Interrelationships Between the Brazilian Financial Market and Foreign Financial Markets: New Evidence During and After the Subprime Crisis

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Abstract

This study analyzed the financial interrelations between Brazil and selected foreign economies (United States (US), Germany, United Kingdom (UK), Japan and China) during and after the Subprime crisis, using three financial market indicators: stock market index, exchange rate and interest rate. The Vector Autoregressive approach and the Granger causality test were used, with daily data. The periods considered were: i) period of crisis (03/14/2007 to 03/31/2010); and ii) post-crisis period (04/01/2010 to 12/30/2019). The results revealed that in the Subprime crisis, the interrelations were intense, especially in the stock and exchange markets. IBOVESPA and Brazilian exchange rate were predominantly affected by the US, German and UK equity markets. Evidence in the post-crisis period showed considerably lesser interrelationships between the Brazilian financial market and foreign financial markets. Thus, the results confirmed that the crisis significantly intensified interrelations, with the main contagion channels as the stock markets and the foreign exchange markets.

Keywords: interrelationships, Subprime crisis, financial market, contagion effect

JEL Classification: G17, C32, C58.

1. Introduction

Integration between international financial markets has been intensively studied, especially those of emerging economies. The removal of capital controls and trade barriers in emerging countries, particularly in the late 1980s and early 1990s, made these markets accessible to foreign investors, providing them with more investment opportunities (Lehkonen, 2015).

Higher levels of financial integration increase competition and reduce intermediation costs, contributing to more sustainable economic growth. A very important factor in this process was the increase in the globalization of investments, which allowed investors to obtain higher rates of return and risk diversification at an international level (Nasser & Hajilee, 2016).

Due to greater financial integration between countries, the debate on the subject was also intensified, especially in periods of occurrence of global economic crises. According to Billio et al. (2015), economic agents consider, for their investment decisions, the pattern of integration between economies. Fuinhas et al. (2014) highlight that to understand the interrelationships between markets, it is essential to analyze the behavior of correlations between asset prices in different countries and their domestic financial markets.

The investor who allocates capital in foreign markets seeks the benefit of diversification on an international level. Investors are able to reduce risk globally by adding foreign financial assets to their domestic portfolios. This benefit is maximized when there is low correlation between shares of foreign and domestic companies. Thus, the investor is able to reduce the total risk of the portfolio without reducing the expected return. However, in periods of crisis, international stock markets tend to show a high correlation (Donadelli & Paradiso, 2014).

In this context, several studies have evaluated the behavior of financial markets, especially in emerging countries, in the face of external shocks caused by crises in the 1990s (Note 1), such as the crises in Latin America (1994), Asia (1997), and Russia (1998). After the 1990s, studies on financial integration intensified, especially in the market crisis of Subprime mortgages in the United States (2008) (Note 2). For all these events, there are empirical studies that showed how the interrelationships between financial markets were impacted by shocks, through the contagion effect.

In general, crises start in some area of the financial market and, consequently, end up causing serious problems on the real side of the economy, affecting production, investments, company profitability, family income, among other aspects. The greater the initial magnitude of the crisis, the greater the impact on the level of economic activity in countries, which can reinforce new financial developments, creating a vicious circle that is difficult to overcome. In the case of the Subprime crisis, the financial turmoil had its origins in credit and derivatives problems related to the US housing market. According to Claessens, Tong, and Wei (2012), the Subprime crisis set in motion a global recession that had not been seen since the Great Depression of 1929.

Blanchard et al. (2010) highlighted as striking features of the crisis the speed and extent to which it spread around the world. When the problems intensified, first in the US and then in Europe, it was thought that emerging countries would not be affected by external shocks. This idea of dissociation soon turned out to be wrong. The authors emphasized that emerging economies were affected in two ways. The first was a severe drop in exports and their terms of trade, particularly in commodity-producing countries like Brazil. The second was the sharp drop in net capital flows. Economies that were more open to trade, had large foreign currency debts, that large short-term external debts or large current account deficits, or any combination of these factors, faced huge losses in their respective activity levels.

Since it belongs to BRICS, there is a greater motivation to study Brazil. According to Jin and An (2016), because BRICS are considered an important source of growth in the world economy, their stock markets become very promising for regional and global portfolio diversification. Thus, among emerging markets, Brazil is one of the main destinations of international capital, being the object of study in several works. As the Subprime crisis is considered the worst financial crisis since 1929, most of the related studies focused on that period. Internationally, several works in the area were conducted, including: Yunus (2013); Zhang, Li, and Yu (2013); Mensi et al. (2014); and Fuinhas et al. (2014). All of these verified that there was an intensification in the interrelations between national financial markets during the Subprime crisis. Literature indicates that the Brazilian stock market is highly integrated with foreign equity markets, especially in the US.

Although there is ample evidence that the interrelationships between stock markets intensify during crises, especially in the Subprime crisis, in the case of Brazil, studies focused on the interrelationship via the stock market. According to Khalid and Kawai (2003), in addition to direct contagion via the stock market, financial contagion can also occur through the foreign exchange market (exchange rate) and the government bond market (interest rate). Thus, the first contribution of this work is to investigate the contagion channels that most affected the Brazilian stock market during the Subprime crisis. For this purpose, three financial indicators (stock market price index, exchange rate and interest rate) were used to analyze the interrelationships between the Brazilian financial market and the financial markets of the USA, Germany, Japan, the UK and China. Therefore, a second contribution of this study was to investigate the nature of these relationships between indicators for a broader set of countries, compared to most studies that limited their analysis to the US. Furthermore, as a third contribution, there is the comparison of results between two periods: i) period considered as the Subprime crisis (03/14/2007 to 03/31/2010); and ii) the post-crisis period (04/01/2010 to 12/30/2019). This allowed for a more robust counterfactual comparison.

This article was structured as follows: in addition to this introduction, section 2 brings the literature review; section 3 presents the Vector Autoregressive (VAR) model and the data; the results and discussions are shown in section 4; and, finally, the final considerations are described in section 5.

2. Literature Review

Volosovych (2011) studied the evolution of financial market integration from the sovereign bond markets of 15 industrialized economies (Austria, Belgium, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom and United States), between the years 1875 and 2009. Data on the returns of long-term sovereign bonds of countries were used at monthly frequency. The econometric method was based on dynamic Principal Component Analysis (PCA). The results demonstrate that financial integration among these countries followed a J-shaped trend, with the beginning of the fund in the early 1920s. The period of least financial integration (the lowest point of the "J") during 134 years was at the time of World

War II. From then onwards, there was an almost constant rise in integration until 2009. It was also found that the integration of financial markets, from the end of the 20th century to the beginning of the 21st century, was the largest ever observed.

In turn, Perobelli, Vidal, and Securato (2013) found evidence of contagion effect among fifteen countries, in eight periods of financial crisis, with the American Subprime crisis being the last of these periods. The methods used by the authors were the Principal Component Analysis (PCA) and the Factor Analysis (FA) technique. Daily data from the stock exchanges of each country in the sample were used, in the period of each world financial crisis, being the period used for the crisis from 07/26/2007 to 03/17/2009. The results revealed that Brazil, USA, France and Japan were the most affected countries, being impacted in all periods studied. In addition, during the Subprime crisis, Brazil was the country with the greatest indication of financial contagion.

Yunus (2013) used the Recursive Cointegration technique to analyze the dynamic interdependence between ten large stock markets in North America, Europe, Latin America and Asia. With daily frequency data, the analysis covered the period between January 1993 and December 2008. The results indicated that international equity markets were integrated and that the degree of integration between these markets increased over time. The study found that the US, Japan, India, China, the UK and Germany led the other markets, with the US being the strongest contributor to the common trend.

