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Financial Contagion in the BRICS Stock Markets: An empirical analysis of the Lehman Brothers Collapse and European Sovereign Debt Crisis

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Abstract

This research analyzes and extends the study of contagion for BRICS emerging stock markets in the context of the last two international financial crises: the Lehman Brothers Bankruptcy Crisis and the European Sovereign Debt Crisis. We investigate changes in the relationship and the co-movements between BRICS markets in response to international shocks that are originated in advanced markets like USA and Europe. Employing data of daily stock market indices of BRICS countries, this research tests for contagion, examining the interactions and characteristics of price movements of BRICS stock markets by applying cointegration, causality and VECM/Gonzalo-Granger statistic and variance decomposition methodology on stock returns as a measure of perceived country risk. The results exhibit that both long-run and short-run relationships patterns exist between BRICS stock markets and have drastically changed during turbulent periods compared with tranquil period, pointing towards the occurrence of contagion phenomenon among BRICS markets during the last two crises. These findings also indicate that changes in the USA and the Euro Zone indices affect BRICS stock markets in the short-run, acting as a leading indicator for investing in BRICS markets. Also imply an increasing degree of global market integration, bringing major implications for portfolio diversification and policy makers.

Keywords: *Financial Contagion; Financial Crises; VAR Models; BRICS Stock Markets; Cointegration; Causality.*

JEL Classification: *G01, G11, G12, G15, G18.*

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1. Introduction

The acronym BRIC was first suggested by Jim O'Neill¹ in 2001, in his publication *"Building Better Global Economic BRICs"*. The initial four countries – Brazil, Russia, India and China corresponded to BRIC. They were the rising stars of the Emerging Markets due to their large size, population and ambitious to become world's leading economies propelled by their audacious growth. In April 2011, South Africa joined the group as a full member, in the 2011 summit in Sanya, China. Hence, the group was renamed BRICS – to reflect the group's expanded membership. Fifteen years later, after a Global Financial Crisis (GFC),² the expectations about the BRICS countries as the world's leading emerging markets economies, still holds as the growth engines of the world economy, today and in the future (Bonga-Bonga, 2015; O'Neill, 2013).

The rampant growth of the BRICS countries has substantial effects for the capitalization of their stock markets as well as for their financial dependence with other stock markets (Mensi et al., 2014; Visalakshmi & Lakshmi, 2016). BRICS economies have matured hastily and are becoming increasingly more integrated with the most developed economies in terms of trade and investment.³

In the past three decades, various countries have been hit by severe financial crises: the Mexican *"Tequila Crisis"* in 1994, the East Asian Crisis in 1997, the Russian Crisis in 1998, the Argentinean Crisis in 2002, the United States of America (USA) Subprime in 2007 and the Lehman Brothers Bankruptcy Crisis (LBBC) in 2008 and, more recently, the European Sovereign Debt Crisis (ESDC) in 2010/11.

¹ Chief economist at Goldman Sachs Asset Management (see O'Neill, 2001).

² The US Subprime Crisis in August 2007 and the collapse of the Lehman Brothers in September 2008, sparked a GFC that affected the real sector and caused a rapid, synchronized deterioration in most major economies (Gentile & Giordano, 2012, 2013). Subsequently, the effects caused the Eurozone Sovereign Debt Crisis, which served as a catalyst towards further investigation of the contagion and spillover effects among the USA, Eurozone, Emerging Markets and Asian stock markets. These interdependencies could provide evidence whether there is a seemingly growing integration in international markets with important implications for portfolio diversification (Bekiros, 2014).

³ The BRICS together constitute more than a quarter of the world's land area, more than 40% of the world's population and about 15% of global GDP. The growth potentials in those culturally and geographically disparate countries are based on diverse attributes. Brazil is a resource-rich country, with resources such as coffee, soybean, sugar cane, iron ore and crude oil. Russia is well known for its massive deposits of oil, natural gas and minerals. India has a rising manufacturing base and is a strong service provider. China has a highly skilled workforce at low wage cost and it is considered the factory of the world. South Africa, the smallest of the five BRICS countries by land mass and world GDP contribution, is the world's largest producer of platinum and chromium, and holds the world's largest known reserves of manganese, platinum group metals, chromium, vanadium and aluminum-silicates (The BRICS Report, 2012).

All these financial crises started in a specific country and region in the globe and, subsequently, their effects spread to other countries and regions. Such transmission of shocks is dubbed *contagion* (Bonga-Bonga, 2015). Notwithstanding, the contagion term is not consensual, this research follows the largest body of the empirical literature based on the Forbes and Rigobon (2002) designation, where contagion is defined as a significant increase of cross-market linkages after a shock to one country or a group of countries. This contagion effect undermines the purpose of the portfolio diversification, revealing the situation where markets that were assumed to be weakly associated before a shock are subsequently found to be strongly associated in such a way that diversification across markets fails to shield the investors from the unsystematic risk (Gentile and Giordano, 2012, 2013). This definition indicates that, if two markets present a high degree of co-movement during periods of stability and continue to be highly correlated after a shock to one market, this indicates interdependence⁴ rather than contagion.

This research enriches the literature by focusing the study on the great importance that the effects of contagion in the financial crises across BRICS countries can reveal based on the magnitude of the interaction among them and what they represent globally. The focus of this research is pointed towards the LBBC and the ESDC in order to identify if there was contagion transmission to the BRICS countries and the implications of this phenomenon due to the great impact that both crises had in the behavior of the investors, which brought massive inflows of foreign direct investment to the BRICS countries, trying to hedge their investments (Nistor, 2015).

To achieve this goal, we implemented a three-step methodology that captures the different patterns of contagion transmission across BRICS countries stock markets, following Baig and Goldfajn (1999), Beirne and Gieck (2012), Gentile and Giordano (2012, 2013), Fourie and Botha (2015), and Boubaker et al. (2016).

Our results clearly reveal an increase in the long-run connections among BRICS stock markets jointly with changes in the causality patterns, which have changed in the turbulent periods compared to the tranquil periods. The evidence suggests that contagion effects strongly influenced the BRICS stock markets over both crises. These results also reveal that BRICS countries were not able to provide portfolio diversification, indicating that both crises affected their stock markets, revealing different degrees of vulnerabilities among them.

⁴ When co-movements do not increase significantly after a shock, then any continued high level of market correlation indicates strong connections among the countries that exist worldwide (Gentile & Giordano, 2012).

This empirical research is organized as follows. Section 2 contains a literature review, Section 3 describes the data and Section 4 the econometric methodology, which is followed by Section 5, the core section, which presents the empirical results and Section 6 concludes.

2. Literature Review

2.1. Contagion Phenomenon: Definition, Theories, Transmission and Measurement

The different definitions of contagion, how it is measured, what causes contagion, how it is transmitted and why, is extremely important to understand so as to evaluate this phenomenon correctly and develop policy responses efficiently. Blaming financial crisis on contagion remains an elusive concern, highly contagious among politicians and economists. Without a clear understanding of financial contagion and the mechanisms through which it works, we can neither assess the problem nor design appropriate policy measures to control for it (Moser, 2003). Such understanding is needed to identify the economic implications both for implementing policies and for investors, who need to understand the nature of changes in stock markets to evaluate the potential benefits of international portfolio diversification and the analytical assessment of risks.

Despite the significant theoretical and empirical interest of financial contagion, there is still no consensus about whether cross-country propagation of shocks through fundamentals⁵ should be considered contagion. Hence, we need to differentiate between *pure contagion*⁶ and shock propagation through

⁵ Financial, real and political links, constitute the fundamentals links of an economy (Gentile & Giordano, 2012; Moser, 2003). The first ones exist when two economies are connected through the international financial system. Real links are fundamental economic relationships between countries. These links have usually been associated with international trade, but other types of real links, like foreign direct investment across countries, may also be present. Finally, political links are the political relationships between countries. Although this link is much less stressed in the literature, when a group of countries share an exchange rate arrangement, a common currency (in the case of the Euro Area Countries), crises tend to be clustered (Gomez-Puig & Sosvilla-Rivero, 2014).

⁶ Masson (1998) defines *pure contagion* as an unanticipated situation. Claessens et al. (2001) and Gentile and Giordano (2012) define *pure contagion* in the sense of Masson's only when the transmission process itself changes when entering crises periods: when a crisis in one country may conceivably trigger a crisis elsewhere for reasons unexplained by macroeconomic fundamentals – perhaps because it leads to shifts in market sentiment, or changes the interpretation given to existing information, or triggers *herding behavior*.

fundamentals⁷. Some have suggested *transmission* (Bordo & Murshid, 2000; Lakshmi et al., 2015); *spillovers* (Broto & Perez-Quiros, 2015; Dungey & Martin, 2007; Masson, 1998, 1999; Muratori, 2014); *interdependence* (Forbes & Rigobon, 2001, 2002, Gentile & Giordano, 2012, 2013) or *fundamentals-based contagion*⁸ (Bonga-Bonga, 2015; Kaminsky & Reinhart, 1998). This differentiation is defined by Moser (2003), indicating that shocks propagation through fundamentals is the result of an optimal response to external shocks, which is not considerate a source of pure contagion. For instance, a crisis in one country can cause disturbances in the equilibrium of other countries, causing an adjustment in the financial and real variables to a new equilibrium. In that case, financial market responses only anticipate and reflect changes in fundamentals, accelerating the adjustment to a new equilibrium, just transmitting and not causing the changes in the equilibrium. In other words, rather than causing a crisis, financial markets responses bring the crisis forward, being an example of fundamentals-based contagion rather than pure contagion (Moser, 2003).

2.2. What is Financial Contagion?

Contagion phenomenon generally is used to describe the spread of market disturbances from one country to another.⁹ In its broadest sense, therefore, financial contagion is related with the propagation of adverse shocks that have the potential to trigger financial crises. The core of the matter is to identify potential propagation mechanisms and define those that represent contagion (Moser, 2003). In spite of the greatest relevance of the contagion phenomenon, there is still no consensus on either the definition or the transmission channels of financial contagion. As a first step, it is helpful to understand what contagion does not mean and what it does mean.

The World Bank¹⁰ distinguishes three definitions of financial contagion: *broad*, *restrictive* and *very restrictive*.

⁷ The theories based on fundamentals channels are the oldest, and the general idea is that links across countries exist because the countries' economic fundamentals affect one another. These theories are usually based on standard transmission mechanisms, such as trade, monetary policy, and common shocks (e.g., oil prices).

⁸ Fundamentals-based contagion refers to the transmission of shocks that is due to real and financial linkages or fundamental relationship of any kind, such as trade or macroeconomic policy, between countries (Bonga-Bonga, 2015; Dornbusch et al., 2000; Forbes & Rigobon, 2001; Masson, 1998).

⁹ The process can be observed through co-movements in exchange rates, stock prices, sovereign spreads and capital flows (Gentile & Giordano, 2012).

¹⁰ Macroeconomics - Definitions of Contagion. Retrieved November 8, 2016, from www.go.worldbank.org/JIBDRK3YCO. (World Bank)

The broad definition: it is vague and generalist, this definition was used in the earliest stages of the research on contagion phenomenon. Under this approach, contagion is the cross-country transmission of shocks or the general cross-country spillover effects during the crisis (Gentile & Giordano, 2012, 2013).

The restrictive definition: it is suitable in more recent literature, where contagion is the transmission of shocks from one country to others or the cross-country correlation, beyond what would be explained by fundamentals or common shocks.¹¹ This definition is usually referred to as *excessco-movement*,¹² commonly explained by *herding behavior*.

The very restrictive definition: it implies an increase in the linkages after a crisis, when cross-country correlations increase during “*crisis times*” relative to correlations during “*tranquil times*”, therefore, this can only be due to factors unrelated to fundamentals, since they cannot change in a short period of time (Gentile & Giordano, 2012, 2013). In fact, Dornbusch et al. (2000) and Forbes and Rigobon (2002) argue that contagion is a significant increase in cross-market co-movements after a (negative) shock to one country (or group of countries).¹³

Forbes and Rigobon (2001) reinforce that this notion of contagion excludes a constant high degree of co-movement in a crisis period, otherwise markets would be just interdependent.¹⁴ There is contagion only if cross-market co-movements increase significantly after the shock.¹⁵ Any continued high level of market correlation suggests strong linkages between the two economies that exist in all states of the world.

