were among the top primary energy consumers. To the best of our knowledge, all of the Fragile Five were also importers, if not of all, then of a subset of energy resources, making the group vulnerable to overall economic conditions and external shocks. Our conclusions on the role of Energy as a potential *net receiver* were confirmed in the literature for China, while directly opposite results were obtained for the US. Both China and the US were among the world's largest GPECs and importers of fossil fuels. In our view, apart from energy consumption and imports, the energy sector's vulnerability to external shocks may therefore be determined by the relative (in relation to the size of the economy) level of energy imports. Such a thesis needs empirical confirmation.

Contrary to our expectations and the findings of Chudik and Fratzscher (2011) referred to in the introduction, we rejected hypothesis 2 (H2). We found the VIX as a *net receiver* in all countries under investigation and we identified the VIX's status as a constant in all the Fragile Five. However, a similar conclusion on the role of stress indices is widespread in the literature. Moreover, contrary to our expectations, the bidirectional spillover between the VIX and sectoral indices turned out to be weak in all the surveyed countries, and the impact of sectoral indices on the VIX outweighed the impact of the VIX on sectoral indices. This may be rooted in fundamentals, such as the potentially higher exposure of the US to the Fragile Five equity market than vice versa. In the literature, views on the direction and strength of the aforementioned relationship in different countries and regions remain quite diverse, which may result from mutual (country/region and the US) equity exposures. In our opinion, the weak connectedness of the sectoral indices and the VIX demonstrates the neutrality of this relationship. Such a finding is also a starting point for further investigation.

When analysing the TCI, we found that compared to the results of global studies, its average level in the Fragile Five countries throughout the research period was relatively low (ranging from

44.95% to 56.04%), especially as tensions over the pandemic crisis came into play. The highest frequency of exceedance of 60% was recorded for India, which in 2021 and 2022 was ranked sixth and fifth respectively in the world in terms of nominal GDP. Both aforementioned observations confirm the view of Hernandez *et al*. (2020) that the spillovers and connectedness among institutions from emerging countries are noticeably smaller than those among institutions from the developed world. In the countries surveyed, the TCI varied over time, periodically exceeding the level of 60% (all countries) or even 70% (Brazil), which resulted from time-specific developments and events of both a local (*e.g.* regional capital outflows, depreciation of national currencies, demonetization and rural crisis in India), and a global (eurozone crisis, tapering talk, coronavirus pandemic) nature. Based on the observed responses, we positively verified hypothesis 3 (H3) and confirmed raising connectedness in times of market stress widely reported in the literature.

The obtained results generate implications for policymakers and investors. Because we identified the Financials and Industrials as major *net transmitters*, these sectors should be particularly monitored by the Fragile Five regulators as well by all investors with exposures to *risk takers* in the countries surveyed, namely sectors such as Energy, Basic Materials, and Real Estate. While macro-prudential actions typically aim at the banking sector, in the Fragile Five countries, policymakers should consider similar sector-specific prudential measures for the industrial sector. Our findings confirmed the need for solutions that would protect risk-takers from the negative effects of shocks. However, we recommend reviewing the economic situation for the dominance of a given uncertainty each time before implementing sector-specific tools. When making decisions, both policymakers and investors should keep in mind that financial market shocks can have different sources, and the role of individual industries in the risk transmission mechanism can change. Sharp increases in the TCI associated with market tensions should be taken as a warning signal when formulating economic policy objectives as well as building investment strategies. Since we ultimately opted for the neutrality of the VIX in the shock transmission, and the results of other researchers seem to be ambiguous in this field, the impact of fear indices on financial markets definitely requires additional in-depth empirical studies.