Zhang, Li, and Yu (2013) investigated whether the Subprime financial crisis would have permanently changed the correlations between the BRICS and the US and European stock markets. The method used was the Dynamic Conditional Correlations (DCC) model. The sample consisted of the main stock market indices of these countries, in daily frequency, from January 2000 to March 2012, with S&P 500 representing the US and MSCI Europe as a proxy for Europe. The analysis showed that before the crisis (2000-2007), return correlations were relatively low. However, since the beginning of the crisis (2008-2012), return correlations have increased considerably, with Brazil and the US having the highest correlation during the crisis. The study concluded that there was a permanent change in the correlations between the stock markets of BRICS, the USA and Europe, with a loss of benefits from the post-crisis international diversification.

Similarly, Donadelli and Paradiso (2014) investigated the dynamics of the financial integration process in the stock markets of 18 emerging countries from January 1994 to July 2012. The sample of emerging countries was divided into a large set with all countries (Global) and into three subsets according to the region of each country (Asia, Eastern Europe and Latin America). In addition to studying the financial integration of national markets, stock indices from ten sectors were used for each country (basic materials, consumer goods, consumer services, finance, industries, health, oil and gas, telecommunications, technology, utilities). Using monthly frequency data, a dynamic analysis was performed using the PCA method. The results showed that the average level of integration of the global set was lower than in the analyzed subsets. However, the stock indices of countries in the same subset did not show identical dynamics; the contagion effect arising from the financial crises did not affect national and sector stock indices in a homogeneous way. Overall, the results show that the level of integration in equity markets in emerging regions is low, both nationally and sectorally, highlighting the benefits of diversification across countries and sectors that can be exploited by investors.

In turn, Mensi et al. (2014), using a Quantile Regression (QR) approach, examined the dependency structure between the emerging stock markets of BRICS countries and some influential global factors. These global factors cover the daily period from September 29, 1997, to September 20, 2013, and are S&P 500; the price of WTI crude oil (West Texas Intermediate) in dollars; the price of gold in dollars; the implied volatility of S&P 500 represented by the VIX index (Volatility Index); and the US economic policy uncertainty index. The main results for the Brazilian stock market showed that the dependence between Brazil and the USA increased during the bull market and decreased in the bear market. In addition, volatility had a negative and significant impact on the Brazilian stock market throughout the period.

Fuinhas et al. (2014) analyzed how greater integration in world financial markets affects the behavior of international capital flows and investor returns. The authors used the Auto Regressive Vector (VAR) and Vector Error Correction (VEC) models, using daily quotations from January 1994 to November 2013, for S&P 500, FTSE100, PSI20, HSI, and IBOVESPA indices. The results rejected the existence of a long-term relationship between the indices in the period studied but confirmed that international diversification brought greater profitability as a benefit. Regarding IBOVESPA, the results showed that the Brazilian stock exchange suffered contagion from all other indices during the study period, mainly from S&P 500.

Dungey and Gajurel (2014) tested for the existence of equity market contagion originating from the USA to advanced and emerging markets during the Subprime crisis. The latent factor model was used as methodology.

The results showed a strong evidence of contagion effects in both advanced and emerging markets. More specifically, in the aggregate equity market indices, contagion from the USA explained a large portion of the variance in stock returns for both groups of countries. In the case of financial sector indices, there was less evidence of contagion than for aggregated indices, especially regarding developed countries. Finally, the results indicated that contagion effects were not strongly related to high levels of global integration.

Nasser and Hajilee (2016) examined equity market integration between five selected emerging markets (Brazil, China, Mexico, Russia and Turkey) and developed markets (US, UK and Germany). The authors used the cointegration approach (VEC) with monthly data from January 2001 to December 2014 to determine the short- and long-term relationship between emerging equity markets and developed equity market returns. The results showed that, in the short term, all stock exchanges in emerging countries were integrated with developed markets. The long-term coefficients for stock market return in all emerging countries showed a significant relationship only with German stock market returns.

The research of Alotaibi and Mishra (2017) aimed to develop an international financial integration index for GCC stock markets. For this, the authors adopet an international asset pricing model of time-varying market integration and DCC-GARCH methodology. The results revealed that trade openness, financial market development, turnover and oil revenue had significant positive impact on integration index of GCC stock markets. Furthermore, the global financial crisis negatively affected the integration index.

Mroua and Trabelsi (2020) investigated the causality and the dynamic links between US dollar and major stock market indices of Brazil, Russia, India, China and South-Africa (BRICS) nations. As methodology, the authors combining the panel generalized method of moments model and the panel auto-regressive distributed lag (ARDL) method. The estimates demonstrated that that exchange rate changes had a significant effect on the past and the current volatility of the BRICS stock indices. Besides, ARDL estimations showed that exchange rate movements presented a significant effect on short- and long-term stocks market indices of all BRICS countries.

3. Methodology and Data

3.1 Autoregressive Vectors (VAR)

VAR model was the main methodology used in this study, in order to obtain the temporal causality relationship between the variables. According to Bueno (2011), VAR is used to analyze the dynamic impact of random perturbations on the variable system. Equation (1) presents a VAR model of order p with a vector of n endogenous variables, X_t and these are linked through a matrix A, in the following way:

$$AX_t = B_0 + \sum_{i=1}^{p} B_i X_{t-i} + B\varepsilon_t \tag{1}$$

where X_t is a vector with n endogenous variables; A an $n \times n$ matrix that defines the contemporary constraints between the variables that make up the $n \times 1$ vector X_t; B_0 a vector of constants n x l; B_i, $n \times n$ matrices; B an $n \times n$ diagonal matrix of standard deviations; and ε_t, an $n \times 1$ vector of random disturbances not correlated with each other contemporarily or temporally, that is:

$$\varepsilon_t \sim i.i.d(0; I_n) \tag{2}$$

in which 0 is the null vector; and I, the identityatrix.

According to Bueno (2011), Equation (1) is called a structural form, as it expresses the relationships between endogenous variables, according to a structured theoretical economic model. Due to the endogeneity of the variables, VAR, instead of being estimated in its structural form, is usually estimated in its reduced form. The reduced form can be expressed as follows:

$$X_t = A^{-1}B_0 + \sum_{i=1}^{p} A^{-1}B_i \, X_{t-i} + A^{-1}B\varepsilon_t = \phi_0 + \sum_{i=1}^{p} \phi_i X_{t-i} + e_t \tag{3}$$

where: $\phi_i = A^{-1}B_i, i = 0,1,2,\dots,p$; and $B\varepsilon_t \equiv Ae_t$.

According to Tsay (2013), the VAR methodology can be estimated using the Ordinary Least Squares (OLS), maximum likelihood (ML) or Bayesian methods. It is noteworthy that, for a VAR model, OLS estimates are asymptotically corresponding to the ML estimates and are the same as the generalized least squares (GLS) estimates. Thus, many inferences used in multivariate multiple linear regressions apply to VAR. Regarding the econometric analysis, VAR has as main advantages the possibility of estimating the impulse-response functions (IRF) and variance decomposition (VD) of the forecast error.

Before estimating the model, it is important to determine the order (p) of VAR. There are some ways to select the number of lags, such as the Likelihood Ratio (LR), the Final Forecast Error (FPE), the Akaike Criterion (AIC), the Schwarz Criterion (SC), and the Hannan-Quinn Criterion (HQ). In this study, in addition to these criteria,

formal and informal methods of verification of temporal correlation were used (for example, Lagrange Multiplier test and correlograms), allowing the choice of a sufficient number of lags to ensure that the residues are noise whites.