Currently this very restrictive definition reveals two major advantages: firstly, it provides a straightforward framework for testing whether contagion occurs or not by comparing co-movements between two markets (such as cross-market

¹¹ Fundamentals causes of contagion include macroeconomic shocks that have repercussions on an international scale and local shocks transmitted through trade links, competitive devaluations, and financial links (Gentile & Giordano, 2012, 2013).

¹² That means a correlation that remains even after controlling for fundamentals and common shocks. Herding behavior is usually said to be responsible for co-movement beyond that what is explained by fundamentals linkages (Gentile & Giordano, 2012).

¹³ This definition is known sometimes as “*shift-contagion*”. Our definition of “*shift-contagion*” following Gentile and Giordano (2012), relies on a significant increase in cross-market co-movements after a shock, which is not related with fundamentals linkages (such as financial, real or political). The only transmission channel that could explain *contagion* is the *behavioral* one.

¹⁴ Regarding the extreme definition of contagion phenomenon, for instance, the research of Bae et al. (2000; 2003) consider extreme return shocks across countries as evidence for contagion.

¹⁵ A contagious event cannot occur in the absence of a shock, indicating that a large shock should occur (Caporin et al., 2013; Constancio, 2012).

correlations coefficients) during a relatively stable period with co-movements immediately after a shock or crisis, which does not require a specification of a structural representation for stock returns. Secondly, it allows distinguishing between permanent and temporal mechanisms of crises transmission. Identifying if the propagation of a crisis is due to permanent or temporal mechanisms has important implications for designing public policy responses (Bejarano-Bejarano et al., 2015).

This empirical research uses the very restrictive definition of contagion, because it provides an alternative explanation for transmission of crisis, namely interdependence, allowing one to answer the questions: Is there contagion or interdependence? Do the periods of highly correlated market movements provide evidence of contagion? Does the cross-market relationship change during periods of crisis? Our main goal is to try to answer these questions in the context of both crises (LBBC and ESDC) from the perspective of the BRICS countries stock markets.

2.3. Causes and Transmission of Contagion

The literature divides the concept of contagion into two broad categories (Bonga-Bonga, 2015; Dornbusch et al., 2000; Forbes & Rigobon, 2001; Masson, 1998; Pritsker, 2000), namely, *fundamentals-based*¹⁶ and *investor-behavior contagions*.¹⁷ The first category emphasizes spillovers that result from the normal interdependence among market economies, referring to the transmission of shocks that is due to real and financial linkages or fundamentals relationship of any kind, such as trade or macroeconomic policies, between countries. These forms of co-movements would not indicate contagion, according to the *restrictive* and *very restrictive* definition of contagion, which is adopted in this research. According to Gentile and Giordano (2012), fundamentals linkages cannot change suddenly in a few months after a shock has occurred. Hence, that is considered interdependence.

¹⁶ *Macroeconomics Causes*: common shocks, trade links and competitive devaluations, real and financial links and macroeconomic policies (Claessens et al., 2001; Dornbusch et al., 2000). *Fundamentals-based contagion* is caused by “*monsoonal effects*” and “*linkages*”. *Monsoonal effects* – are random aggregate shocks that hit a number of countries in a similar way (such as a major economic shift in industrial countries, a significant change in oil prices or changes in US interest rates) that may adversely affect the economic fundamentals of several economies simultaneously and, therefore, may cause a crisis (Eichengreen et al. 1996; Masson, 1998). *Linkages* – are normal interdependencies, such as those produced by trade and financial relations between countries and which can easily become a carrier of crisis (Kaminsky & Reinhart, 2000; Masson, 1998).

¹⁷ Liquidity problems, information asymmetries and costs, multiple equilibriums and changes in the rules of the game (see Claessens et al., 2001; Dornbusch et al., 2000).

The second category involves a financial crisis that is not linked to observed changes in macroeconomics or other fundamentals but is solely the result of a change in investor behavior which alters the flow of international portfolio investments in such a manner that it cannot be explained by economic fundamentals. For example, a crisis in one emerging market country can trigger investors to withdraw funds from many emerging markets without taking into account the fundamental economic differences between them¹⁸ (Bonga-Bonga, 2015). If the transmission force is based on the irrational behavior of the market agents, known as “*irrational phenomena*,”¹⁹ then even countries with good fundamentals can be seriously affected, in this case we have contagion.

The initial literature has generally been divided as to whether transmission through real or financial channels constitutes contagion. Forbes and Rigobon (2001, 2002) and Gentile and Giordano (2012) argue that the theoretical literature of contagion could be split into two groups: *crisis-contingent* and *non-crisis-contingent* theories.²⁰ The first one is related to the financial linkages, explaining why transmission mechanisms change during a crisis and therefore why a shock leads to an increase in the cross-market linkages. On the other hand, the second one is related to the real linkages, if transmission mechanisms are the same during a crisis as during more stable periods, and therefore cross-market linkages do not change (increase) after a shock. Theories belonging to the second group may be interpreted as interdependence rather than contagion (see Forbes & Rigobon, 2002; Gentile & Giordano, 2012).

2.4. Contagion: Testing and Measurement

Gentile and Giordano (2012, 2013) describe contagion as the amount of co-movement among asset prices which exceeds what is explained by fundamentals, since fundamentals cannot change in a few months. They argue that a degree of

¹⁸ This event is known as “*Fight-to-quality phenomenon*” and refers to a sudden shift in investment behaviors in a period of financial turmoil where investors try to sell assets perceived as risky and instead purchase safe assets. An important feature of *flight-to-quality* is an insufficient risk taking behavior by investors. Though excessive risk taking can be a source of financial crisis, insufficient risk taking can severely dislocate credit and other financial markets during the financial crisis. These shifts in portfolio investments result in further negative shocks to the financial sector. In accordance to this phenomenon demand for 10-year US Treasuries and gold increased during the recent financial turmoil (Kazi & Wagan, 2014).

¹⁹ This can occur in the form of speculative attacks, financial panics, herd behavior, loss of confidence, and increased risk aversion (Gentile & Giordano, 2012, 2013).

²⁰ *Crisis-Contingent Theories*: multiple equilibria, endogenous liquidity shocks, political contagion and random global monetary shocks. *Non-Crisis-Contingent Theories*: trade, policy coordination, country reevaluation and random real global shocks.

extreme connection or asymmetry that goes beyond interdependencies must be present in order for contagion to be present.

Research on contagion range from testing conditional correlation to contagion of bond spreads, sovereign ratings, credit default swaps (CDS) spreads, stock market returns, differences in interest rates, common trends and cycles, monetary policy and currency market (Bianconi et al., 2013; Caporin et al., 2013; Fourie & Botha, 2015; Gentile & Giordano, 2012, 2013, Gomez-Puig & Sosvilla-Rivero, 2011, 2014; Matos et al., 2015). For instance, Andenmatten and Brill (2011), following Forbes and Rigobon (2002) methodology, also performed a bivariate test for contagion to examine whether the co-movement of sovereign CDS premium increased significantly after the beginning of Greek debt crisis in October 2009. Their findings revealed that in European countries, both contagion and interdependence occurred. In addition, Baig and Goldfajn (1999) in the context of the Asian crisis, using the same methodology, performed a cross-market correlation for exchange rates, stock returns, interest rates, and sovereign bond spreads. The findings for sovereign spreads highlighted strong evidence of contagion and high correlation among exchange rate, stock returns and interest rates co-movements. They conclude that spreads directly reflecting the risk perception of financial markets, indicating that pure contagion may be the result of the behavior of investors or other financial agents (Claessens et al., 2001).

Bonga-Bonga (2015) provides evidence of contagion phenomenon by analyzing financial contagion between South Africa and its BRICS equity market from December 1996 to May 2012, the initial period corresponds with the liberalization of a number of BRICS equity markets. By applying a conditional correlation framework, they find evidence of cross-transmission and dependence between South Africa and Brazil. Furthermore, the research also ascertained that South Africa is more affected by crises originating from China, India and Russia than these countries are by crises from South Africa. Furthermore, Matos et al. (2015) performed a test to identify common trends and cycles between BRIC's stock markets, providing evidence of contagion effect, with Brazil and China financial markets playing a leading role in the transmission of contagion. They conclude that worldwide investors should consider reactions in Chinese and Brazilian markets during a crisis as a predictor of other BRIC reactions through the *contagion channel*.²¹

²¹ Trade, banks/lending institutions, portfolio investors and wake-up calls/fundamentals reassessment (Forbes, 2012).

A wide range of empirical techniques has been used to quantify contagion in the literature. For instance, Forbes (2012) refers tools to measure contagion range from *cross-market correlations analysis* (Forbes & Rigobon, 2001, 2002) to *probability analysis* (Constancio, 2012; Eichengreen et al., 1996; Gomez-Puig & Sosvilla-Rivero, 2011, 2014) to *latent factor/GARCH models* (Bekaert et al., 2011, 2005; Dungey & Yalama, 2010) to *extreme values/co-exceedance/jump* (Bae et al., 2003; Berger & Pukthuanthong, 2012; Boyer et al., 2006; Forbes, 2012) and *VAR models* (Beirne & Gieck, 2012; Fourie & Botha, 2015; Matos et al., 2015).

More related to our approach, Boubaker et al. (2016) use VAR-VECM to measure contagion between US stock market and developed and emerging stock markets during the Subprime crisis in September 2008. They provided significant evidence of contagion effects between the US stock market and the developed and emerging equity markets after the global financial crisis. Beirne and Gieck (2012) use a global VAR to measure interdependence and contagion across bonds, stocks and currencies for over 60 economies during periods of crisis. Their analysis reveals that shocks to equity markets typically originate in the US and that bond market shocks tend to originate in the Eurozone. Gentile and Giordano (2012, 2013) use cointegration and VECM/Granger causality tests to measure the existence and direction of contagion in European countries during the LBBC and ESDC, pointing out the occurrence of contagion phenomenon in both crises. Fourie and Botha (2015) using the same methodology provided by Gentile and Giordano (2012, 2013), but for sovereign ratings, proved contagion in European countries, during the two recent windows of crises: Lehman Crisis and European Union Sovereign Debt Crisis.

3. Data

Our main objective is to test for contagion during the last two international financial crises,²² using an important financial market indicator: The Stock Market Index (SMI). Further on, we apply a tree-step econometric analysis²³ to test for contagion that will be discussed in detail later. We will analyze the different connections and co-movement between countries to identify any cross-market or cross-country connections that can explain and assess contagion phenomena in the BRICS stock markets.

²² The recent Lehman Brother bankruptcy Crisis (LBBC) and the European Sovereign Debt Crisis (ESDC).

²³ First: A bivariate dynamic cointegration analysis. Second: Granger causality test and VECM/GonzaloGranger statistic.Third: We apply the Variance decomposition method following Baig and Goldfajn (1999), Beirne and Gieck (2012), Gentile and Giordano (2012, 2013), Fourie and Botha (2015) and Boubaker et al. (2016).

Morgan Stanley Capital International (MSCI) for *large-caps* is the main source used for stock price indices. The sample consists of five countries from the Emerging Markets known as BRICS: (Brazil (BRA), Russia (RUS), India (IND), China (CHI) and South Africa (SAF)) and one developed country, the United States (USA), using daily stock indices closing prices for each country. The daily frequency sample was considered, because interdependence phenomena can explode in a few days. So, if we had considered weekly or monthly data, we could have lost the measurement of interactions (innovations), which may last only a few days (Gentile & Giordano, 2012, 2013; Jin & An, 2016; Voronkova, 2004).

Table 1. Variables Explanation

| Variables | Explanation | Type |
|------------|---|------------------|
| BRA | Log-level value of MSCI Brazil Stock Price Index | Exog./Endogenous |
| RUS | Log-level value of MSCI Russia Stock Price Index | Exog./Endogenous |
| IND | Log-level value of MSCI India Stock Price Index | Exog./Endogenous |
| CHI | Log-level value of MSCI China Stock Price Index | Exog./Endogenous |
| SAF | Log-level value of MSCI S. Africa Stock Price Index | Exog./Endogenous |
| USA | Log-level value of MSCI U. States Stock Price Index | Exogenous |

Notes: Regarding to national holidays, the index level was assumed to stay the same as that on the previous trading day. The USA variable is implicitly imputed in the data, because as it is stated in the literature that linkage patterns may be distorted when the influence of the US market is not taken into consideration (see Bekaert et al., 2011; Gentile & Giordano, 2012, 2013; Khalid & Kawai, 2003; Yang et al. 2003).