Noteworthy, our study faced some limitations. Firstly, as we indicated in the Research methodology section, the choice of the sectoral indices was determined by three factors: 1) the conclusions drawn from the review of the literature on the subject, which underscores the importance of the selected sectors in spillover transmission; 2) the data availability; and 3) the completeness of the sectoral index time series in the Refinitiv Datastream. The adopted criteria meant that we had to use indices calculated by different index providers and based on a slightly different methodology. Secondly, although intuition suggests that the analysis of the transmission mechanism should be carried out primarily for the largest sectors, as we were looking for a common spillover pattern, the same sectors had to be analysed in each country. These sectors had diverse, and not necessarily the largest, shares in the financial market. Thirdly, in determining the shares of average annual market values of sectoral indices in the sum of average annual market values of all indices covered in the Fragile Five during the analysis period, we generally relied on daily observations of market value. In the case of Brazil, for the basic materials and real estate sectors, these shares were calculated on the basis of monthly observations, as these were the only ones available. However, we assumed that this approach could only slightly distort the results. Finally, some limitations related to the applied model. As we pointed out in the introduction, we decided to use the connectedness approach of Diebold and Yilmaz (2014) and perform the relevant analysis in terms of the TVP-VAR model, on the grounds that doing so permits testing how pervasive risk is throughout a financial market in response to episodes of price uncertainty from a specific source and offers more precise and less biased estimates. This approach allowed us to determine *risk transmitters* and *risk takers* as well as directions of contagion, and thus establish the spillover pattern. Unfortunately, it did not allow us to isolate the micro- and macroeconomic rationales for the existence of such a pattern. These rationales are also rarely analysed in depth by researchers using the same methodology, as their identification is mostly intuitive (we also presented such an intuitive, macroeconomic background of the identified pattern in our article), and their confirmation requires separate studies.

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Appendix:

Table 11. Summary statistics and conventional unit root analysis results: Brazil

	En	Fin	In	Mat	Rea	VIX
Mean	0.000013	0.00029	0.00019	0.00034	-0.000058	17.50
Median	0.00012	0.00014	0.000083	0	0	16.84
Maximum	0.19	0.10	0.10	0.13	0.14	48.98
Minimum	-0.31	-0.12	-0.18	-0.17	-0.19	8.88
Standard Deviation	0.027	0.016	0.015	0.018	0.019	5.02
Skewness	-0.75	-0.31	-1.30	-0.50	-0.86	1.06
Kurtosis	14.37	8.67	21.83	10.34	15.11	5.24
Jarque-Bera	17492.28	4323.052	48020.81	7292.16	19895.72	1266.75
Jarque-Bera p-value	0.00	0.00	0.00	0.00	0.00	0.00
ADF test	-38.96 (1)	-59.54 (0)	-62.98 (0)	-57.22 (0)	-21.13 (6)	-5.12 (0)
PP test	-59.56 [15]	-59.52 [5]	-62.97 [1]	-57.22 [9]	-58.39 [11]	-5.39 [8]

Note: in Tables 11-15, the number of lags in the ADF test (in parentheses) is imposed by the Akaike information criterion (AIC), while the bandwidth for the PP test is given automatically by the Newey–West bandwidth (in brackets) in terms of the Bartlett kernel spectral estimation method. The 1%, 5% and 10% critical values for the ADF and PP tests with an intercept term correspond to −3.47, −2.88 and −2.58, respectively.
Source: own elaboration.

Table 12. Summary statistics and conventional unit root analysis results: India

	En	Fin	In	Mat	Rea	VIX
Mean	0.00041	0.00050	0.00033	0.00042	-0.0000012	17.50
Median	0	0.000074	0.00031	0.00018	0	16.84
Maximum	0.097	0.083	0.065	0.075	0.12	48.98
Minimum	-0.13	-0.17	-0.15	-0.15	-0.21	8.88
Standard Deviation	0.014	0.014	0.013	0.014	0.022	5.02
Skewness	-0.30	-0.82	-0.78	-0.75	-0.54	1.06
Kurtosis	11.069	14.84	10.49	9.81	8.18	5.24
Jarque-Bera	8704.64	18984.4	7783.97	6468.59	3721.40	1266.75
Jarque-Bera p-value	0.00	0.00	0.00	0.00	0.00	0.00
ADF test	57.24 (0)	-52.92 (0)	-50.52 (0)	-54.28 (0)	-53.76 (0)	-5.12 (0)
PP test	-57.24 [7]	-52.90 [3]	-51.041 [12]	-54.67 [13]	-53.77 [3]	-5.39 [8]

Source: own elaboration.