The focus of the estimation of VAR in the study is to identify any temporal causality relationship between the different financial markets of the countries that make up the sample. In this case, the interest is to verify how changes in stock indices, exchange rate and interest rate of economies outside Brazil affected the Brazilian financial market. This was done using the Granger causality test (Granger, 1969). The causality between series occurs when past or present values of a stationary variable are able to predict future values of another variable. It is noteworthy that the Granger causality test can be performed in models with more than two variables, being known as the Granger causality test/Exogeneity block. The logic is the same as for the bivariate example; the model with and without restriction is estimated and the F test is used (Bueno, 2011).

According to Lütkepohl (2007), Granger causality may not show the complete history of interactions between variables in a system, it is often necessary to know the response of a variable to an impulse in another variable in a system that involves several variables. Thus, the impulse-response function was used to estimate the trajectory of a series given a structural shock. Here, a shock to one variable directly affects another variable and is also transmitted to all endogenous variables through the dynamic structure of VAR. Thus, the intensity with which the Brazilian financial market reacted to shocks in external financial markets was identified.

In general, dynamic analysis done with VAR models is employed with orthogonal impulse response functions (based on the Cholesky ordering method). According to Sims (1980), the Cholesky decomposition is widely used in the literature, as the errors are orthogonal so that the impulse response covariance matrix is diagonal. However, impulse-response functions are very sensitive to the ordering of variables in the model, which makes defining the ordering of variables extremely important.

In addition to the Cholesky ordering method, which uses the "orthogonality hypothesis", there is another method, called generalized, which does not vary if there is a reordering of the variables in VAR (Lütkepohl, 2007; Koop, Pesaran, & Potter, 1996; Pesaran & Shin, 1998). According to Edwing (2003), the generalized method has two main advantages: a) the results of the generalized impulse-response function are more robust than the orthogonalized method; and, b) since orthogonality is not imposed, the generalized impulse-response function allows for a more accurate interpretation of the response of the initial effect to a shock caused by a variable on the other variables considered in the estimated model. However, generalized method also has disadvantages, as detailed, for example, by Kim (2013).

3.2 Data

As previously described, this paper analyzes, during and after the Subprime crisis, the interrelationships between the Brazilian financial market and the following external financial markets: the United States (US), Germany, the United Kingdom (UK), Japan and China. The interrelationships were estimated using, for each country, three important financial market indicators (stock market index, exchange rate and interest rate), with daily data. It is noteworthy that only the observations of the dates in which simultaneous observations occur between the data series were considered. According to Hamao, Masulis, and Ng (1990), discarding unsynchronized stock exchange closing data does not compromise the accuracy of the empirical results.

Many studies, such as those described in this paper, have examined whether the interrelationships between markets increased significantly during the crisis (period of turbulence) compared to periods before or after the crisis (period without turbulence). If the interrelationships increase significantly during the crisis period, in relation to the pre- or post-crisis period, the evidence indicates the occurrence of the contagion effect. In this sense, in addition to the Subprime crisis period, a post-crisis period (without economic turmoil) was used to compare the results and verify whether the difference between the estimates confirms the contagion event in the Brazilian financial market during the crisis.

Although the crisis was global in magnitude and the consequences reached almost every country in the world, the timing at which the negative consequences are observed in each country can vary. To avoid doubts regarding the definition of the crisis period, it is worth emphasizing that the concern of this study was to analyze the occurrence of contagion from foreign economies to the Brazilian financial market. In other words, how the negative effects of the crisis on the financial market of global economies impacted the Brazilian financial market (in terms of stock market index, exchange rate and interest rate). Thus, the definition of the crisis period considered the initial moment in the US and the persistence of negative repercussions on external economies.

There is no consensus on the exact start date of the Subprime crisis. However, according to Longstaff (2010), it

can be divided into two phases. The first started in the first quarter of 2007, when investors and financial institutions (e.g., New Century Financial Corporation, Bear Stearns, Merrill Lynch, Fannie Mae and Freddie Mac) holding assets linked to Subprime credit suffered huge losses. The second began in 2008, when the financial crisis severely impacted the global economy. This phase was defined by a massive deleveraging of the global economy that made major financial institutions close their doors or close to bankruptcy. The bankruptcy declaration of the Lehman Brothers bank in 2008 is arguably the most remarkable event of that time and, after that, came the negative effects of the crisis lasting until the first quarter of 2010 (Kao et al., 2019).

Among the financial institutions that posted big losses at the start of the Subprime crisis, New Century Financial Corporation was the first to file for bankruptcy on April 2, 2007. However, trading in the company's shares ended on March 13, 2007. Thus, it was established that the crisis started after this episode. From then on, the crisis unfolded and generated consequences that lasted until the first quarter of 2010. Therefore, March 31, 2010, was defined as the end of the crisis. Thus, for the period of the Subprime crisis, the period from March 14, 2007, to March 31, 2010, was considered, which totaled 538 observations for each variable. For the post-crisis period, the period from April 1st, 2010, to 30 December 2019 was taken, covering a total of 2012 observations for each variable.

The variables used in this study are described in Table 1. Data were collected from investing.com (Note 3), Federal Reserve (Note 4), Chinese Central Bank (Note 5) and English Central Bank (Note 6). Daily frequency interest rates were the hardest to find. Thus, in order to use a common interest rate for all countries, some interest rate variables were obtained through the website of the Central Bank of the respective country.

Table 1. Variables, unit, acronym and sources

Variable	Units	Acronym	Source
S ão Paulo Stock Exchange Index	Index	IBOV	Investing.com
S&P 500 Index	Index	SP	Investing.com
SSEC Index	Index	SSEC	Investing.com
Nikkei Index 225	Index	N225	Investing.com
DAX Index	Index	DAX	Investing.com
FTSE 100 Index	Index	FTSE	Investing.com
Brazil exchange rate	US$/BRL	REAL	Investing.com
US exchange rate	€/US$	DOL	Investing.com
China exchange rate	US$/¥	YUAN	Investing.com
Japan exchange rate	US$/¥	YEN	Investing.com
Germany exchange rate	US$/€	EURO	Investing.com
UK exchange rate	US$/£	LIB	Investing.com
Yield on the Brazilian bond maturing in 6 and 12 months	Interest rate (% per year)	IBR	Investing.com
US bond yield maturing in 6 and 12 months	Interest rate (% per year)	IEUA	Federal Reserve
Yield on Chinese bonds maturing in 6 and 12 months	Interest rate (% per year)	ICH	Chinese Central Bank
Yield on Japanese bonds maturing in 6 and 12 months	Interest rate (% per year)	IJAP	Investing.com
German bond yield maturing in 6 and 12 months	Interest rate (% per year)	IALE	Investing.com
Yield on English bond maturing in 6 and 12 months	Interest rate (% per year)	IRU	English Central Bank

Source: the authors.

Brazil's stock market was portrayed by the São Paulo Stock Exchange Index (IBOVESPA). The American stock market was represented by the S&P 500 index. The Chinese stock market was symbolized by the SSEC index. The Japanese stock market was represented by the Nikkei 225 (N225) index. The DAX index was used for Germany. For the UK stock market, the FTSE 100 index was used. For all indices, the closing value of each day was used.

The exchange rate of each country was quoted in national currency, that is, the dollar was applied in relation to each country's currency. In the case of the USA, for exchange rate we used the euro in relation to the dollar. The euro was chosen because it is among the six strongest currencies in the world and is official currency of several countries. Exchange rates were expressed as the average of the closing value for the purchase and sale of commercial exchange.

As a proxy for the interest rate of each country, the interest rate (in % per year) that the government bond issued by the government of each country was yielding on the day of purchase was used. According to the availability

of data for the two periods, the option was for bonds with 6 months of maturity during the crisis period and for bonds with 12 months of maturity in the post-crisis period.