The daily stock indices (in log-level) were presented also through graphical representation over the period of the study (see Appendix A). Visually, all indices were recovering jointly from 2003 until the beginning of the 2008 as a period of economic growth that lasting until 2007. But subsequently, the USA subprime mortgage crisis, undermined the confidence of banks in each other's solvability decreased sharply leading to the breakdown of the interbank lending market and turmoil on the financial marketing the second half of 2007. Large downturns in stock prices followed and the interconnectedness of stock market indices rose again as all markets suffered from similarly intensive losses. Hence, after April 2008 until the insolvency of Lehman Brothers in September 2008, stock markets' tendencies started to move jointly (see Appendix A).

Regarding daily data, it is necessary to consider the differences in time zones and in trading hours of the exchanges when interpreting the results. Therefore, we considered a central time window around the two crises (LBBC and ESDC) as

suggested by Jin and An (2016). A two-day rolling average, as suggested by Forbes and Rigobon (2002) to account for time synchronization of different markets, which lay in different time zones has not been considered in this research due to severe autocorrelation problem as highlighted by Chiang et al. (2007) and Ahmad et al. (2013).

3.1. Variable Transformation

We took natural logarithms of our data before proceeding to the analysis process (see table 1). The log form of stock indices were used in order to reduce the heteroskedasticity present in the data (Singh & Kaur, 2016), smoothing out the fluctuations, to make the data series linear and very helpful for the purpose of further analysis (Verma & Rani, 2016). Moreover, for evaluating the rate of daily returns needed for further analysis, the initially log-level variables were taken and calculated (Ahmad et al., 2013; Malliaris & Urrutia, 1992; Mensah & Alagidede, 2017; Pragidis & Chionis, 2014; Syriopoulos et al. 2015) on the following basis:

$$R_t = [\log(P_t) - \log(P_{t-1}) \times 100] = \left[\log\left(\frac{P_t}{P_{t-1}}\right) \times 100 \right] \quad (\text{eq. 1})$$

where, R_t is the percentage daily returns value at time t , P_t and P_{t-1} , are the percentage daily returns value at two successive days: t and $t - 1$, respectively.

After the transformation, the percentage daily stock return variables were defined as: *SRBRA*, *SRRUS*, *SRIND*, *SRCHI*, *SRSAF* and *SRUSA*. Daily closing prices of the BRICS stock markets were retrieved from *Thomson Reuters Datastream* database and are expressed in US dollars,²⁴ and the time range of the time series goes from January 1, 2003 to October 31, 2016.²⁵ *Eviews 9.0* and *R programming*²⁶ were used for arranging the data and implementation of econometric analyses.

4. Methodology

In order to test for contagion, we implemented a three-step methodology coherent with our definition of contagion as *a significant increase of cross-market linkages after a shock to one country or a group of countries* based on both crises (LBBC and ESDC). This methodology will provide three different indicators that

²⁴ Using US dollars avoid problems related to the local currency (See Bekaert & Harvey, 1995; Chen et al., 2002; Mollah et al., 2014; Roll, 1992; Singh & Kaur, 2016).

²⁵ Data was set in the begin of 2003 to avoid contamination in the stock market from earlier bond crises in Russia and Latin America (Cronin et al., 2016, p. 6).

²⁶ The *OPTMALAG* command from *R programming*, chooses the lag order that maximize Johansen statistics.

together corroborate to assess contagion phenomenon in the BRICS stock markets.

As first step, we implement the Johansen cointegration test to detect the cross-market connections in the long-run, allowing the identification of signs of contagion and the detection of the so called “*Contagion Windows*” by looking direct in the data without any kind of previous assumptions. We use a *bivariate dynamic cointegration analysis*²⁷ to test for the presence of new long-run relationship among BRICS countries through the application of the dynamic rolling cointegration analysis²⁸ (*rolling indicator*) for each pair of countries. Any increase of the percentage of cointegrated countries over the total number of possible pairs signals a shift²⁹ of the shock transmission channels and represents the first indicator of potential contagion. According to the results obtained in this step, it is possible to detect contagion windows by looking directly into the data, finding evidence which either confirms or rejects the assumption of the time periods during which the contagion process could have started to propagate during the two financial crises analyzed – LBBC and ESDC.

In order to determine the number of cointegrating equations, a VECM(k) was applied according to Johansen (1988),

$$\begin{aligned}\Delta X_t &= \eta_x + \sum_{i=1}^k \lambda_{x,i} \Delta X_{t-i} + \sum_{i=1}^k \theta_{x,i} \Delta Y_{t-i} + \alpha_1 \beta' \begin{bmatrix} X_{t-1} \\ Y_{t-1} \end{bmatrix} + \epsilon_{x,t} \\ \Delta Y_t &= \varphi_y + \sum_{i=1}^k \lambda_{y,i} \Delta Y_{t-i} + \sum_{i=1}^k \theta_{y,i} \Delta X_{t-i} + \alpha_2 \beta' \begin{bmatrix} X_{t-1} \\ Y_{t-1} \end{bmatrix} + \epsilon_{y,t}\end{aligned}\quad (eq. 2)$$

where, ΔX_t and ΔY_t are daily changes of stock returns referred to markets X and Y , X_t and Y_t are the correspondent log-price indices (in log-level). The long-run impact matrix can be expressed as $\Pi = \alpha \beta'$, where $\alpha' = [\alpha_1, \alpha_2]$, and $[\epsilon_x, \epsilon_y]$ is a vector of white noise processes. The vector of coefficient β contains the parameters of the common stochastic, trend, while α_1 and α_2 measure the speed of convergence. In particular, $\beta' \begin{bmatrix} X_{t-1} \\ Y_{t-1} \end{bmatrix}$ represents a common stochastic trend

²⁷ To individuate significant connections among pairs of markets, the bivariate Johansen cointegration test is applied to allows the identification of relations between pairs of markets which lead to slow price adjustment processes – long-run connections (Gentile and Giordano 2012, 2013).

²⁸ See the recent contributions of Mylonidis and Kollias (2010), Arce et al. (2012), Peri and Baldi (2013) and Ludwig (2014).

²⁹ We defined “shift” as a significant increase in cross-market co-movements after a shock, not related with fundamentals links (Gentile and Giordano, 2012).

towards which price dynamic slowly converges. Hence, the Johansen cointegration test mainly relies on the assumption that the rank of Π equals the number of cointegrating vectors. If the matrix Π has a rank r , there are r cointegrating relations. When $r = 0$, there is no long-run relation among international markets and the equation 2 would be reduced to a VAR(k).

Now, for detecting possible periods of contagion, the above dynamic Johansen cointegration test is applied between all the possible pairs of countries with a *rolling window of 1000-days*,³⁰ by computing at each step t (t , represents each month) of the procedure the following *rolling indicator* of cross-country connections:

$$\left[\begin{array}{c} \text{Percentage of} \\ \text{Cross - Country Connections} \end{array} \right]_t = \left[\frac{\text{\# of long - run relations}}{\text{Max.\# of Long - run relations among all countries}} * 100 \right] \quad \text{eq. 3}$$

Using the rolling indicator in equation 3, it is possible to discriminate as follows:

- Crisis periods are identified recording the *highest* values of cross-country connections.
- Tranquil periods are identified recording the *lowest* values of cross-country connections.

By comparing these highest and lowest percentage values, it may be possible to either confirm or reject the assumption made regarding the timing of the two crises episodes investigated: Contagion occurs when cross-country co-movements (percentage of cointegrated countries, known as cross- country connections), increase during the crisis periods relative to cross-country connections during the tranquil periods.

As second step, through the *Granger causality test* and *Vector Error Correction Model (VECM)/Gonzalo-Granger statistic*, which capture new significant short connections among the BRICS countries after a financial shock, allowing also the identification of which country propagates the impulses of contagion – *leading countries* and which country is the target of contagion – *follower countries*.

³⁰ The length of 1000 days-window is chosen in order to make the cointegration results more robust, allowing to explore the asymptotic properties of the Johannsen test (Gentile and Giordano, 2012, 2013). Further, in the presence of autocorrelation coefficients, the power of the trace test is as low as the nominal size for a window length of 250 days and becomes acceptable for windows of at least 1000 days – four years (Ludwig, 2014, 19).

The Granger causality test provides evidence for short-run relationship among BRICS countries. Alongside with cointegration technique (long-run relationship), it allows one to find out which country has a dominant role in the contagion process, being able to influence others “*leading country*” and it allows one to identify the most fragile country, in other words, it is possible to identify the reaction of this country related to other countries’ price innovations “*follower country*”.

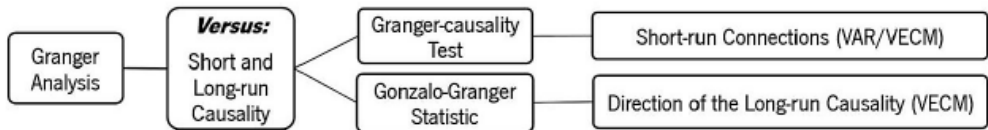


Figure 1. Framework implementation of the Granger Causality Methodology

In order to apply the Granger causality test, the following considerations were taken into account: first, the time series were tested for unit root in each sub-period established in the first step followed by the cointegration test among pairs of countries. Second, the results of unit root test applied earlier revealed that all the time series are nonstationary at log-level. However, the series are stationary at their first difference (I(0)), that is, all the series are integrated of Order one (I(1)). Based on these results, if the series are found to be (I(1)) and not cointegrated,³¹ the causality test proceeded according to the following equations:

$$\Delta X_t = \alpha_x + \sum_{i=1}^k \beta_{x,i} \Delta X_{t-i} + \sum_{i=1}^k \theta_{x,i} \Delta Y_{t-i} + \epsilon_{x,t}$$

$$\Delta Y_t = \alpha_y + \sum_{i=1}^k \beta_{y,i} \Delta Y_{t-i} + \sum_{i=1}^k \theta_{y,i} \Delta X_{t-i} + \epsilon_{y,t} \quad (eq. 4)$$

However, if the series are found to be (I(1)) and cointegrated, causality test will be tested based on equation 5. For cointegrated series, different approaches to causality testing have to be applied. Based on results of Sims et al. (1990), Demetriades and Hussein (1996) argue that test statistics derived from a level VAR framework are not valid unless the variables employed are either (I(0)) or (I(1)) and cointegrated. This assumption drives the causality test for equation 4 if the series are not cointegrated.

³¹The Equation 4 is only valid if the series are not cointegrated (MacDonald and Kearney, 1987).

On the other hand, Engle and Granger (1987) and Granger (1988) argue that in the presence of cointegration, causality tests derived from the cointegration relationship, which ignore the ECT, are misspecified and suggest the re-parameterization of the model in the equivalent error correction model form (VECM). Therefore, the causality test in this case is conducted in the following equations:

$$\begin{aligned}\Delta X_t &= \alpha_x + \sum_{i=1}^k \beta_{x,i} \Delta X_{t-i} + \sum_{i=1}^k \theta_{x,i} \Delta Y_{t-i} + \phi_x ECT_{x,t-1} + \epsilon_{x,t} \\ \Delta Y_t &= \alpha_y + \sum_{i=1}^k \beta_{y,i} \Delta Y_{t-i} + \sum_{i=1}^k \theta_{y,i} \Delta X_{t-i} + \phi_y ECT_{y,t-1} + \epsilon_{y,t}\end{aligned}\quad (eq. 5)$$

The VECM-based test allows the differentiation between two types of causality: the short-run dynamics of the VAR and the disequilibrium adjustment of the error correction mechanism (ECM). Indeed, the F-test on the estimated coefficients θ_i provides evidence regarding a short-term adjustment dynamics. The t-test of the estimated coefficient ϕ provides evidence for the existence of an arbitrage type error correction mechanism that drives the variables back to their long-term equilibrium relationship that is embodied in the cointegration vector. In this step, the objective is to identify the creation of new short-run relations among countries as evidence of contagion (θ_i), conducting the Granger causality test separately for each contagion window (sub-periods defined in the first step) based on the stock returns of all countries. Regarding the lag length k ,³² the criteria is chosen in order to generate a white noise error term ϵ_t .