Table 13. Summary statistics and conventional unit root analysis results: Indonesia

	En	Fin	In	Mat	Rea	VIX
Mean	0.00019	0.00052	0.00021	0.000099	-0.000085	17.50
Median	0.000089	0.00017	0.000085	0.000085	0	16.84
Maximum	0.15	0.14	0.12	0.13	0.14	48.98
Minimum	-0.098	-0.11	-0.11	-0.10	-0.16	8.88
Standard Deviation	0.018	0.014	0.016	0.017	0.018	5.02
Skewness	0.30	0.0079	-0.011	0.18	-0.053	1.06
Kurtosis	8.00	10.32	8.51	7.43	8.51	5.24
Jarque-Bera	3366.14	7117.18	4039.50	2628.75	4043.97	1266.75
Jarque-Bera p-value	0.00	0.00	0.00	0.00	0.00	0.00
ADF test	-54.68 (0)	-53.43 (0)	-55.12 (0)	-52.75 (0)	-52.12 (0)	-5.12 (0)
PP test	-54.81 [12]	-53.39 [3]	-55.13 [7]	-52.97 [15]	-52.23 [17]	-5.39 [8]

Source: own elaboration.

Table 14. Summary statistics and conventional unit root analysis results: South Africa

	En	Fin	In	Mat	Rea	VIX
Mean	0.000039	0.00037	0.00022	0.00034	0.00025	17.50
Median	0.00015	0.00014	0	0	0.00035	16.84
Maximum	0.22	0.075	0.076	0.12	0.12	48.98
Minimum	-0.43	-0.13	-0.097	-0.16	-0.21	8.88
Standard Deviation	0.022	0.012	0.012	0.016	0.014	5.02
Skewness	-2.22	-0.92	-0.23	-0.27	-2.098	1.06
Kurtosis	56.080	16.0057	9.22	9.53	46.83	5.24
Jarque-Bera	377233.10	22941.98	5166.99	5715.82	257744	1266.75
Jarque-Bera p-value	0.00	0.00	0.00	0.00	0.00	0.00
ADF test	-27.84 (2)	-56.063 (0)	-58.020 (0)	-56.35 (0)	-24.30 (5)	-5.12 (0)
PP test	-51.87 [21]	-56.11 [14]	-58.13 [17]	-56.35 [7]	-53.43 [12]	-5.39 [8]

Source: own elaboration.

Table 15. Summary statistics and conventional unit root analysis results: Turkey

	En	Fin	In	Mat	Rea	VIX
Mean	0.00063	0.00043	0.00063	0.00098	0.00026	17.50
Median	0.00053	0.000064	0.00063	0.00070	0	16.84
Maximum	0.076	0.083	0.076	0.068	0.096	48.98
Minimum	-0.10	-0.12	-0.11	-0.12	-0.10	8.88
Standard Deviation	0.016	0.019	0.015	0.016	0.017	5.02
Skewness	-0.47	-0.22	-0.41	-0.53	-0.37	1.06
Kurtosis	6.13	6.35	7.091	6.34	7.25	5.24
Jarque-Bera	1422.14	1513.78	2316.30	1631.40	2472.39	1266.75
Jarque-Bera p-value	0.00	0.00	0.00	0.00	0.00	0.00
ADF test	-53.34 (0)	-53.35 (0)	-55.79 (0)	-56.52 (0)	-56.32 (0)	-5.12 (0)
PP test	-53.33 [11]	-53.26 [21]	-55.92 [12]	-56.53 [3]	-56.34 [3]	-5.39 [8]

Source: own elaboration.