4. Results and Discussions

4.1 Subprime Crisis Period Analysis

The econometric procedures were performed with the variables expressed in natural logarithms. After applying the natural logarithm, the first difference was applied to obtain the returns and variations of the variables. Before performing the VAR model estimations, Table 2 shows the cross-correlation between stock price indices, exchange rates and interest rates between different countries. According to Chiang, Leon, and Li (2007), international systemic financial crises have two specific phases: i) the first phase is characterized by a relevant increase in the degree of movements between international stock market returns during the crisis (contagion effect); and ii) the second is based on the high correlation between asset returns observed after the shock (herd effect).

Table 2. Correlation matrix of the external financial markets with Brazil (Subprime crisis)

	DLIBOV	DLSP	DLSSEC	DLDAX	DLN225	DLFTSE	DLREAL	DLLIB	DLEURO	DLIENE	DLYUAN	DLDOL	DLIBR	DLIJAP	DLIEUA	DLIRU	DLICH
DLIALE	0.2	0.18	0.05	0.23	0.19	0.21	-0.2	-0.11	-0.23	0.07	-0.05	0.23	0.1	0.06	0.17	0.27	0.01
DLICH	0.04	0.02	-0.01	0.08	0.06	0.06	-0.06	-0.1	-0.04	-0.02	0.02	0.04	0.03	0.05	0.07	0.08	
DLIRU	0.22	0.16	0.04	0.21	0.17	0.19	-0.28	-0.25	0.02	0.2	-0.01	-0.02	0.05	0.07	0.25		
DLIEUA	0.23	0.29	0.04	0.32	0.21	0.34	-0.25	-0.16	-0.07	0.38	0.07	0.07	0.06	0.04			
DLIJAP	-0.02	0	0.07	0.01	-0.03	-0.03	0.04	0	0.05	0.02	0	-0.05	0.02				
DLIBR	-0.12	-0.1	-0.04	-0.07	-0.1	-0.06	0.07	0.1	0.08	-0.11	0	-0.08					
DLDOL	0.42	0.4	0.11	0.33	0.21	0.3	-0.47	-0.66	-1	-0.03	-0.16						
DLYUAN	-0.09	-0.05	0.05	-0.04	0	-0.07	0.08	0.08	0.16	0.01							
DLIENE	0.45	0.52	0.04	0.45	0.28	0.4	-0.33	-0.15	0.03								
DLEURO	-0.42	-0.4	-0.11	-0.32	-0.21	-0.3	0.47	0.66									
DLLIB	-0.45	-0.42	-0.15	-0.37	-0.32	-0.31	0.47										
DLREAL	-0.69	-0.65	-0.11	-0.55	-0.29	-0.56											
DLFTSE	0.72	0.67	0.26	0.88	0.55												
DLN225	0.43	0.31	0.26	0.53													
DLDAX	0.71	0.73	0.17														
DLSSEC	0.18	0.08															
DLSP	0.82																

Caption: + / 1

Source: the authors based on the present research data.

According to Zhang, Li, and Yu (2013), before the Subprime crisis, correlations between returns were relatively low. However, in this crisis, correlations between returns intensified significantly. In Table 3, it is observed that IBOV (DLIBOV) showed a high correlation with other stock markets, specifically the US, UK and Germany. The highest correlations of the Brazilian exchange rate were with DLIBOV and DLSP. The Brazilian interest rate did not show relevant correlations with other variables.

Then, the Granger/Block exogeneity causality test was performed. At first, the causality for each market indicator was investigated, that is, a VAR for stock indices, another for exchange rates and another one for interest rates. Based on the Likelihood Ratio (LR), Final Prediction Error (FPE), Akaike Criterion (AIC), Schwarz Criterion (SC), Hannan-Quinn Criterion (HQ) criteria and temporal correlation tests, the three models were estimated with five lags. Table 3 presents the result between each market during the Subprime crisis. It is observed that, during the crisis, the US and Japanese stock markets caused towards Granger the Brazilian stock market.

Regarding exchange rates, it is noted that the Brazilian exchange rate was influenced by all other exchange rates, except for the Chinese one. According to McCauley and McGuide (2008), the fear and panic that gripped

financial markets during the crisis led foreign investors to look for safer assets. As investors simultaneously rushed to the dollar and other currencies of developed countries, there was an offloading of shares in several emerging markets, resulting in the widening of the distance between the currencies of these countries and the "safe" currencies of the developed countries.

Table 3. Granger causality/Exogeneity block among financial markets (Subprime crisis)

			Dependent variable		
H$_0$: Does not cause	DLIBOV	H$_0$: Does not cause	DLREAL	H$_0$: Does not cause	DLIBR
DLSP	13.8585**	DLDOL	54.3461***	DLIEUA	4.3427
DLDAX	5.7714	DLEURO	54.4399***	DLIALE	10.2198*
DLFTSE	2.5619	DLLIB	22.4734**	DLIRU	3.2188
DLN225	9.6298*	DLIENE	23.9555**	DLIJAP	3.5306
DLSSEC	4.4008	DLYUAN	6.8132	DLICH	5.3577
Todos	62.6466***	Todos	146.419***	Todos	32.4909

Source: the authors based on the present research data.

Note. *** Significant at 1%, ** Significant at 5%, * Significant at 10%; "All" indicates the causality test for the set of all independent variables.

To get a complete picture, a VAR was estimated to analyze causality across all countries and markets during the crisis. VAR was conducted with 18 variables and 5 lags, with each dependent variable equation (e.g., DLIBOV) having 18 variables on the right side, including its own lags and lags from the other 17 variables, plus a constant. It is noteworthy that the development of the model was based on information criteria (LR, FPE, AIC, SC and HQ), LM test (done with 5 lags), correlograms and the parsimony criterion. As 13 lags are needed to eliminate the model's autocorrelation and cross-correlation, many degrees of freedom are lost, and the variable responses end up losing economic sense. Thus, the model was estimated with 5 lags, to avoid this problem and prioritize parsimony. A summary of results for all markets and countries is presented in Table 4.

Table 4. Granger Causality Results/Exogeneity Block Summarized (Subprime crisis)

	H$_1$: Cause		
Effect	Stock markets	Exchange rates	Interest rates
DLIBOV	DLSP	DLREAL, DLDOL, DLEURO, DLIENE	*DLIBR*, DLIEUA
DLSP	*DLSSEC*	DLREAL, DLDOL, DLEURO, *DLLIB*, DLIENE, *DLYUAN*	DLIBR
DLDAX	DLSP, DLFTSE	DLDOL, DLEURO, DLLIB, DLIENE	
DLFTSE	DLSP	DLDOL, DLEURO, *DLLIB*, DLIENE	
DLN225	DLSP, DLDAX	DLDOL, DLEURO, *DLLIB*, DLIENE	
DLSSEC		DLIENE	DLIBR
DLREAL	DLSP, DLFTSE	DLDOL, DLEURO, DLLIB, DLIENE	*DLIBR, DLICH*
DLDOL		DLREAL, DLIENE	DLICH
DLEURO		DLREAL, DLIENE	DLICH
DLLIB	DLSP, DLDAX, DLFTSE, DLN225	DLREAL, *DLDOL*, DLIENE	*DLIEUA, DLICH*
DLIENE	DLSP, *DLDAX*, DLFTSE	*DLREAL, DLLIB*	
DLYUAN		DLDOL, DLEURO	
DLIBR	*DLDAX*	*DLREAL*, DLYUAN	*DLIALE*
DLIEUA	*DLSP, DLDAX*, DLFTSE	DLREAL, DLIENE	DLIALE,
DLIALE	*DLN225*		DLIBR, *DLIJAP*
DLIRU	*DLFTSE*	DLREAL, DLIENE	DLIEUA, DLICH
DLIJAP	*DLDAX*		
DLICH	DLSP, DLSSEC	DLYUAN	DLIALE

Source: the authors based on the present research data.