We analyze the contagion windows defined in the previous step, looking for changes in the short-run connections between countries. Hence, changes in the connections detected after a crisis period is a signal of shocks transmission through countries and consequently, a signal of contagion. Moreover, together with the short-run versus³³ of the connections, the detection of the long-run versus of the countries connections is also very important and reached by implementing the Gonzalo-Granger statistic, allowing the identification of the

³² The criteria information is given by the Akaike information criterion (AIC), the Schwartz information criterion (SIC), the Hannan-Quinn criterion (HQ) and the Likelihood ratio statistic (LR). In this research, the SIC is preferable only when the serial correlation is not an issue. Otherwise, the preferable criterion will be the one that guarantees no serial correlation.

³³ The versus of the long-run (cointegrated analysis) is two types of causality: short-run connections obtained by the Granger causality test and the long-run causality, which is obtained in the context of the cointegration analysis based on the first step and it is applied in the Gonzalo-Granger statistic.

direction of connections in the crisis episodes. In order to detect the direction of the long-run causality among BRICS countries, we apply Gonzalo and Granger (1995) methodology³⁴ to identify the direction through which adjustment is done. Hence, it is possible to estimate which country is the *leader* and which is the *follower* in the contagion transmission in the context of a bivariate cointegration analysis (Engle and Granger, 1987). Furthermore, we can measure the speed of convergence to the long-run equilibrium (α) of the two hypothesized countries, while (β) contains the parameters of the common stochastic trend (Gentile and Giordano, 2012, 2013).

Gonzalo and Granger's model of price-discovery is based on the following VECM specification given by Arce et al. (2012), adapted to our context (with USA stock return as a exogenous variable):

$$\begin{bmatrix} \Delta X_t^k \\ \Delta Y_t^j \end{bmatrix} = v_0 + ECT + USA + \begin{bmatrix} \sum_{i=1}^p \lambda_{1,i} \Delta X_{t-i}^k \\ \sum_{i=1}^p \delta_{2,i} \Delta Y_{t-i}^j \end{bmatrix} + \begin{bmatrix} \sum_{i=1}^p \delta_{1,i} \Delta Y_{t-i}^j \\ \sum_{i=1}^p \lambda_{2,i} \Delta X_{t-i}^k \end{bmatrix} + \begin{bmatrix} u_{1,t} \\ u_{2,t} \end{bmatrix} \quad (eq.6)$$

The above empirical model is a VAR system formed by two equations defined from the vector, which includes X_t^k and Y_t^j as the pair of BRICS stocks markets, $k, j = \text{Brazil, Russia, India, China, South Africa}$ ($k \neq j$); and an error correction term (ECT) defined by the expression $\alpha(X_{t-1}^k - \beta_2 Y_{t-1}^j - \beta_3 Z_{t-1}^{USA} - \beta_4)$, where β_2, β_3 and β_4 are estimated in an auxiliary cointegration regression and the parameter vector $\alpha' = (\alpha_1, \alpha_2)$ contains the error correction coefficients measuring each price's expected speed of adjustment. Furthermore, the exogenous variable (USA) is defined by the expression $\sum_{i=1}^p v_i^{USA} \Delta Z_{t-i}^{USA}$. The estimation of the VECM equation is restricted to the existence of a cointegration relation between the stock market from both pair of countries. This cointegration relation appears in the ECT as $(X_{t-1}^k - \beta_2 Y_{t-1}^j - \beta_3 Z_{t-1}^{USA} - \beta_4)$. The parameters $\lambda_{1,i}, \lambda_{2,i}, \delta_{1,i}, \delta_{2,i}$ and $v' = (v_{1,i}, v_{2,i})$ for $i=1, \dots, p$, with p indicating the total number of lags, contain the coefficients of the VAR system that measure the effect of the lagged first difference in the pair of stocks from BRICS countries markets based on the first

³⁴The method proposed by Gonzalo and Granger (1995) decomposes the time series X_t as: $X_t = \alpha(\beta' \alpha) \beta' X_t + \beta_1 (\alpha_1 \beta_1)^{-1} \alpha_1 X_t$ where first component is $I(0)$ and the transitory part, while the second component is $I(1)$ and the permanent part (see Gonzalo and Granger, 1995, Equation 11). The decomposition of the $[X_t, Y_t]$ into two components (transitory and permanent), allow the obtainment of different kind of information. For example, policymakers may be primarily interested in the trend (permanent component) behavior, but those concerned with business cycles are more interested in the cyclical component (transitory component). Moreover, singling out the common factors allow us to investigate how they are related to other variables (Gonzalo and Granger, 1995).

difference of such stocks at time t . Finally, u_t denotes a White noise vector $u_{i,t} \sim N(0,1)$.

The price-discovery for the pair of stocks from the BRICS markets, denoted by GG_{X^k} and GG_{Y^j} , respectively, can then be constructed from the elements of the vector α' , which contains the coefficients that determine each market's contribution to price-discovery:

$$GG_{X^k} = \frac{\alpha_2}{(\alpha_2 - \alpha_1)} \quad GG_{Y^j} = \frac{-\alpha_1}{(\alpha_2 - \alpha_1)} \quad eq.(7)$$

Given that $[GG_{X^k} + GG_{Y^j}] = 1$, we would conclude that the $X^k(Y^j)$ market leads the price-discovery process whenever GG_{X^k} is higher (lower) than 0.5. The intuition for this is the faster the speed in eliminating the price difference from the long-term equilibrium attributable to a given stock market, the higher the corresponding α according equation 6, and the higher the price discovery (Arce et al. 2012).

At this point, we adapted the equation 7 to the view of Gentile and Giordano (2012, 2013), for instance, assuming a pair of countries, as in the first step, the long-run coefficients matrix Π in equation 2 can be expressed as $\Pi = \alpha\beta'$, where α measures the speed of convergence to the long-run equilibrium of the two hypothesized countries, while β contains the parameters of the common stochastic trend. Furthermore, following equation 4, if the parameter of the speed adjustment of the first country (α_1) is statistically not significant, while the parameter of the speed adjustment of the second country (α_2) is positive and significant, it means that the adjustment process towards the long-term relationship is determined by changes to the variable of the second country in response to changes of the variable of the first country, indicating that the leading role in the contagion transmission is played by the first country. Otherwise, if (α_1) is negative and statistically significant, while (α_2) is not significant, this implies that the second country plays the *leading role*. However, when both countries are significant³⁵, both countries contribute to the contagion transmission process and the Gonzalo-Granger statistic, defined as $\left[\frac{\alpha_2}{(\alpha_2 - \alpha_1)'}\right]$, allows one to determine which country makes the greatest contribution to the contagion transmission process. Hence, if the application of the ratio in equation 7 for the first stock market exceeds 0.5, the price of the first country plays a more important role, while if it is lower than 0.5, the price of the second country plays a bigger role in the contagion transmission (Arce et al. 2012; Gentile and Giordano 2012).

³⁵ In that case, there is a shift of signals (Gentile and Giordano 2012, 2013).

Third and the last step is dedicated to the rate of involvement indicator, which identifies the most vulnerable countries, measuring how much of the domestic risk is explained by innovations in other BRICS countries. We apply the forecast-error *variance decomposition* (FEVD) to test for the exposure to external shocks as a degree of vulnerability of each country. Indicating that, as far as the proportion of the movements explained by other countries increases, the vulnerability of the system also increases and becomes more exposed to external shocks (more exposed to external markets). Following the conceptual framework discussed previously, at this point, our assumption is that contagion occurs every time the degree of vulnerability of one country – measured as the fraction of its movements due to an other country’s shocks – increases after a crisis period. In other words, an increasing degree of vulnerability after a crisis period is considered as evidence of contagion.

The FEVD, looking from the econometric point of view, measures the fraction of the forecast-error variance of an endogenous variable that can be attributed to orthogonalized shocks themselves or to another endogenous variable, giving the portion of the movements in the dependent variables that are due to their “own” shocks, versus shocks to the other variables.³⁶

Initially, the FEVD indicator is given by the moving-average representation of the VECM as follows:

$$R_t = \sum_{s=0}^{\infty} C(s)u(t - s) \tag{eq. (8)}$$

where, the $i, j - th$ component of $C(s)$ represents the impulse-response of the $i - th$ country in s periods to a shock of one standard error in the $j - th$ country, and u is the orthogonalized innovation in the sense that it has an identity covariance matrix. Initiating from this mathematical representation of the stock return, the variance of the $n - step$ forward forecast variance of the $i - th$ return time series $[R_{i,t+n}]$ is given as follows:

$$\delta_i(n)^2 = \sum_{j=1}^n C_{i,1}(j)^2 + \dots + \sum_{j=1}^n C_{i,N}(j)^2 \tag{eq. (9)}$$

³⁶ A shock to the $i - th$ variable will directly affect that variable; however, it will also be transmitted to all other variables in the system through the dynamic structure of the VAR. Variance decompositions determine how much of the s -step-forward forecast error variance of a given variable is explained by innovations to each other explanatory variables for $s = 1, 2, 3, \dots, T$.

where, N is the number of countries included in the sample ($N = 5$)³⁷. For each country stock market i the ratio:

$$W_i(k) = \frac{\sum_{j=1}^n C_{i,k}(j)^2}{\delta_i(n)^2} \quad \text{eq. (10)}$$

represents the portion of movements in country i due to shocks from country k , on the time horizon n . Therefore, for $[i = k]$ the ratio is as follows:

$$W_i(i) = \frac{\sum_{j=1}^n C_{i,i}(j)^2}{\delta_i(n)^2} \quad \text{eq. (11)}$$

indicating the portion of its forecast error variance which is explained by its own innovations. Consequently, its complement to one $[1 - W_i(i)]$ is the rate of involvement indicator, which measures the degree of vulnerability of country i , since it is the percentage of the variance of country i explained by innovations in other countries, being considered as a *measure of country exposure to external shocks*. In more detail, the *rate of involvement* – measures the degree of vulnerability of each country, as a *degree of exposure to the external shocks* – indicating how much “domestic” risk is explained by innovation in foreign countries.

All three indicators results point towards the evidence of contagion across BRICS stock markets over the last two financial crises (the LBBC and ESDC).

5. Results

5.1. Contagion Windows Definition

In the *first-step* result, we started by analyzing the connections among the BRICS markets through time. At each point of time ($t = \text{each month}$),³⁸ we estimated the linkages across markets. These linkages are able to influence and determine the stock returns between the BRICS stock markets. A sharp increase of cross-market connections signals a contagion phenomenon, as we can see in figure 1 below.

Using a 1000-days rolling window and the dynamic bivariate cointegration test, in the first of the three-step analysis, we detected the connections between markets (long-run relationships) that lead to slow price adjustment processes. Further, applying the *rolling indicator* (Percentage of connections, discussed in methodology section), it is possible to detect the increasing or decreasing

³⁷ Brazil, Russia, China and South Africa.

³⁸ The results contemplate in total 121 months and consequently, 121 rolling windows in total.

connections between markets that can confirm the assumption of tranquil or turbulent period of crisis. To identify these periods, the results of the rolling indicator are combined with the quartiles³⁹ to divide and set the precise timing of the contagion window by looking directly in the data in order to define when the contagion phenomenon started to spread between the two financial crises (LBBC and ESDC).⁴⁰ Supposing the rolling indicator exceeds the III^o quartile ($\theta_{III} = \text{UpperBound} = 75^{th}$ percentile = 40%), the percentage of relevant connections is considered significantly high and, therefore, the period is considered as turbulent. On the other hand, supposing the percentage of connections is high (but does not exceed the θ_{III}) and there are no significant changes in the number of connections, then we assume it as evidence of interdependence rather than contagion phenomenon (Gentile & Giordano, 2012, 2013). Therefore, the so called “*tranquil*” period is identified as equal or under the III^o quartile until the I^o quartile ($\theta_I = \text{Lower Bound} = 25^{th}$ percentile = 10%). Consequently, the “*crisis*” period is identified when the rolling indicator reveals a higher percentage of connections above the upper bound and the “*tranquil*” period is given when the rolling indicator reveals a lower percentage of connections equal to the θ_{III} (but without significant changes in the number of connections, indicating high interdependence) or below, until the θ_I (lower bound).