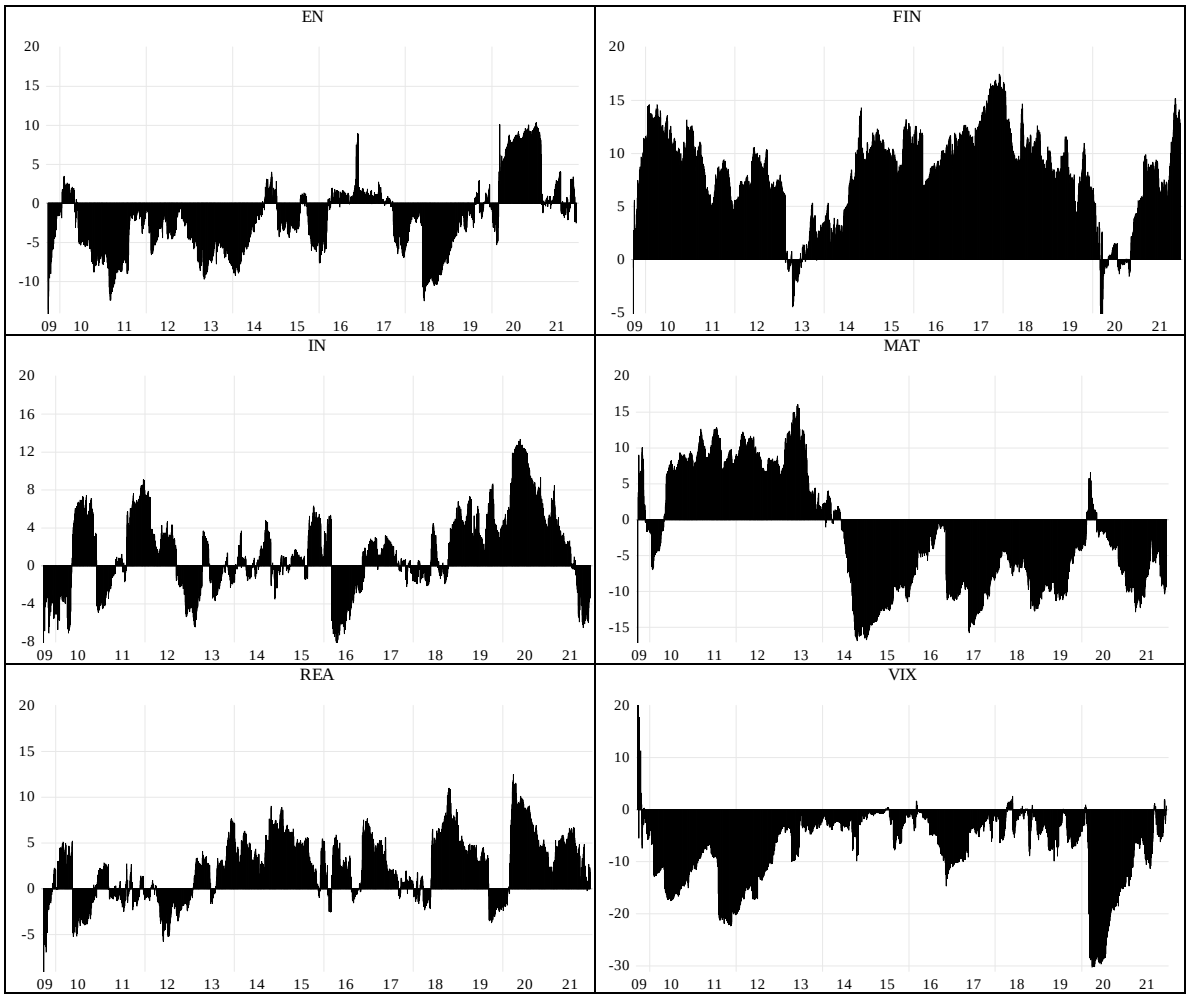

Figure 1. Net total directional connectedness: Brazil (%)

Note: as we can see in Figure 1, Financials appear to be a persistent *net transmitter* of shocks in the Brazilian economy. By contrast, the VIX assumes a persistent *net receiving* role. Real Estate, Industrials, Basic Materials, and Energy assume both roles over time; nonetheless, in the last two cases, the role of the *net receiver* was dominant.

Source: own elaboration.