Note. at least 5% significance, based on chi-square statistics. Italic represents statistical significance at only 10%. Bold indicates that the causality test for the set of all independent variables was not statistically significant.

Results show that the Brazilian financial market had significant temporal correlations with foreign economies, especially for exchange rates. Evidence suggests that, among equity markets, the DLSP was the major cause of turmoil in the Brazilian stock market. The US (DLSP) and UK (DLFTSE) stock markets showed influence on

the Brazilian exchange rate. The Brazilian stock market (DLIBOV) was influenced by DLREAL, DLDOL, DLEURO and DLIENE, while all exchange rates, except the Chinese one, influenced the Brazilian exchange rate (DLREAL), indicating that during the crisis there was an intensification of the interrelationships between these economies through the exchange markets. The Granger causality test for the Brazilian interest rate did not show statistical significance for the set of variables.

Then, impulse response functions during the crisis were analyzed. With the complete model, a shock of 01 standard deviation was introduced in each variable of foreign economies and then the impacts on the Brazilian financial market (DLIBOV, DLREAL and DLIBR) were analyzed. Figure 1 shows how a shock originated in the stock market of foreign economies during the Subprime crisis affected the Brazilian financial market. The results show that IBOVESPA (DLIBOV) was impacted by all stock markets in the first period after a shock of 01 standard deviation, mainly by DLSP, DLFTSE and DLDAX. The same happened with the Brazilian exchange rate. However, responding negatively to a positive shock from external stock markets. It is observed that, on the second day and on the following days, the trend was towards stability, that is, the effects of foreign stock markets on DLIBOV and DLREAL were quickly dissipated, signaling the rapid absorption of information in these markets. In addition, shocks to DLSP, DLDAX, DLFTSE, DLN225 and DLSSEC generated small and insignificant variations in the interest rate of Brazilian government bonds.
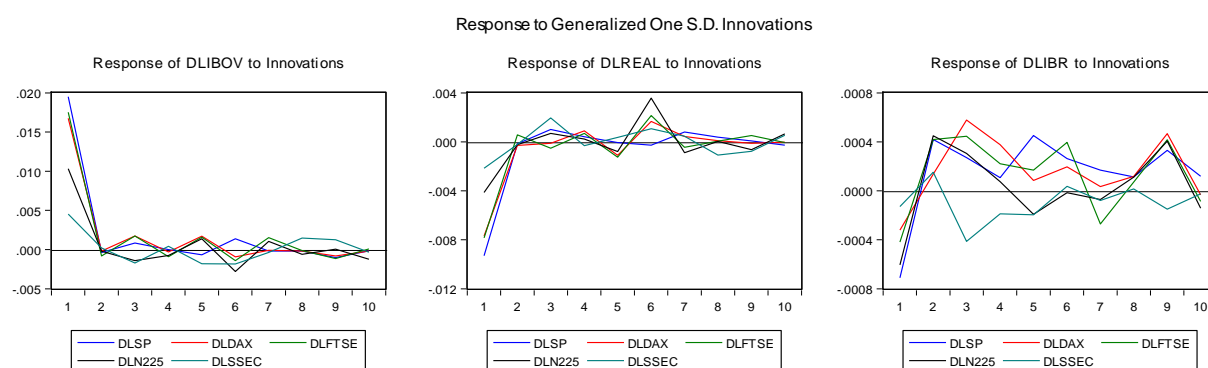

Figure 1. IBOVESPA (DLIBOV), exchange rate (DLREAL) and interest rate (DLIBR) responses to the stock markets of foreign economies (Subprime crisis)

Source: the authors based on the present research data.

Figure 2 shows the impact of shocks originating in the exchange rates of external economies (DLDOL, DLEURO, DLLIB, DLIENE and DLYUAN). The results suggest that shocks in the exchange markets of these economies, with the exception of the Chinese one, significantly affected IBOVESPA (DLIBOV) and the Brazilian exchange rate (DLREAL). Much of the impact on these variables occurred on the first day of the shock, corroborating the rapid absorption of information in capital markets. Brazil's interest rate proved to be little affected by foreign exchange markets. The responses were on a very small scale compared to DLIBOV and DLREAL and were not statistically significant.
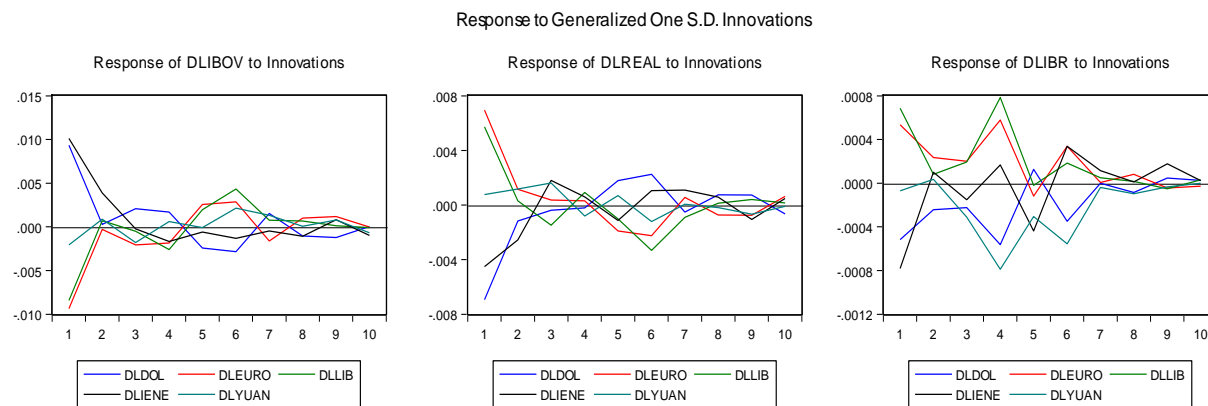

Figure 2. IBOVESPA (DLIBOV), exchange rate (DLREAL) and interest rate (DLIBR) responses to the exchange rates of foreign economies (Subprime crisis)

Source: the authors based on the present research data.

Figure 3 shows the responses of the Brazilian financial market to interest rate shocks in external economies during the Subprime crisis. The results show that IBOVESPA (DLIBOV) was positively impacted by the interest rates in Germany (DLIALE), the USA (DLIEU) and the UK (DLIRU). The Brazilian exchange rate also showed sensitivity to DLIEUA, DLIALE and DLIRU. The Brazilian interest rate responded minimally to DIALE and DLIEUA. There was no statistical significance in the response of the other variables.