To detect and discriminate between crises periods and tranquil periods, we observed the increasing connections between the countries given by the rolling indicator. For instance, the date of the sharpest fall in the BRICS markets was May 2008⁴¹ (see Appendix A). The same month shows a sharp increase of cross-market connections, as demonstrated in Figure 1, signaling a contagion phenomenon (Gentile & Giordano, 2012). These findings strongly support the idea that contagion involves externalities and is distinct because it reflects market failure and dangerously amplified transmission of instability (Gonzalez-Paramo, 2011). Moreover, the results support the view of (Constancio, 2012, p. 110), that the spread of instability is abnormal and amplified, going beyond the bounds of normality.

³⁹ The use of quantiles to identify significant increases (abnormal) of asset price co-movements, is justified by recent econometrics techniques (Caporin et al., 2013; Gentile & Giordano, 2012, 2013; Koenker, 2005; Koenker et al. 1994; Mensi et al., 2014)

⁴⁰ Constancio(2012, p. 110) and Caporin et al.(2013) maintain that a contagious event cannot occur in the absent of a shock, a large shock should occur. Enforcing the finds in this research in line with other studies (e.g. Fourie & Botha, 2015; Gentile & Giordano, 2012, 2013).

⁴¹ May 2008 was also the month where the Dow Jones index reached the highest peak. The following months revealed that the crisis had become evident, spreading from the housing market to the global financial markets (Mollah et al., 2014).

Our results based on the rolling indicator, revealed two contagion windows (see Table 2). The *first contagion window* reveals the Lehman Brothers Crisis – from May 2008 to July 2009,⁴² while the “tranquil” period goes from January 2003 to April 2008 (when the indicator is almost always below the III^o quartile going down until the I^o quartile). At the end of the “tranquil” period, the stock market started to show high signs of co-movements, which we considered as interdependence.

Table 2. Contagion Windows Definition

| Stock Market Returns | |
|---|---|
| <i>Lehman Brothers Bankruptcy Crisis</i> | <i>European Sovereign Debt Crisis</i> |
| Duration: 15 Months | Duration: 7 Months |
| 01-05-2008 – 31-07-2009: Approximately 327 days. In 86.67% of the cases the rolling indicator is strictly above the upper bound III ^o Quartile ($\theta_{III^o} \rightarrow 40\%$). | 01-04-2011 – 31-10-2011: Approximately 152 days. In 71.43% of the cases the rolling indicator is strictly above the upper bound III ^o Quartile ($\theta_{III^o} \rightarrow 40\%$). |

⁴² The first window goes from May 2008 to July 2009. The data and the percentage indicator evidenced this period as a period of highly connections across the countries. The beginning of the contagion window shown in the graphical representation is coherent with the data from BRICS market (see Appendix A and Figure 1), but is also coherent with the signs given by the international markets. The Dow Jones index peaked in May 2008, as already mentioned earlier, giving strong support to the contagion window chosen. Indeed, the subprime crisis had devastating effects, bursting the global asset bubble and quickly jumped to the stock market. By October 2008 it had already erased around US \$25 trillion from the value of stock markets. At the end of the first quarter of 2009, global market capitalization had already fallen 53% (Chittedi, 2014).

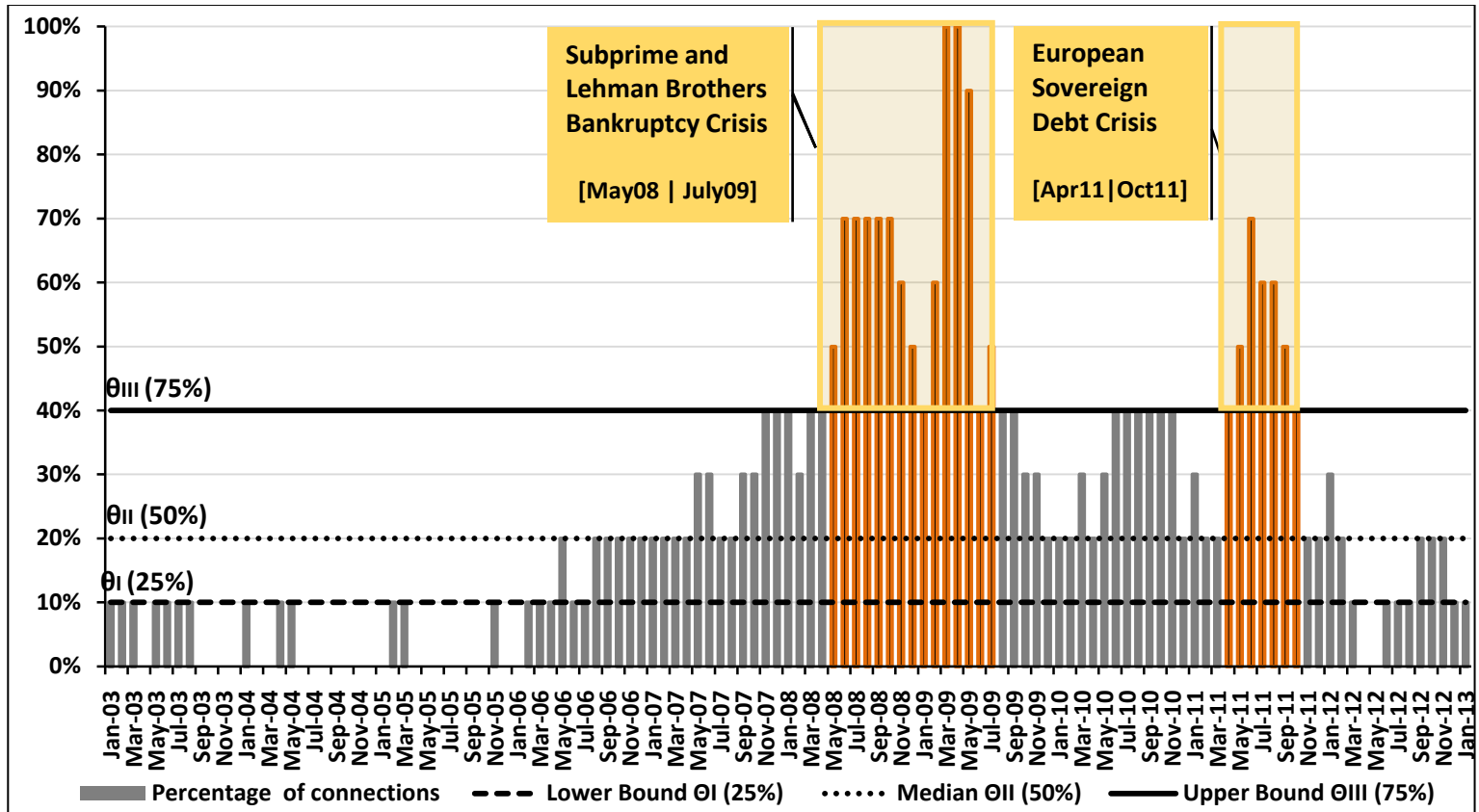


Figure 1. Graphical representation of the contagion window, using stock returns based on the results of the rolling indicator.

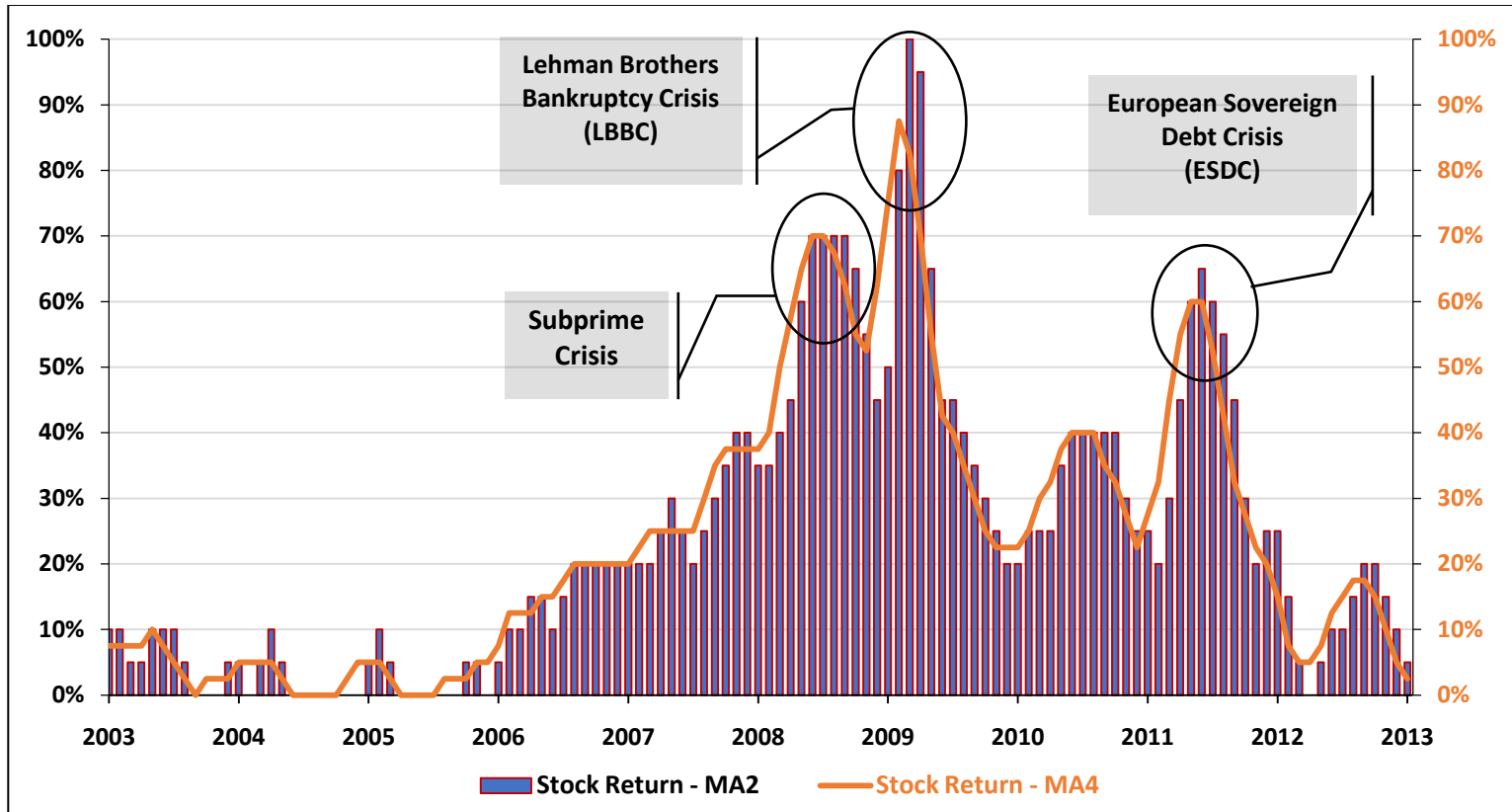


Figure 2. Graphical representation of the percentage of significant connections (rolling indicator), computed by applying a moving average of two months (MA2) and four months (MA4).

The *second contagion window* is related to the European Sovereign Debt Crisis – from April 2011⁴³ to October 2011. In this window, we considered the first and last month that did not pass the III^o quartile because the jump from the previous month was very high (20% higher), showing evidence of contagion (see Figure 1). Therefore, the “*tranquil*” period is defined from August 2009 to March 2011,⁴⁴ lasting 20 months (covering approximately 434 days). In this window, the indicator shows high co-movements in almost the whole period, but they do not grow significantly. Hence, any continued high level of market correlation suggests strong connections that exist in all states of the world, suggesting a situation of interdependence (Gentile & Giordano, 2012).

In Figure 2, we present the total amount of possible relationships obtained from the rolling indicator for the BRICS stock returns. It highlights the differences in the pattern of crisis, making it possible to see the pattern of Subprime Crisis separately from the LBBC by applying a moving average of two and four months.

The intensity of cross-market connections given by the rolling indicator shows a different pattern related to the stock market return, identifying two episodes of contagion. The first one begins around May 2008 and ends around July 2009, including consequently, both the Subprime and Lehman Bankruptcy

⁴³ The date of the sharp jump to the contagion refers to the announcement of the third country (Portugal) asking for a bailout of e78 billion (\$110 billion) from the EU and the IMF (Ray, 2015).