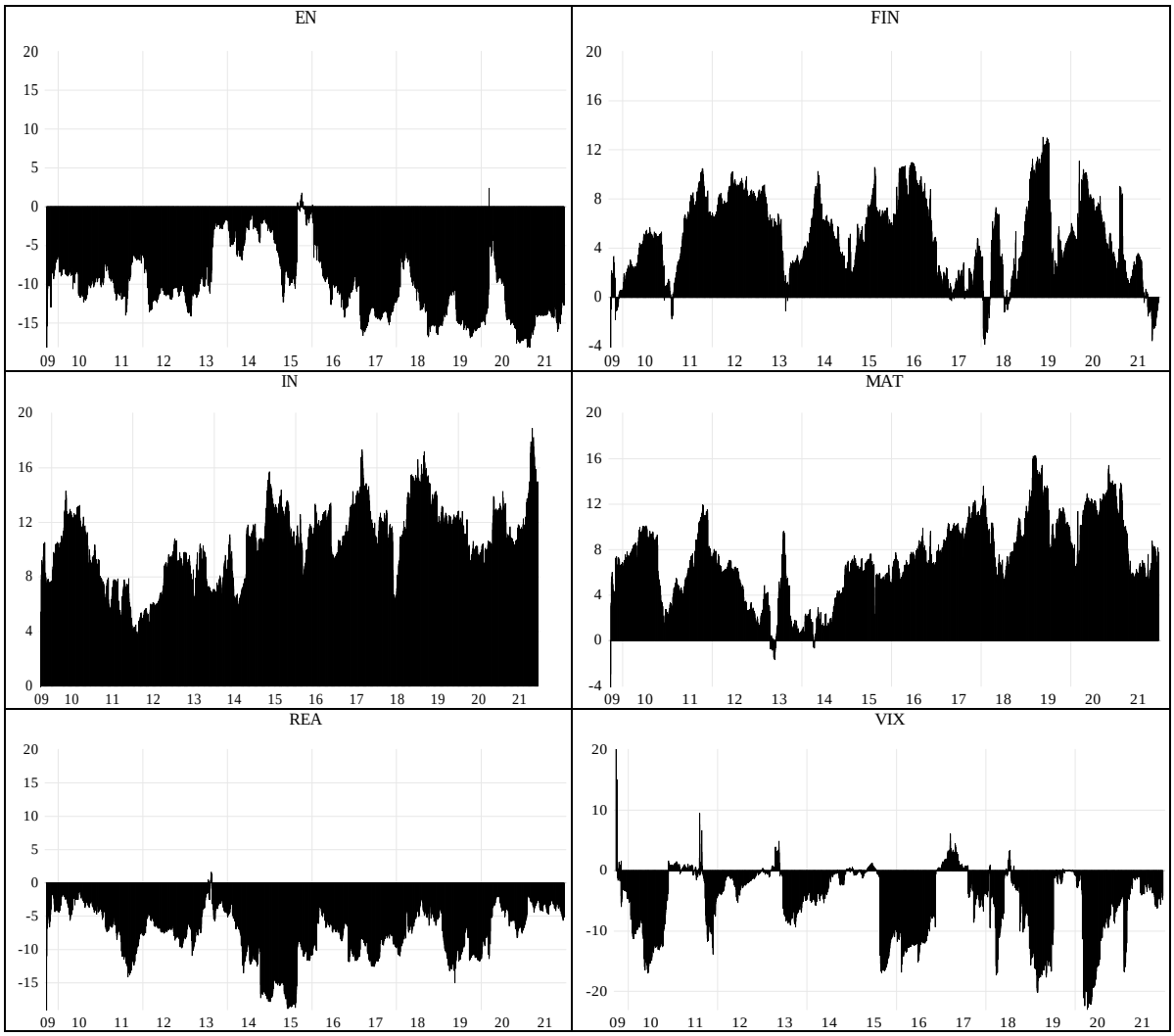

Figure 2. Net total directional connectedness: India (%)

Note: Figure 2 shows that in India, Industrials, Basic Materials and Financials act as *net transmitters* throughout the study period. The three other indices (Energy, Real Estate, and the VIX) are consistent *net receivers*.

Source: own elaboration.