These results signal the massive intervention of Central Banks in the financial system to try to counterbalance the negative effects of the crisis on the real economy. At the epicenter of the crisis, the Central Banks, mainly the Fed, ended up acting as investors and lenders of last resort, creating special programs to provide liquidity for financial institutions, buy back assets and refinance debt. According to Claessens et al. (2010), the main forms of intervention by Central Banks during the crisis were: (i) provision of liquidity through loan guarantees and others; (ii) support to short-term wholesale financing markets; (iii) retail deposit guarantees and other liabilities; (iv) purchases or exchanges of non-productive or illiquid assets; and (v) capital injections into banks.
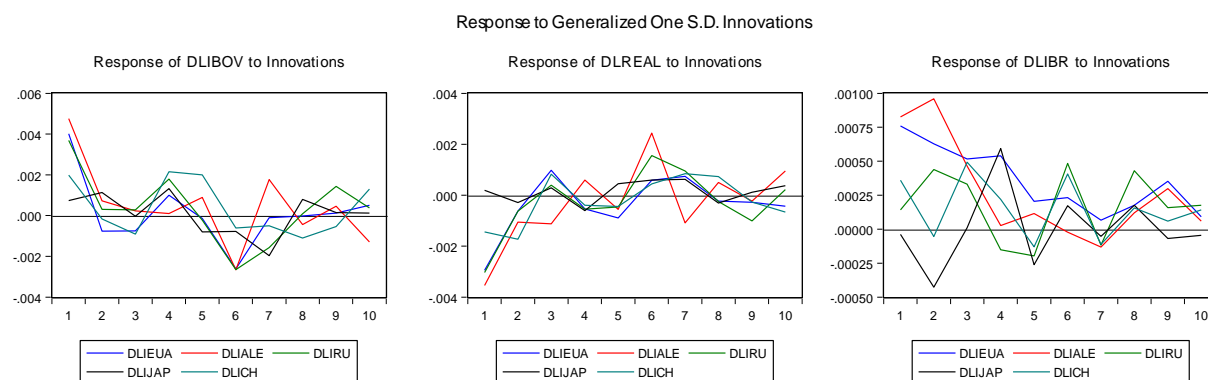

Figure 3. IBOVESPA (DLIBOV), exchange rate (DLREAL) and interest rate (DLIBR) responses to interest rates of foreign economies (Subprime crisis)

Source: the authors based on the present research data.

In general, among foreign economies, the USA, the source of the Subprime crisis, was the one that most impacted Brazil during the crisis. This evidence is in line with the results of Horvath and Paldalf (2012), Perobelli, Vidal, and Securato (2013), Yunus (2013), Zhang, Li, and Yu (2013), Fuinhas et al. (2014) and Nasser and Hajilee (2016). All these studies indicated a strong integration between the US and Brazilian stock markets during the crisis. The effects of shocks in these countries on the IBOVESPA (DLIBOV) and the exchange rate (DLREAL) were greater and dissipated more quickly compared to the interest rate (DLIBR), demonstrating a greater capacity for assimilation and pricing of information by those countries. markets.

4.2 Post-Crisis Period Analysis

In this case, the estimates considered the variables in natural logarithms, with the exception of interest rates in Germany (IALE) and Japan (IJAP). In this period, the public bonds of these two countries presented negative interest rates. As there was no change in the results using these variables in natural logarithm, by adding a constant that made these series positive, we decided to keep them in their original form. After that, the first difference was applied to obtain the returns and variations of the variables.

Table 5 demonstrates the cross-correlation between the variables. The level of correlation between the variables, in general, was significantly lower when compared to the crisis period. Thus, as in Benelli and Ganguly (2008), the first evidence indicates that the behavior of markets in the period of turmoil, in general, was different from that observed in the "calm" period, without turbulence (post-crisis). Among the equity markets, the DLFTSE and DLDAX were the only ones that maintained a higher correlation. IBOVESPA, even if to a lesser extent, remained more correlated with the American stock market. Brazil's exchange rate remained more correlated with the IBOVESPA, while the interest rate was more correlated with the exchange rate (DLREAL). In general, the foreign and Brazilian financial markets did not show correlations as high as those observed in the crisis. This indicates that the interrelationships between these economies intensified punctually during the crisis period.

Table 5. Correlation matrix of foreign financial markets with Brazil (post-Subprime crisis)

	DLIBOV	DLSP	DLSSEC	DLDAX	DLN225	DLFTSE	DLREAL	DLLIB	DLEURO	DLIENE	DLYUAN	DLDOL	DLIBR	IJAP	DLIEUA	DLIRU	DLICH
IALE	0.11	0.19	0.04	0.19	0.12	0.16	-0.11	-0.15	-0.2	0.09	-0.05	0.2	0.05	-0.01	0.06	0.12	0
DLICH	-0.02	-0.02	-0.01	0	-0.06	-0.02	0.01	-0.02	0.02	0	0.04	-0.02	0.03	0.01	0.04	0.01	
DLIRU	0.09	0.12	0.02	0.15	0.05	0.1	-0.01	-0.1	-0.03	0.18	-0.03	0.03	0.03	0.01	0.1		
DLIEUA	0.04	0.1	0.02	0.14	0.05	0.14	0	0.06	0.08	0.24	0.01	-0.08	-0.01	-0.03			
IJAP	0	0.02	-0.02	0.03	0	0.04	0	-0.01	-0.06	-0.02	-0.01	0.06	-0.01				
DLIBR	-0.12	0.01	0.01	0.03	0	0	0.16	-0.03	-0.01	0.01	-0.01	0.01					
DLDOL	0.21	0.25	0	0.07	-0.01	0.1	-0.33	-0.58	-1	-0.24	-0.17						
DLYUAN	-0.11	-0.1	-0.12	-0.1	-0.05	-0.13	0.11	0.19	0.17	0.07							
DLIENE	0.1	0.29	0.11	0.29	0.4	0.27	0.03	0.12	0.25								
DLEURO	-0.21	-0.25	0	-0.07	0.01	-0.1	0.33	0.24									
DLLIB	-0.21	-0.26	-0.01	-0.18	-0.08	-0.03	0.24										
DLREAL	-0.49	-0.43	-0.1	-0.25	-0.07	-0.28											
DLFTSE	0.43	0.61	0.23	0.81	0.36												
DLN225	0.15	0.24	0.28	0.35													
DLDAX	0.39	0.63	0.18														
DLSSEC	0.16	0.15															
DLSP	0.54																

Caption: +1

Source: the authors based on the present research data.

The results for the post-crisis period do not indicate the occurrence of a shock that would cause a significant increase in the interrelations between the markets (contagion effect), nor a high correlation between the markets (herd effect). According to Forbes (2012), contagion can take many forms and most channels of contagion result from an interdependence between countries in good times and bad, and during a period of turmoil, the integration (relationship) of markets tends to be strengthened. In this sense, perhaps there might even have been an increase in Brazil's interdependence with the US after the Subprime crisis, as pointed out by Zhang, Li, and Yu (2013), but the indication of contagion only occurred during the crisis period.

For this period, the causality for each market indicator was also verified, through a VAR for each type of market. Based on the information criteria (LR, FPE, AIC, SC and HQ) and on the temporal correlation tests, the following lag numbers were used for VAR: one for the stock indices; four for exchange rates; and four for interest rates. Table 6 presents the result of the Granger causality/Block exogeneity test of between financial markets for Brazil. The results reveal that, in the post-crisis, the stock market in Brazil was temporally correlated with the stock market in the United Kingdom and Japan. Note that in the post-crisis period there was no statistically significant temporal correlation for the Brazilian exchange rate and interest rate. These results reinforce the hypothesis of contagion during the Subprime crisis, since there is no evidence of interdependence between the foreign exchange and government bond markets for the period.

Table 6. Granger causality/Block exogeneity among financial markets (Subprime crisis)

			Dependent variable		
H₀: Does not cause	DLIBOV	H₀: Does not cause	DLREAL	H₀: Does not cause	DLIBR
DLSP	1.0426	DLDOL	4.8182	DLIEUA	3.953791
DLDAX	0.1505	DLEURO	5.2085	DLIALE	7.167185
DLFTSE	3.5761*	DLLIB	2.3333	DLIRU	7.668970
DLN225	5.7637**	DLIENE	2.8294	DLIJAP	2.645239
DLSSEC	0.0847	DLYUAN	2.3508	DLICH	3.100874
Todos	11.8019***	Todos	15.4653	Todos	22.7990

Source: the authors based on the present research data.

Note. *** Significant at 1%, ** Significant at 5%, * Significant at 10%; "All" indicates the causality test for the set of all independent variables.