⁴⁴ The “*tranquil*” period defined from August 2009 to March 2011 was a period where the world financial markets were in a very high level of tension. The problems of the Eurozone started to spread across the Union. The global financial markets started to react, and the BRICS stock market was not an exception. In March 2010, the Greek Prime Minister (Papandreou) proposes a new financial package for Greece that includes additional public sector pay cuts and a 2% sales tax increase. On May 2010, IMF and Eurozone leaders agree to a e110 billion (\$143 billion) bailout package for Greece. Portugal starts to show vulnerabilities; the bond yields start to rise together with high volatility in the value of the euro (Ray, 2015). On June 2010, the Euro closes at its lowest rate of exchange against the US dollar since March 2006. In July 2010, the EU releases the results of “*stress tests*” conducted on 91 European financial institutions. The results were very bad; seven institutions did not maintain the minimum amount of capital required by examiners. In September 2010, it becomes known that the cost of bailing out Anglo Irish Bank could reach as much as e34.3 billion (\$46.6 billion). The results elevate Ireland’s budget deficit to 32% of GDP. In November 2010, Ireland’s government officially applies for bailout funds from the EU and the IMF. Embattled Irish Prime Minister Brian Cowen submits a harsh austerity budget and promises to call a general election in 2011. Within a week an e85 billion (\$113 billion) rescue package is approved by European leaders. In April 2010, Portugal’s Prime Minister (Socrates), requests a bailout relief from the EU and the IMF. The volatility in the markets exploded, and the contagion effect starts to spread. In June 2010, Standard & Poor’s downgrades Greece’s credit rating to CCC, turning Greece the world’s lowest-rated sovereign debt (Ray, 2015). The data from BRICS stock market showed that the contagion effect had reached the highest peak in the ESDC indicated by the second contagion window (see Figure 1).

Crisis. The indicator shows that the peak is achieved in March and April 2009, reaching 100% of cross-market linkages as significant (see Figure 1). The second contagion window pointing to the ESDC, from April to October 2009, reaching a peak of cross-market linkages of 70%. This result indicates that the impact in the BRICS economies seems to be weaker and shorter, compared to the first contagion window.

The first part of our research has considered until now just the long-run connections, implying just the slow price adjustment process given by the Johansen cointegration test. However, to verify the presence of a contagion effect, the total number of connections (long-run and short-run) is needed. Hence, the Granger causality test, the second step of our analysis will be applied in the next section.

5.2. Revealing the Contagion Process

In our *second-step* results, we analyze the results arising from the number of cross-market connections related with the “*crisis*” periods and compare them with the “*tranquil*” periods, by applying the cointegration test and the Granger causality test. The bivariate cointegration test allows the identification of connections between pairs of markets which lead to slow price adjustment process (long-run connections). But it is also possible to find the *versus* of each significant connection by applying the Gonzalo-Granger statistic. Furthermore, the Granger causality test identifies connections which have a short-term influence on the price discovery process (short-run connections), as demonstrated by Gentile and Giordano (Gentile & Giordano, 2012, 2013).

The results from both techniques (cointegration test/Gonzalo Granger statistic and Granger causality test), allow the identification of significant cross-market connections and the directions of the relation. Subsequently, by applying the two tests it is possible to establish which countries have a dominant role in the contagion process, because they are able to influence others “*leading countries*”, and which countries are more vulnerable and reactive to other countries’ price innovations “*follower countries*”, as one can see in Table 3. The difference lies in the time horizon of the price adjustment process induced by the existence of cross-market connections, which is the long-run for the connections identified by the bivariate Johansen cointegration test, while the short-run is the connections detected with the Granger causality test. Hence, to comprehend the relationship among markets and equilibrium restoration, the VECM according Gonzalo and Granger(1995) is applied to obtain the coefficients of ECT of speed of

adjustment parameters $[\alpha_1, \alpha_2]$ ⁴⁵ to restore the long-run relationship whenever a disequilibrium situation appears.

Our results determined that in the *first turmoil* – LBBC, that Brazil, China, and South Africa (leading countries) are statistically not significant, which brings to light that these markets are weekly exogenous. However, they are the first to be affected by innovations (excluding Russia and India) and consequently, they are transmitting the shocks to the other markets (follower countries), being responsible for the contagion transmission process. Looking closely at the coefficients of ECT in Table 3, in the long term, a shock in the financial markets (LBBC), impacts the stock market in China⁴⁶ (BRA-CHI(5%)) positively and negatively in India⁴⁷ (for IND(6%)-CHI and IND(7%)-SAF) and China (CHI(15%)-SAF). The information from the long term relationship indicates that under the LBBC, the stock market in China (BRA-CHI(5%)) provided some hedge against the contagion effect from LBBC, while India (IND(6%)-CHI and IND(7%)-SAF) and China (CHI(15%)-SAF) does not provide any hedge (Bianconi et al., 2013, p. 90).

In the *second turmoil* – ESDC, our analysis indicates that Brazil, Russia, China and South Africa (leading countries) are statistically not significant, and consequently, they are all hit by the ESDC in the first moment (excluding India). Furthermore, the innovations from the ESDC affect positively India (BRA-IND(12%)), China (BRA-CHI(16%)) and South Africa (for RUS-SAF(15%)), CHI-SAF(20%)), which means that these countries seem to have a higher level of resilience, providing some hedge against the ESDC. In contrast, India (IND(9%)-SAF) is affected negatively, and consequently, does not provide any kind of hedge.

⁴⁵ For instance, in the case of (IND-SAF) for the LBBC, a positive shock in the pair of markets recover the equilibrium level of the negative values of the ECT's; the VECM is valid since the ECT coefficient is significantly negative. This suggests that the long-run linkages are confirmed by the short-run linkages, suggesting contagion effects, since the ECT coefficient records a rise in magnitude during the instability period, suggesting thus a *shift* in the adjustment speed for the equity markets of these countries. This insight reflects the effects of the LBBC on the linkages between the US stock market and the BRICS markets (Boubaker et al., 2016). Indeed, looking at India stock market (IND-SAF), whenever a disequilibrium arises, then only 7% adjustment takes place in the first day, while the rest is reached in the coming days for India stock market (See Singh & Kaur, 2016). See Table 3.

⁴⁶ In the case of Brazil-China pair of countries, just the coefficient of ECT from China (follower country) is statistically significant.

⁴⁷ In the case of India-China and India-South Africa pair of countries, just the coefficient of ECT from India (follower country) is statistically significant.

Table 3. Results from Cointegration Test/Gonzalo-Granger Statistics

| January 2003 to April 2008 - Tranquil period | | | | |
|--|------------------------------|----------------------------------|--------------------|----------------------------|
| Pair of Countries | Gonzalo-Granger Statistic | Speed of Adjustment [α] | | Results |
| | | α_1 | α_2 | Leading/Follower Countries |
| BRAZIL - INDIA | GGBRA | -0.001675 | | Leading country |
| | GGIND | | 0.011453*** | Follower country |
| May 2008 to July 2009 - Turbulent period: Subprime and Lehman Brothers Crisis | | | | |
| Pair of Countries | Gonzalo-Granger Statistic | Speed of Adjustment [α] | | Results |
| | | α_1 | α_2 | Leading/Follower Countries |
| BRAZIL - CHINA | GGBRA | -0.004429 | | Leading country |
| | GGCHI | | 0.044729*** | Follower country |
| INDIA - CHINA | GGIND | -0.056525*** | | Follower country |
| | GGCHI | | -0.002313 | Leading country |
| INDIA - S. AFRICA | GGIND | -0.069595*** | | Follower country |
| | GGSAF | | -0.002708 | Leading country |
| CHINA - S. AFRICA | GGCHI | -0.146660*** | | Follower country |
| | GGSAF | | 0.061711 | Leading country |
| August 2009 to March 2011 - Tranquil period | | | | |
| Pair of Countries | Gonzalo-Granger Statistic | Speed of Adjustment [α] | | Results |
| | | α_1 | α_2 | Leading/Follower Countries |
| BRAZIL - CHINA | GGBRA | -0.042440** | | Follower country |
| | GGCHI | | 0.018214 | Leading country |
| April 2011 to October 2011 - Turbulent period: European Sovereign Debt Crisis | | | | |
| Pair of Countries | Gonzalo-Granger Statistic | Speed of Adjustment [α] | | Results |
| | | α_1 | α_2 | Leading/Follower Countries |
| BRAZIL - INDIA | GGBRA | -0.024887 | | Leading country |
| | GGIND | | 0.117500*** | Follower country |
| BRAZIL - CHINA | GGBRA | 0.015320 | | Leading country |
| | GGCHI | | 0.157903*** | Follower country |
| BRAZIL - S. AFRICA | GGBRA | 0.258053*** | | Leading country |
| | GGSAF ← | | 0.237389*** | Leading country |
| RUSSIA - S. AFRICA | GGRUS | 0.081265 | | Leading country |
| | GGSAF | | 0.150673*** | Follower country |
| INDIA - S. AFRICA | GGIND | -0.085531* | | Follower country |
| | GGSAF | | 0.093486 | Leading country |
| CHINA - S. AFRICA | GGCHI | 0.023620 | | Leading country |
| | GGSAF | | 0.200972*** | Follower country |

Notes: The results obtained from the VECM in the context of the Granger causality test, allow the obtainment of the speed of adjustment of the first country (α_1) and second country (α_2) respectively, in other words, the coefficients of error correction terms. [***] indicates the level of significance at 1% level; [**] at 5% level; [*] at 10% level. [←] represents the leading country that makes the greatest contribution to the contagion transmission process by applying the Gonzalo-Granger statistic.

Analyzing the results of long and short connections among the markets, it is possible to notice that Brazil, China and South Africa dominated the stock market during the LBBC as leading countries (May 2008 to July 2009) and the number of cross-markets connections increased sharply from 8 (January 2003 to April 2008) to 12 (May 2008 to July 2009). Thereafter, when the analysis is directed to the ESDC (April 2011 to October 2011), the number of cross-market connections increased from 7 (August 2009 to March 2011) to 10 (April 2011 to October 2011), wherein, China clearly lost the dominant role in the contagion transmission played in the Lehman Crisis.

Regarding Brazil and South Africa, Brazil is the major leading country in the ESDC, playing a dominant role in the contagion transmission structure by influencing Russia, India, China (both short/long-run) and South Africa⁴⁸ stock markets; it is followed by South Africa with much less intensity, playing a leading role in Brazil and India stock markets.

A higher dominant role can be seen in the ESDC for Brazil stock market (now influencing also South Africa, see Appendix B, Table 3 and Figure 3), while for China, the dominant role of influencing other markets diminished clearly. Furthermore, South Africa, which during the LBBC had been able to influence Brazil, India and China stock markets, in the recent ESDC, it was only capable of influencing Brazil and India, losing the dominant role in transmitting contagion to China's stock market.

Regarding the LBBC, it is possible to analyze that Brazil and China were the greatest leading countries in the contagion transmission. In the first crisis, there is evidence of high connections concentrated in the leading countries (Brazil, China and South Africa); while in the second crisis the evidence points towards a dominant role in the contagion transmission mechanism coming strongly from Brazil, with much less intensity from the others. In 2008-09 crisis, Russia and India absorbed shocks without being able to influence other countries (pure follower country), signaling a high degree of vulnerability. In the case of China, this market absorbed shocks but also spread them, while in the case of Brazil, which is a major contributor to the contagion transmission (even in tranquil periods of times), was highly capable of spreading shocks to all other countries (in both crises) and was not influenced by any of them, excepting for South Africa in both crises.

⁴⁸ The result in absolute value did not exceed 0.5 for Brazil (-11, 48). For South Africa, the value (12, 48) exceeded in absolute value 0.5. Therefore, the price of the second asset (South Africa (SAF)), plays a bigger role compared to the first asset (Brazil (BRA)), see Table 3 above.