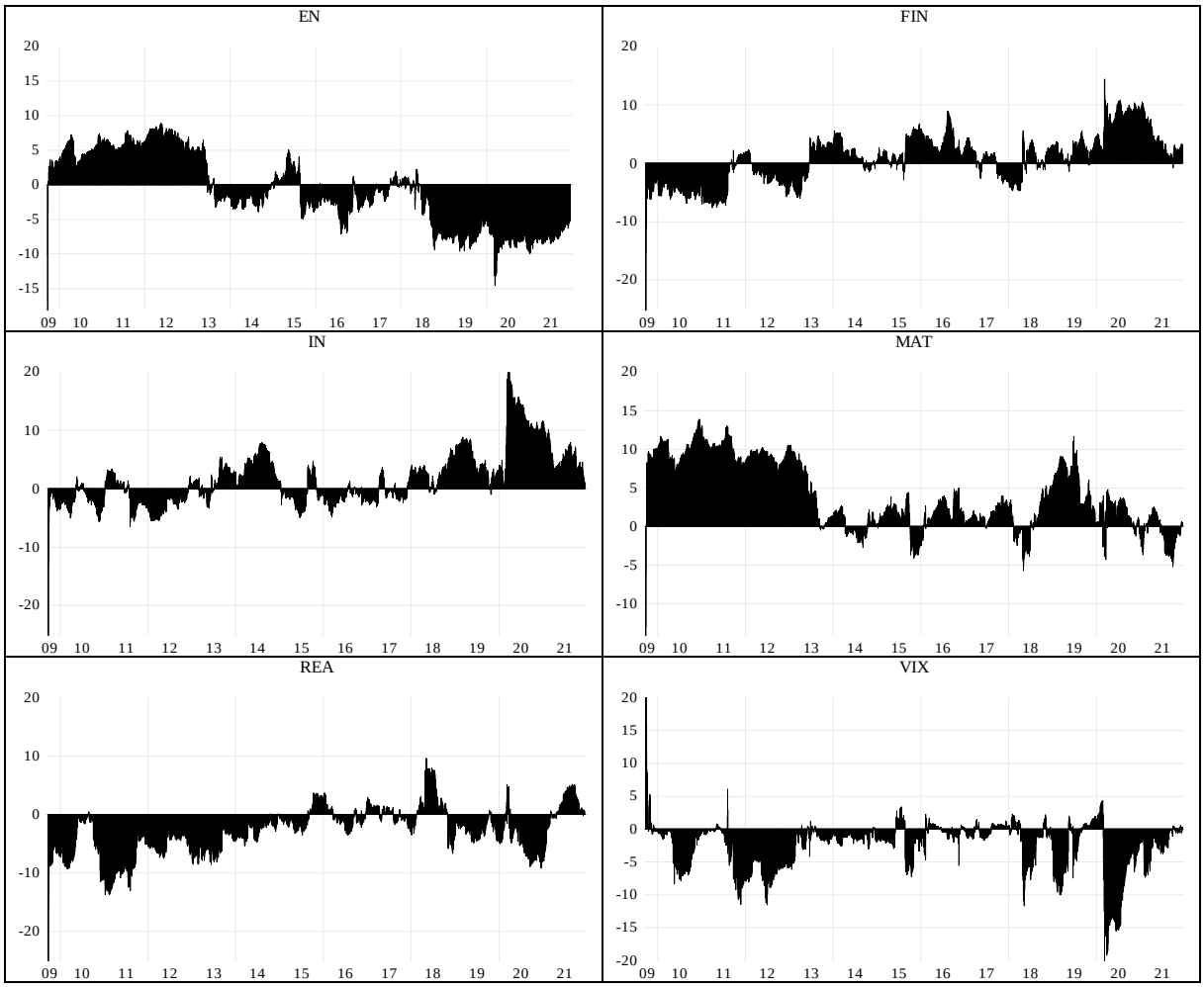

Figure 3. Net total directional connectedness: Indonesia (%)

Note: Figure 3 reveals that in Indonesia only the VIX acts as a persistent *net receiver* of shocks. The other indices (Financials, Industrials, Basic Materials, Real Estate, and Energy) perform both roles alternately.

Source: own elaboration.