As in the case of the crisis period, a VAR was estimated to analyze the causality between all countries and markets after the Subprime crisis. Based on the information criteria (LR, FPE, AIC, SC and HQ), the LM test (done with 5 lags) and correlograms, the model with four lags was estimated. A summary of the results for all markets and countries over the same period is presented in Table 7. For Brazil, there was no causality for the stock market and the exchange rate, as the results were not statistically significant. Thus, the Brazilian interest rate was the only one to show temporal correlation with other external financial markets, namely: the US stock market (DLSP) and the German stock market (DLDAX), in addition to the Brazilian exchange rate (DLREAL). The empirical results indicate that there was a temporal correlation only among foreign economies, mainly among stock markets. It is confirmed that the US stock market (DLSP) caused all foreign stock markets in the period. IBOVESPA (DLIBOV) only caused the UK exchange rate (DLLIB).

Here, it is worth highlighting some points. At first, the non-statistical significance of the results for Brazil seems to suggest that the Brazilian financial market no longer has relations with foreign economies in the post-crisis period. This is a mistaken interpretation, since the absence of temporal precedence in the variables in Brazil, in this period, does not mean that the Brazilian financial market detached itself from foreign economies. According to Nasser and Hajilee (2016), the development of the financial market in emerging economies is linked to the long-term integration between these and the financial markets of developed economies. With regard to the short term, there were no shocks that intensified the interrelations between the financial markets in the post-crisis period, which strengthens the occurrence of the contagion effect in Brazil during the Subprime crisis.

It is also worth remembering important internal factors that contributed to the performance of the IBOVESPA index in the period. Especially in 2014, 2015 and 2016, a scenario of fiscal crisis, deterioration of public accounts, impeachment process, high inflation and low growth prevailed in the Brazilian economy. Added to this are issues related to presidential elections, fighting corruption, among others. Thus, investors' decision-making in the Brazilian financial market was heavily conditioned by changes in these factors.

Finally, it is examined the impulse-response functions in the post- Subprime crisis period. From the complete model, a shock of one standard deviation was introduced in each variable of foreign economies and the impacts on the Brazilian financial market (DLIBOV, DLREAL and DLIBR) were analyzed. The generalized impulse response function was used, the order of the variables in the sample not being relevant. Figure 4 shows how a shock originated in the stock market of external economies in the post-crisis period affected the Brazilian financial market. The results show that IBOVESPA was affected by the US stock market (DLSP), but with a much smaller effect than in the period of the Subprime crisis. The same occurred for DLFTSE and DLDAX. The Brazilian exchange rate responded negatively to a positive shock from all foreign stock markets, mainly to DLSP, DLFTSE and DLDAX, again with lesser effects than in the crisis. Interest rate results were not significant.

Table 7. Granger Causality Results/Exogeneity Block Summarized (post Subprime crisis)

Effect	H₁: Cause		
	Stock markets	Exchange rates	Interest rates
DLIBOV	*DLSP*, DLN225		DLIEUA
DLSP	DLFTSE, *DLN225*	DLREAL, DLLIB	
DLDAX	DLSP, DLFTSE, *DLN225*	DLLIB, DLIENE	*DLIBR*
DLFTSE	DLSP, DLDAX	DLLIB	DLIBR
DLN225	DLSP, DLDAX	DLIENE	*DLICH*
DLSSEC	DLSP, *DLFTSE*		*DLICH*
DLREAL	*DLSP*		
DLDOL	DLSP	DLIENE	
DLEURO	DLSP	DLIENE	DLIALE
DLLIB	DLIBOV	*DLREAL*, DLIENE	DLIEUA
DLIENE			*DLICH*
DLYUAN			*DLIRU*
DLIBR	*DLSP*, DLDAX	DLREAL	
DLIEUA	*DLFTSE*	DLREAL	
DIALE			DLIEUA
DLIRU	*DLN225*	DLLIB, DLIENE, DLYUAN	DLICH
DIJAP	DLFTSE, DLN225		DLIALE, DLIRU
DLICH	*DLN225*		

Source: the authors based on the present research data.

Note. at least 5% significance, based on chi-square statistics. Italic represents statistical significance at only 10%. Bold means that the set of variables had no statistical significance at 10%.
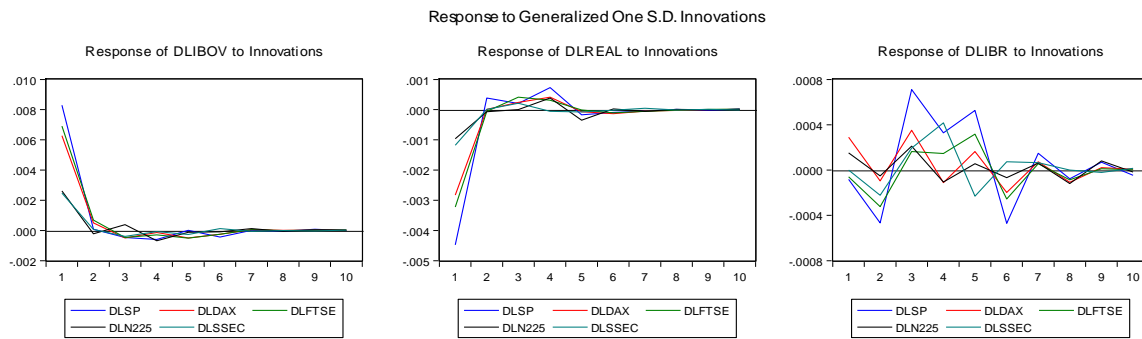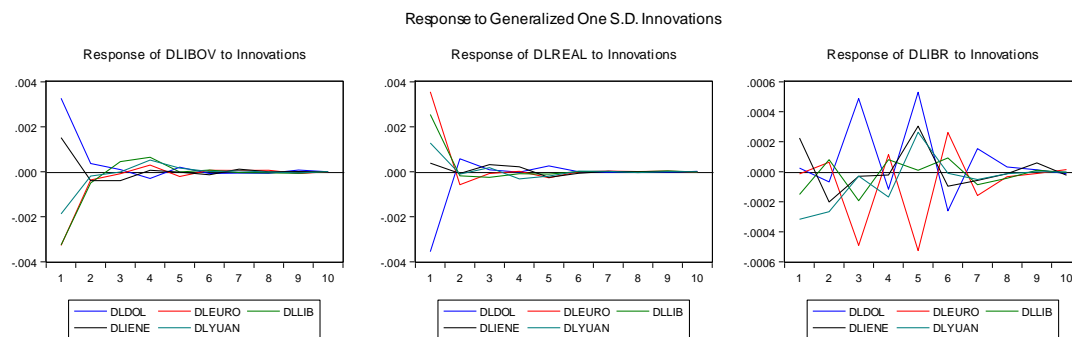
Figure 4. IBOVESPA (DLIBOV), exchange rate (DLREAL) and interest rate (DLIBR) responses to the stock markets of foreign economies (post Subprime crisis)

Source: the authors, based on present research data.

Figure 5 shows the impact of shocks originating in the exchange rates of external economies in the post-crisis period. The results suggest that a shock in foreign exchange markets in foreign economies, except China, significantly affected IBOVESPA (DLIBOV). The Brazilian exchange rate (DLREAL) was rather influenced by the exchange rates of the USA (DLDOL), Germany (DLEURO) and the United Kingdom (DLLIB). Despite significant responses, they were to a much lesser degree compared to the crisis period. Much of the impact on these variables occurred on the first day of the shock, evidencing the rapid absorption of information in capital markets. The results for the Brazilian interest rate were not statistically significant.