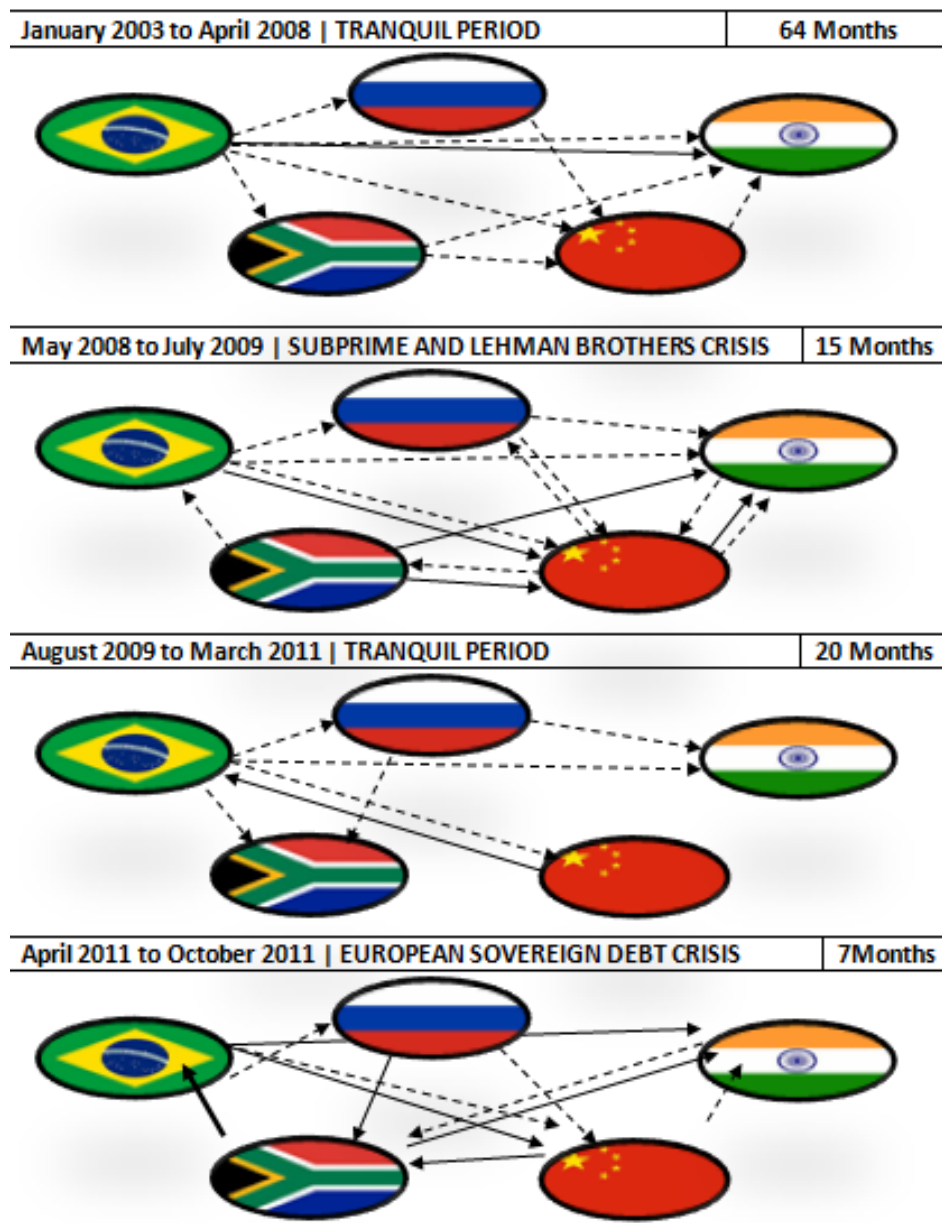


Figure 3. Stock return contagion test: short and long-run connections before and after the crises episodes.

Notes: *Dashed line* represents the short-run connections, *solid line* is used to indicate the long-run connections and the *thick solid line* indicates that both countries contribute to the contagion transmission. Although one country plays a bigger role (*“leading country”*).

Our results also reveal the risk profile of India and China in the LBBC as sharply higher compared to the other countries based on the number of relevant connections. Therefore, the contagion process is mainly related to India and China stock markets. While in the ESDC, the risk profile of India and South Africa is the same but lower than the previous crisis, indicating that the process of contagion is mainly related with these two countries, with Brazil as a major source in spreading the contagion to all BRICS stock markets in both crises. One difference between the two crises studied that clearly emerges, is related to the amount of short-run connections during LBBC (10 short-run connections over 14 total connections) compared to the ESDC (5 short-run connections over 11 total connections). Moreover, it seems that the LBBC is characterized by a strong increase in the number of short-run links, while the ESDC is characterized by a higher level of long-run connections (7 long-run links⁴⁹ over 11 total connections).

The most important result from this analysis is related to the evidence of contagion as opposed to interdependence or spillover. The number of connections detected among countries (in both contagion windows), increased after the “*crisis episodes*” but did not remain at such a high level after the shock. Indeed, the number of connections increased intensively during “*crisis periods*” and then decreased drastically during “*tranquil periods*”. This movement is a critical test to distinguish between contagion and interdependence. As stated earlier in this research, contagion is a significant increase in the co-movement between assets during a period of crisis, compared with a tranquil period. Therefore, if there is a high level of market co-movement in all periods, that is the case of interdependence. As it is possible to see in this research (see Figure 1 and Figure 2), a higher number of connections in the BRICS stock markets which do not hold steady after a shock, returning to the low values once the crisis is gone, is a signal of a temporary distortion of the transmission channels due to shocks – that is contagion, instead of a systematic change in the common economic structure, based on the real or financial links.⁵⁰

5.3. Measuring Countries Degree of Exposure to the Contagion Process

The *last step* is reached by applying the variance decomposition methodology, following Gentile and Giordano (2012, 2013). This methodology allows one to measure of each country’s degree of exposure to the influence of foreign markets, indicating *the rate of involvement in the contagion process*.

⁴⁹ The influence of Brazil over South Africa, even though weaker, was considered (see Table3).

⁵⁰ These theories are usually based on standard transmission mechanisms, such as trade, monetary policy, and common shocks, for example, oil prices (See Gentile & Giordano, 2012, 2013; Kishor & Singh, 2014; Nikkinen et al., 2013).

Furthermore, the results in Table 4 below reveal that South Africa is incredibly more significantly involved in the ESDC compared with its involvement in the LBBC. Indeed, all the BRICS countries exhibited a significant increase in the involvement of the contagion process in the second crisis ESDC. Regarding South Africa, for a time frame of 5 days (short term), the ratio of the forecast error variance (*the rate of involvement indicator*)⁵¹ explained by foreign markets increased from 2.82% (LBBC) to 31.32% (ESDC), making South Africa the most involved country in the contagion process with the highest degree of exposure to external shocks followed by India (from 11.27% to 27.30%), Russia (from 9.21% to 24%), China (from 21% to 31.36%) and Brazil (from 4.87% to 14.26%), with the lower degree of exposure to the contagion process.

Directing the analysis to the two crises considered, the variance decomposition methodology provides an insight about the contagion intensity for the countries in the sample. For instance, during the LBBC, the most involved country in the contagion process was China, the degree of exposure rose (from 12.92% to 21%) after the crisis, much higher than the other countries. Still in the LBBC window, it is interesting to notice that South Africa represented the lowest level of vulnerability (from 9.23% to 2.82%), followed by India (from 11.82% to 11.27%), indicating that these two countries seem to have a strong degree of exogeneity to the system, not being affected essentially by the LBBC compared to the other countries.⁵²

Concerning the ESDC, in the short-term, the most exposed country to external shocks and consequently more vulnerable and involved in the contagion process is South Africa (from 6.52% to 31.32%), followed by Russia (from 9.31% to 24%), India (from 4.52% to 27.30%), Brazil (from 2.08% to 14.26%) and lastly, China (from 24.24% to 31.36%).

Focusing the analysis on the ESDC, our results highlight that South Africa, Russia, India and Brazil are countries more exposed to financial contagion, mostly because of their higher degree of fragility (31.32%, 24%, 27.30% and 14.26%) in the short period, while for the long period the degree of fragility was (59.69%, 51%, 38.45% and 55.82%) for South Africa, Russia, Brazil and India, respectively. Furthermore, China records the worst performance in terms of rise of rate of involvement, mostly because of its high pre-Lehman vulnerability (from 24.24% to

⁵¹ The degree of vulnerability of each country.

⁵² Looking at the long period, for South Africa (from 14.28% to 4.15%), Russia (from 12.17% to 9.44%) and Brazil (from 6.26% to 5.14%) was essentially unaffected in the LBBC, whereas for India (from 14.75% to 17.86%) there was an increase in the vulnerability to external shocks. As regards South Africa, the results indicate that it is even more unaffected compared to the short period.

31.36% for the short period; and from 32.60% to 50.38% for the long period). Comparing both crises in terms of growth rate of vulnerability, the results indicate that South Africa is the most exposed to the financial contagion (28.50% for the short period; and 55.54% for the long period), followed by India (16.03%) and Russia (14.79%) in the short period. In the long period, Russia (41.56%) overtakes India (37.96%), becoming more exposed to the financial contagion than India, followed by Brazil with a growth rate of vulnerability of (33.31%), indicating a large increase in the degree of exposition to external markets in contrast with the short period.

Table 4. Rate of Exposure to the Contagion Process based on the Stock Returns.

| Countries | Forecast Horizon (Days) | Tranquil period | Turbulent period | Df ₁ | Tranquil period | Turbulent period | Df ₂ |
|-----------|-------------------------|-----------------------|-------------------|-----------------|---------------------------|--------------------------|-----------------|
| | | Pre-Lehman Bankruptcy | Lehman Bankruptcy | | Pre-Sovereign Debt Crisis | EU Sovereign Debt Crisis | |
| Brazil | 5 | 2.16 | 4.87 | 2.71 ↑ | 2.08 | 14.26 | 12.18 ↑ |
| | 10 | 6.26 | 5.14 | -1.12 ↓ | 2.26 | 38.45 | 36.19 ↑ |
| Russia | 5 | 7.72 | 9.21 | 1.49 ↑ | 9.31 | 24.00 | 14.69 ↑ |
| | 10 | 12.17 | 9.44 | -2.73 ↓ | 13.91 | 51.00 | 37.09 ↑ |
| India | 5 | 11.82 | 11.27 | -0.55 ↓ | 14.52 | 27.30 | 12.78 ↑ |
| | 10 | 14.75 | 17.86 | 3.11 ↑ | 19.91 | 55.82 | 35.91 ↑ |
| China | 5 | 12.92 | 21.00 | 8.08 ↑ | 24.24 | 31.36 | 7.12 ↑ |
| | 10 | 13.42 | 28.19 | 14.77 ↑ | 32.60 | 50.38 | 17.78 ↑ |
| S. Africa | 5 | 9.23 | 2.82 | -6.41 ↓ | 6.52 | 31.32 | 24.80 ↑ |
| | 10 | 14.28 | 4.15 | -10.13 ↓ | 6.40 | 59.69 | 53.29 ↑ |

Notes: The results are presented in percentage and the variance decomposition was computed based on 5 days (short period) and 10 days (long period) forecast horizon. Table 4 indicates the rate of involvement indicator $[1 - W_i(i)]$, measuring the degree of vulnerability of country i (each country's stock market) explained by innovations in all other countries, working as a measure of country's exposure to the external shocks (see Web Appendix B.3). [Df₁] represents the difference between tranquil and turbulent period in the Lehman Crisis. [Df₂] represents the difference between tranquil and turbulent period in the Sovereign Debt Crisis. For the results of each country's contribution to the contagion process individually.

6. Conclusion

Our research contributes to a better understanding of the contagion phenomenon by analyzing the changes in cross-market connections for the BRICS stock markets. The application of VECM cointegration/Granger causality

methodology detected contagion measuring shifts in the shocks transmission channels caused by the creation of new long-run equilibrium together with the raising of new short-run connections, by analyzing changes in the long/short-run connections in both contagion windows (LBBC and ESDC).

Our findings reveal that there was evidence of contagion in both crises, given that the number of cross-market connections increased sharply after such crises events occurred and reduced afterwards. Moreover, new long-run relationship between BRICS markets was created, causing a deterioration of the diversification benefits in both crises compared to the tranquil times (see Summary of the Results, Appendix C).