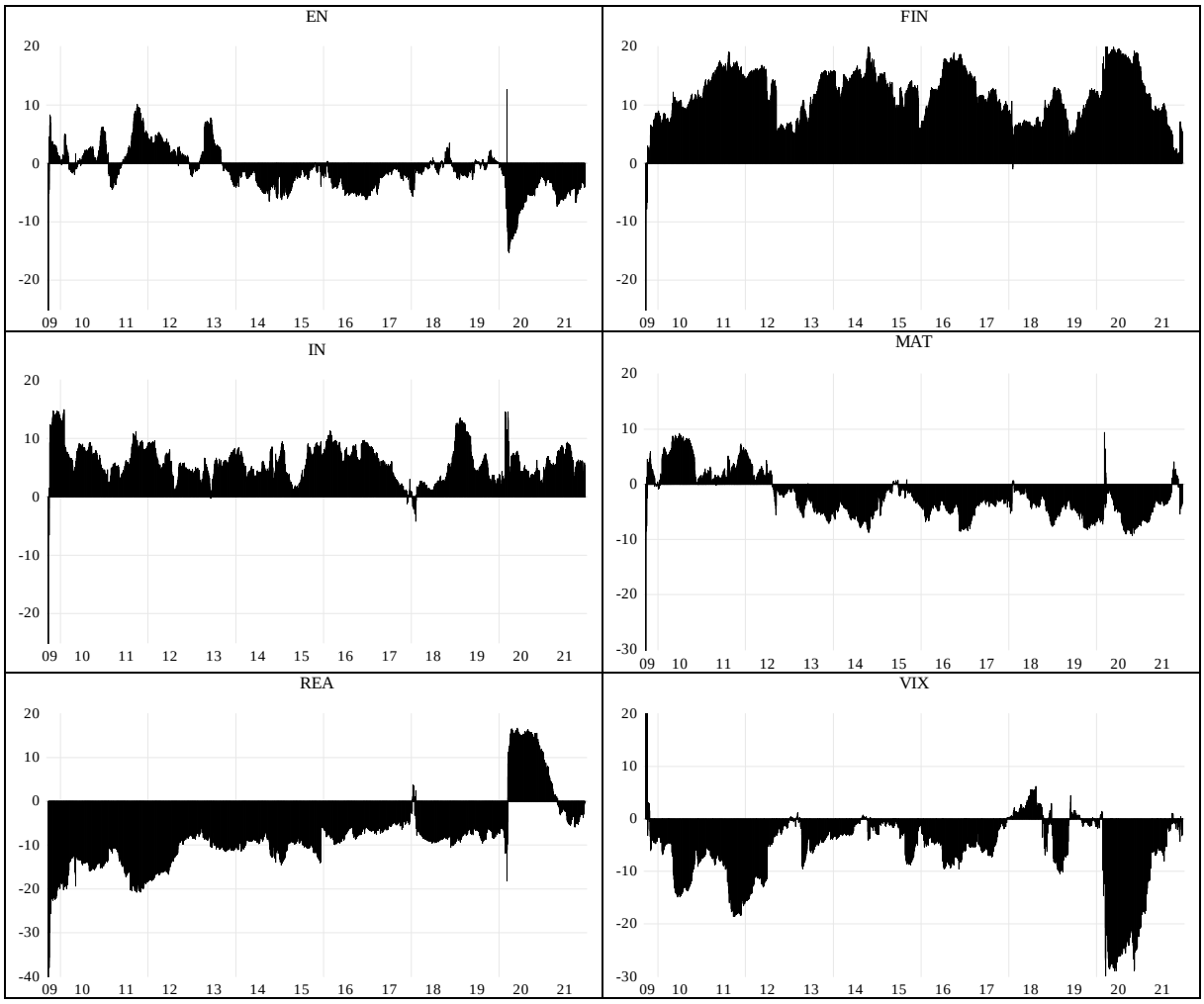

Figure 4. Net total directional connectedness: South Africa (%)

Note: Figure 4 reveals that in South Africa, the persistent *net transmitters* are Financials and Industrials. It may be observed that the VIX is a persistent *net receiver*. Basic Materials, Real Estate, and Energy sometimes play the former, but at other times, also the latter role.

Source: own elaboration.