Figure 5. IBOVESPA (DLIBOV), exchange rate (DLREAL) and interest rate (DLIBR) to the exchange rates of foreign economies (post Subprime crisis)

Source: the authors, based on present research data.

Figure 6 shows the responses of the Brazilian financial market to interest rate shocks in foreign economies after the Subprime crisis. Evidence shows that the DLIBOV was affected by interest rates in Germany (DIALE) and the UK (DLIRU). Among international interest rates, only Germany impacted Brazil's exchange rate significantly. Again, the interest rates of foreign economies did not affect the Brazilian interest rate with statistical significance.
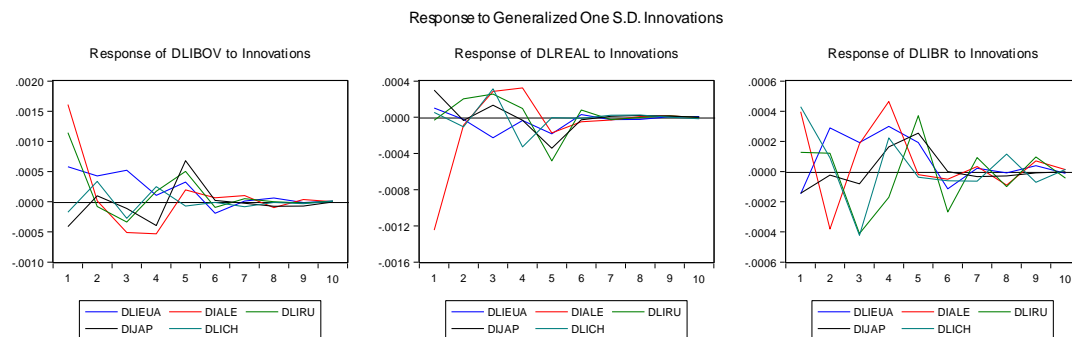

Figure 6. IBOVESPA (DLIBOV), exchange rate (DLREAL) and interest rate (DLIBR) responses to interest rates of foreign economies (post Subprime crisis)

Source: the authors, based on present research data.

In general, the results of the impulse-response functions strengthen the hypothesis of contagion during the Subprime crisis. Comparing with the crisis period, the Subprime crisis made the interrelations intensify abruptly and the main contagion channels were the stock markets and foreign exchange markets. Finally, interest rate results show that government bond markets were not a relevant channel of contagion. However, the significant response of DLIBOV and DLREAL to shocks in DLIEUA, DLIALE and DLIRU during the crisis period, show the massive intervention of Central Banks during the Subprime crisis. In addition, government bond markets showed lesser linkages with each other and with the stock and foreign exchange markets.

Evidence in the post-crisis period demonstrates that the interrelationships between the Brazilian financial market and international financial markets were much less intense. In this period, the results indicate that the interrelationships between the foreign and Brazilian financial markets did not remain high after the Subprime crisis. In other words, the interrelations increased during the crisis due to contagion. As the interrelations between the financial markets did not remain high in the post-crisis period, this shows that there was no increase in the interdependence between the international and Brazilian financial markets; only the contagion effect during the Subprime crisis.

Despite interrelations not remaining high after the crisis, DLIBOV and DLREAL were predominantly influenced by the US financial market. Therefore, considering the definition of contagion, as the transmission of a negative shock from one country to other countries that generates a significant increase in the interrelationships between these markets, the results do not support the case of contagion in the post-crisis period, but strengthen contagion during the Subprime crisis.

Finally, the evidence found supports the possibility of the contagion effect during the Subprime crisis, as in the sense of Dornbusch, Park, and Claessens (2000), from the shock in the American economy, one can observe movements that characterize herd behavior, loss of confidence and increased risk aversion. What started as a crisis in the US practically impacted the entire world. Initially, it affected countries that had a lot of banking business with the US, then financial institutions in other countries and reached various sectors of the real economy (Blanchard et al., 2010).

In a world where one can follow market movements from all countries in real time, the mood of investors easily spills over from one market to another. In this sense, the intensification of the interrelationships between stock markets during the crisis can be interpreted as a reflection of the herd effect described by Chiang, Leon and Li (2007), where the loss of investor confidence in a country leads investors from other countries into the abyss. As the turmoil grew and spread, equity markets became the means by which investors showed greater aversion to risk, trading their shares for less risky assets, which greatly intensified the interrelationships between exchange rates and the stock markets.

5. Concluding Remarks

There is a lot of data on how the interrelationships between financial markets intensified during the Subprime crisis. In Brazil, studies focused exclusively on interrelationships via the stock market. Thus, this work analyzed the interrelations between Brazil and foreign economies (USA, Germany, UK, Japan and China) during and after the Subprime crisis, through three financial market indicators: stock index, exchange rate and interest rate. For this purpose, the Vector Autoregressive (VAR) approach and the Granger causality test were used, with daily data.

The empirical results during the crisis showed that the contagion of the Brazilian economy occurred predominantly via the stock market and the exchange rate. IBOVESPA (DLIBOV) and the Brazilian exchange rate (DLREAL) showed significant increases in the interrelationships with the US (DLSP and DLIEU), UK (DLFTSE and DLIRU) and public securities markets and Germany (DLDAX and DLIALE), and with the exchange rates of these countries as well (DLDOL, DLLIB and DLEURO, respectively), along with that of Japan (DLIENE). These indications reveal that Brazil's stock market has become the means by which investors have signaled great risk aversion, trading their shares for less risky or volatile assets, which has greatly intensified the interrelationships between stock markets and exchange rate of these countries.

Evidence in the post-crisis period showed considerably lower interrelationships between markets compared to the crisis period. It was found that the Brazilian stock market and the exchange rate in Brazil responded significantly to stock indices and exchange rates in external economies. However, the magnitude observed in the interrelationships between these variables was much milder compared to the crisis period.

The analysis of the interrelationships between the Brazilian financial market and foreign economies contributes to a better understanding of the behavior of the Brazilian stock market after an international systemic crisis,

contributing to the management of portfolio risks. This evidence is important to assist directors of publicly traded companies, shareholders and, above all, policy makers in the preparation of measures to protect the Brazilian stock exchange and companies listed on it from shocks or major negative events involving the global economy. Furthermore, it is relevant for investors and funds, as the results help to identify investment opportunities and portfolio diversification.

While there are paths that can be taken to reduce vulnerabilities to contagion in the future, when a negative shock occurs in a country, there will hardly be easy solutions to end contagion in an increasingly integrated world. However, this does not mean that risks should be ignored. As there are protocols to increase immunity against a disease, there are measures that can mitigate contagion.

Acknowledgments

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Notes

Note 1. Mejá-Reyes (2000), Hecq, Palm, and Urbain (2000), Hecq (2002), Westermann (2002), Gérard, Thanyalakpark, and Batten (2003), Khalid and Kawai (2003), D'Ecclesia and Costantini (2006), Diamandis and Drakos (2011), among others.

Note 2. Pukthuanthong and Roll (2009), Bekaert et al. (2011), Horvath and Paldalf (2012), Yunus (2013), Zhang, Li, and Yu (2013), Donadelli and Paradiso (2014), Fuinhas et al. (2014), Ranjeeni (2014), Mensi et al. (2014), Billio et al. (2015), Nasser and Hajilee (2016), Yarovaya and Lau (2016), Pan and Mishra (2018), among others.

Note 3. Data available at: https://www.investing.com/.

Note 4. Data available at: https://www.federalreserve.gov/datadownload/Choose.aspx?rel=H15.

Note 5. Data available at: http://www.pbc.gov.cn/en/3688247/3688990/index.html.

Note 6. Data available at: https://www.bankofengland.co.uk/statistics/yield-curves.

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