In the last decades, the BRICS countries underwent an important process of trade and financial liberalization to benefit from the advantages of market integration. Therefore, integrated financial markets allow, investors to allocate consumption risk more efficiently, decreasing the costs of capital faced by firms and stimulating investment and economic growth. However, an increased financial integration has intensified contagion effects across markets, causing severe welfare losses for large geographical regions and facilitating the transmission of international shocks to domestic stock markets. The consequences have important implications for the decisions of investors', regulatory and monetary authorities and for the effective portfolio diversification (Zouhair et al., 2014). Indicating that the effects of contagion in the BRICS markets can change investors' behavior, leading to high correlations and financial instability in the markets, which can cause phenomena like "*fight-to-quality*", "*heard behavior*" and "*bandwagon*" effects⁵³ may arise (Gentile & Giordano, 2012; Kazi & Wagan, 2014).

Evidence from the impact caused by both crises in the BRICS stock markets also provides meaningful insights pertinent to international asset pricing, risk management and the dynamic interactions in the global economy. For instance, gold's ability to act as a safe haven in the case of South Africa may have financial implications regarding the presence of diversification opportunities during extreme market conditions. With the "*financialization*" of the commodity markets, gold and oil can provide further protection against losses when the traditional assets (equities and bonds) experience large declines. Hence, including BRICS commodities in traditional portfolios, allow investors to avoid the downside risk in their investments. Gold can also provide protection against dollar

⁵³ A way of thinking in group, in which investor's probability of adopting any belief increases with the proportion who have already done so. Hence, investors do not discriminate among economic fundamentals across countries.

devaluations (Mensi et al., 2014). This research is also particularly helpful for portfolio risk managers, energy traders, policymakers and international investors who should be cautious about making investments in simultaneous markets that exhibit *pure* contagion. Knowledge of the dependencies between BRICS markets is crucial for policymakers to help them discern the directions of the co-movements and to safe guard the BRICS stock markets from contagion during future crises or major events.

Understanding the reasons of financial contagion between BRICS and international stock markets can help policymakers to develop a prevailing financial system to make BRICS markets more immune to international shock transmission, limiting their exposure to the contagion effects by improving stock market liquidity, as the BRICS markets increasingly become more integrated with the international markets.

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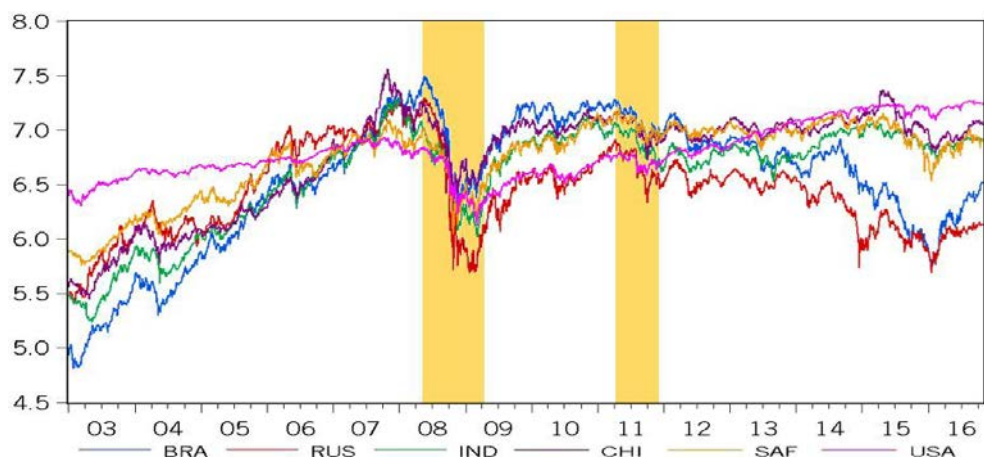
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APPENDICES**Appendix - A: Movement of BRICS and USA stock market****Figure A1.** Movement of BRICS and USA stock market

Notes: Indices for full sample in daily log-level from January 1, 2003 to October 31, 2016 (13 years and 10 months, 3609 observations). The Highlighted first shadow refers to the period of the GFC 2007-2008 and the second shadow period refers to the European Sovereign Debt Crisis started in 2011 that will be studied in this research as a contagion window. The source is the author's own, generated using EVIEWS 9.0 program.

Appendix - B: BRICS significant long/short-run connections

| January 2003 to April 2008 - TRANQUIL PERIOD | | | | | | | | | | | 64 Months | |
|---|-------------|-------------|------------|-------------|----------|-------------|-------------|-------------|-------------------|-------------|-------------|-----------|
| Leading | Brazil ↓ | | Russia ↓ | | India ↓ | | China ↓ | | S. Africa ↓ | | Total | |
| Follower | L | S | L | S | L | S | L | S | L | S | | |
| Brazil | - | - | - | - | - | - | - | - | - | - | - | 0 |
| Russia | - | 25.32237*** | - | - | - | - | - | - | - | - | - | 1 |
| India | 17.31886** | 24.05892*** | - | - | - | - | - | 19.78111*** | - | 19.48169*** | - | 3 |
| China | - | 82.19540*** | - | 15.84963*** | - | - | - | - | - | - | 34.70646*** | 3 |
| S.Africa | - | 22.47240*** | - | - | - | - | - | - | - | - | - | 1 |
| Total | 4 | | 1 | | 0 | | 1 | | 2 | | | 8 |
| May 2008 to July 2009 - SUBPRIME AND LEHMAN BROTHERS CRISIS | | | | | | | | | | | 15 Months | |
| Leading | Brazil ↓ | | Russia ↓ | | India ↓ | | China ↓ | | S. Africa ↓ | | Total | |
| Follower | L | S | L | S | L | S | L | S | L | S | | |
| Brazil | - | - | - | - | - | - | - | - | - | 5.140423* | - | 1 |
| Russia | - | 8.971141** | - | - | - | - | - | 6.109858** | - | - | - | 2 |
| India | - | 11.05739*** | - | 6.185956** | - | - | 19.49457** | 13.01904** | 20.04872*** | - | - | 4 |
| China | 20.23250*** | 6.795994* | - | 6.575766** | - | 16.81226*** | - | - | 30.33040*** | - | - | 4 |
| S.Africa | - | - | - | - | - | - | - | 7.534769* | - | - | - | 1 |
| Total | 3 | | 2 | | 1 | | 3 | | 3 | | | 12 |
| August 2009 to March 2011 - TRANQUIL PERIOD | | | | | | | | | | | 20 Months | |
| Leading | Brazil ↓ | | Russia ↓ | | India ↓ | | China ↓ | | S. Africa ↓ | | Total | |
| Follower | L | S | L | S | L | S | L | S | L | S | | |
| Brazil | - | - | - | - | - | - | 20.76682*** | - | - | - | - | 1 |
| Russia | - | 14.12754*** | - | - | - | - | - | - | - | - | - | 1 |
| India | - | 10.58508** | - | 11.07829** | - | - | - | - | - | - | - | 2 |
| China | - | 26.93599*** | - | - | - | - | - | - | - | - | - | 1 |
| S.Africa | - | 10.57669* | - | 17.87384*** | - | - | - | - | - | - | - | 2 |
| Total | 4 | | 2 | | 0 | | 1 | | 0 | | | 7 |
| April 2011 to October 2011 - EUROPEAN SOVEREIGN DEBT CRISIS | | | | | | | | | | | 7Months | |
| Leading | Brazil ↓ | | Russia ↓ | | India ↓ | | China ↓ | | S. Africa ↓ | | Total | |
| Follower | L | S | L | S | L | S | L | S | L | S | | |
| Brazil | - | - | - | - | - | - | - | - | 23.57002** | - | - | 1 |
| Russia | - | 13.02791*** | - | - | - | - | - | - | - | - | - | 1 |
| India | 19.62523** | - | - | - | - | - | - | 4.862423* | 15.79387** | - | - | 3 |
| China | 17.52990** | 8.602761** | - | 10.18745*** | - | - | - | - | - | - | - | 2 |
| S.Africa | - | - | 15.79805** | - | - | 6.371144* | 16.42875** | - | - | - | - | 3 |
| Total | 3 | | 2 | | 1 | | 2 | | 2 | | | 10 |

Notes: The table represents the long-run (L = long-term relation extract from the bivariate cointegration test). The values represented for the long-term are from Johansen cointegration statistic. Regarding the short-run (S = short-term relation detected applying the Granger causality test). The values presented is based on the Chi-square value statistic [χ^2]. [***] indicates rejection of the null hypothesis of no long-run or short-run relationship at 1% level; [**] at 5% level; [*] at 10% level. [#] represents the influence from one country to other countries. The number in bold identifies that both countries contribute to the contagion transmission process. Therefore, by applying Gonzalo-Granger statistic $\left[\frac{\alpha_2}{(\alpha_2 - \alpha_1)} \right]$, it is possible to establish which country makes the greatest contribution to the contagion transmission process. For instance, South Africa (in bold) contributes more to the contagion transmission than Brazil. Hence, South Africa plays a leading role in the contagion transmission. [-] indicates no significant connections among couple of countries from BRICS stock markets.

Appendix - C: Summary of the Results

The main results obtained in our research and summarized in Table C1, corroborate with the discovery of more short-run than long-run connections. Indeed, short connections are higher due to the nature of equity prices – shorter-term and more responsive, responding faster to shocks (Fourie and Botha, 2015). Therefore, in the short-run the domestic and global destabilizing factors cause varying levels of vulnerability in the BRICS stock market and price movements. These disturbances are temporary in nature since the variables revert to their equilibrating process to maintain the long-run co-movements. One adverse effect of such disparity is that it could possibly create arbitrage opportunities and short term speculative gains (Visalakshmi and Lakshmi, 2016). Another interesting feature regards Brazil. This country plays a major role in both crises as a leading country, serving as a channel of transmission and spreading the contagion effect to all other countries. Even in tranquil periods, its links are strong among the other BRICS countries. Another surprising finding pertains to South Africa, the smaller country among BRICS, but the only one connected with and capable of influencing Brazil in both contagion windows.⁵⁴

Table C1. Summary Results from Three-step Methodology in both Crises.

| Sbprime Lehman Brothers Bankruptcy Crisis <i>2008-05-01 - 2009-07-31: 15 Months</i> | European Sovereign Debt Crisis <i>2011-04-01 - 2011-10-31: 7 Months</i> |
|---|---|
| Contagion Evidence: The number of cross-market connections has largely increased between the tranquil and the turbulent pe-riod: there is evidence of a contagion process. | Contagion Evidence: The number of cross-market connections has largely increased between the tranquil and the turbulent pe-riod: there is evidence of a contagion process. |
| Direction of Contagion: Brazil, China and South Africa dominated the stock market, playing a leading role in the transmission mechanism. South Africa was able to lead two major countries, India and China. Nevertheless, China was connected and influenced by all other countries to-gether with India, whereas Brazil was just connected with South Africa. India and Russia are considered pure follower countries. | Direction of Contagion: Brazil plays a major role in the contagion transmis- sion, being able to influence all other countries fol- lowed by far by South Africa, playing a leading role in the transmission mechanism. China has lost its leading role in the shock transmission mechanism. India (as a pure follower country) and South Africa were the most influenced by other countries. |
| Contagion Process: Exposure to External Shocks: China was the most exposed country in the Lehman Crisis both in the short period and in the long pe-riod. In the case of South Africa, the results revealed that this country is strongly not exposed, neither in the short period nor in the long period, revealing a high degree of exogeneity to the system. India also presents a weak degree of exposure in the short pe-riod, but was affected in the long period. Brazil and Russia in contrast, show an increase in the degree of exposure in the short period but in the long period, they present a lower rate of vulnerability. | Contagion Process: Exposure to External Shocks: All countries are highly involved, becoming more ex- posed to the financial contagion. South Africa is the most exposed country in this crisis with the highest degree of fragility. Brazil, Russia and India, show al- most the same rise in the rate of involvement both in the short and long period, indicating a high degree of exposure to external markets and consequently, increasing domestic risk explained by innovations in foreign countries. Nevertheless, China seems to have the lower rate of vulnerability, comparing to the other BRICS countries. |

⁵⁴ South Africa has the most developed and opened financial market among BRICS countries with rapid financial market development and sophistication, being globally well recognized as a source possessing sophisticated professional services and financial expertise (see Liu et al. 2013; Zhang et al. 2013). This financial influence is capable of transmitting financial shocks in great degree and magnitude to the other BRICS countries (Bonga-Bonga 2015).