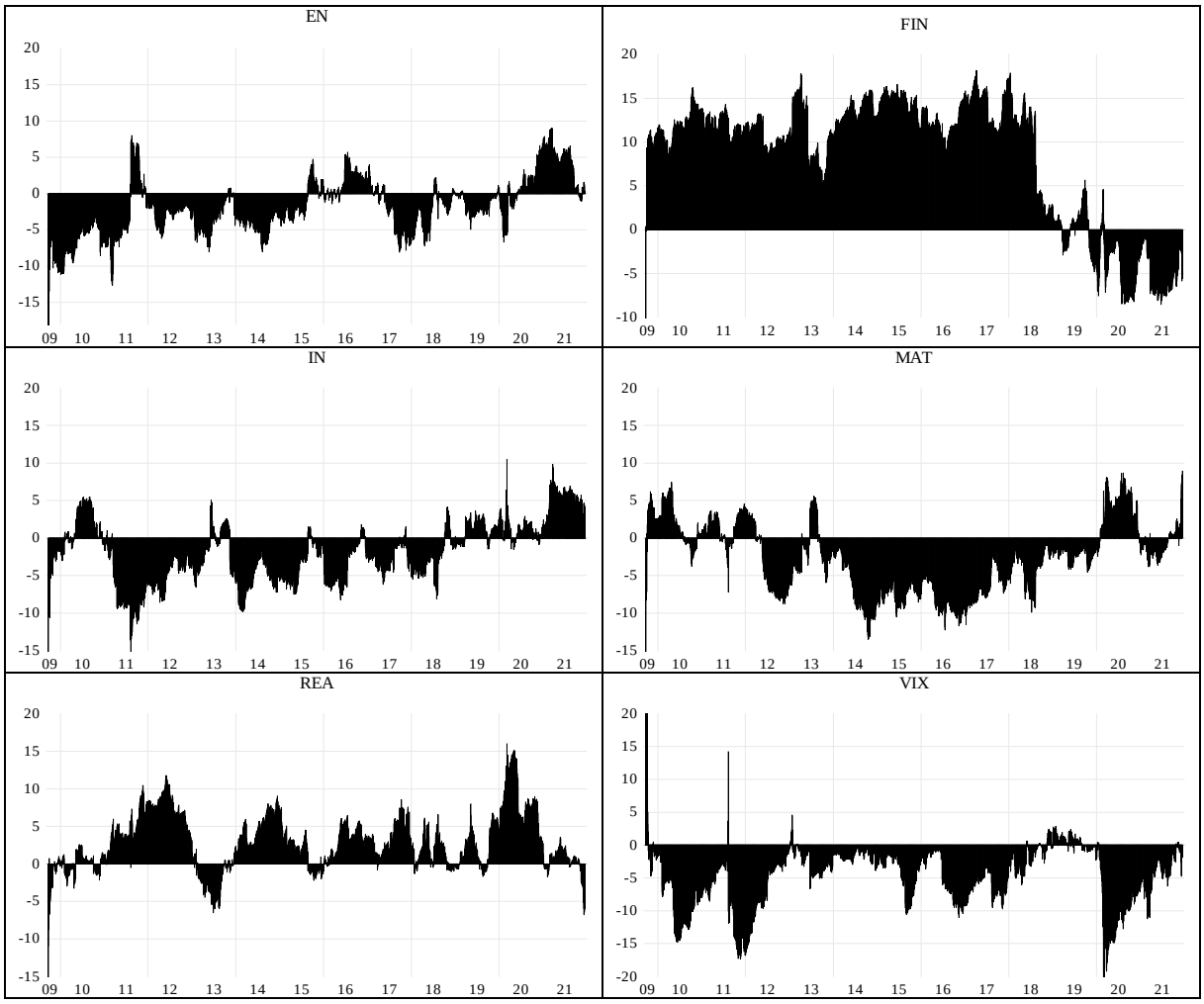

Figure 5. Net total directional connectedness: Turkey (%)

Note: As can be seen from Figure 5, in the case of Turkey, only the VIX can be considered a persistent *net receiver*.

Source: own elaboration.

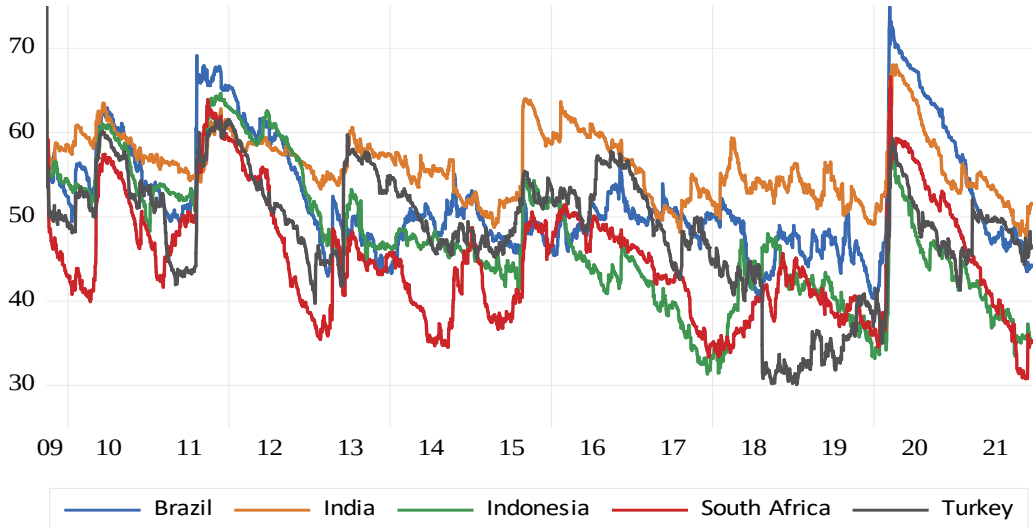

Figure 6. Dynamic total connectedness: Brazil, India, Indonesia, South Africa, Turkey (%)

Source: own elaboration.

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Conflict of Interest

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