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The Contagion of the Subprime Crisis in the Sector Indices of the Brazilian Stock Market: An Approach to Multivariate Conditional Volatility Models

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ABSTRACT

Oscillations within the financial market during the subprime crisis caused an increase in volatility and a fall in asset prices, in addition to increasing the degree of normal market movements. This study analyzed the contagion effect of the international financial crisis on the Brazilian stock market indices upon studying the estimated covariance patterns between the Brazilian and American stock market indices. The empirical analysis was based on the multivariate BEKK-GARCH models. The results showed that the estimation of the covariance structure between 2007 and 2010 had clear evidence of contagion in the indices investigated: Electricity (IEE), Telecommunications (ITEL), Consumption (ICON), Industrial Sector (INDX), Real Estate (IMOB), and Financial (IFNC). During the period of the international financial crisis, there was an increase in the covariance between the American and Brazilian market indices. The IMOB and IFNC indices showed the highest contagions among all the ones analyzed, reflecting the losses of the civil construction industry along with internal and external credit scarcity.

KEYWORDS

Contagion, Financial Crisis, Multivariate BEKK-GARCH Model

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O Contágio da Crise do *Subprime* nos Índices Setoriais do Mercado Acionário Brasileiro: Uma Abordagem dos Modelos de Volatilidade Condicional Multivariados

2

RESUMO

As oscilações no mercado financeiro durante a crise do *subprime* ocasionaram a elevação da volatilidade e queda dos preços dos ativos, além de elevar o grau dos movimentos comuns entre os mercados. Este trabalho analisou o efeito contágio da crise financeira internacional sobre os índices do mercado de ações do Brasil, a partir do estudo do padrão das covariâncias estimadas entre os índices do mercado acionário brasileiro e americano. A análise empírica foi baseada nos modelos multivariados GARCH-BEKK. Os resultados mostraram que a estrutura das covariâncias estimadas, entre os anos de 2007 e 2010, indicou claras evidências de contágio nos índices considerados. No período da crise financeira internacional, houve uma elevação da covariância entre os índices dos mercados norte-americano e brasileiro. Os Índices Imobiliário e Financeiro apresentaram os maiores contágios entre todos analisados, refletindo as perdas das indústrias de construção civil, somadas à escassez de crédito interno e externo.

PALAVRAS-CHAVE

Contágio, Crise Financeira, Modelo GARCH-BEKK

The process of economic globalization has gained strength with financial globalization. The deregulation of financial markets, particularly after the collapse of the Bretton Woods system in the 1970s, as well as the development of new information and communication technologies, have contributed to the intensification of this process over the last few decades.

Especially in the 1990s, many countries opened their capital accounts and liberalized their domestic financial markets as a reflection of the liberal wave that characterized such period (Ocampo et al., 2008). According to Vo (2009), the degree of financial integration rose significantly in the 1980s and 1990s, partly explained by the increased globalization of investments, which sought high rates of returns and opportunities for risk diversification.

The intensification of financial globalization has come with a boost in world economic instability. As highlighted by Terra and Soihet (2006), increased flow of international capital was associated with the occurrence of financial crises on a global scale, arousing the interest of investigations on the degree of exposure of countries to financial shocks in the global economy. The Mexican Peso crisis (1994), the Asian Financial crisis (1997), the Russian Financial crisis (1998), the Brazilian Exchange Rate crisis (1999), and the Argentina crisis (2001) did not have their effects concentrated strictly within their borders. On the contrary, the negative effects quickly spread to other markets, many of which had few commercial or financial links to the original country.

The subprime crisis, which began in the North American financial market in 2007 (Dungey, 2008; Celik, 2012; Horta et al., 2010), was the most intense among those that have occurred in recent decades, having its effects spread to most countries, including emerging ones. According to the International Monetary Fund report (FMI, 2008), the World Economic Outlook, the global financial crisis was the most severe one since the 1930s, leading the world economy to a drastic downturn.

The bankruptcy of investment bank Lehman Brothers, the fourth largest investment bank in the US, in September 2008, marks the transformation of the financial crisis into a global crisis. Until then, the crisis effects had been transmitted only to developed countries, with emerging markets being little affected. However, with the systemic character acquired in mid-2008, emerging economies were hit by the crisis, not confirming the decoupling hypothesis according to which such economies, driven by the favorable external situation, solid fiscal accounts, and inflation under control, would be immune to the crisis and be able to sustain economic dynamism in their countries.

The impacts on the Brazilian economy after the worsening of the financial crisis were felt in several sectors. The industrial sector, which, until then, had one of the most expressive and lasting growth cycles in recent decades, achieving an accumulated growth rate of 6% in 2007, registered a strong deceleration in 2008 (3.1%). According to the Brazilian Institute of Geography and Statistics data (IBGE, 2020), industrial production shrank by 14% between November and December 2008, and the accumulated growth rate of this sector until the months of September and December that year fell from 6.8% to 3.1%, respectively. Another sector impacted by the global crisis was consumption due to the reduction in world demand, and consequently, its impacts on exports. In this context, according to data from the Institute for Applied Economic Research (IPEA, 2009), the volume of exports between December 2008 and January 2009 dropped by 29%, the biggest drop since January 1985.

In the Brazilian financial market, not only the worsening of the international financial crisis but also an increase both in risk aversion and in foreign investor liquidity preference caused the Brazilian economy to witness a sudden movement of capital flight because of greater uncertainty in

emerging markets, which impacted the real and financial side of this economy. The capital market was the target of a significant capital outflow triggered by the international crisis, resulting mainly in greater volatilities in the returns of assets traded in such market. The IBOVESPA, an indicator of the average performance of the Brazilian stock market, showed a significant increase (around 100%) in monthly volatility in September and October 2008, according to B3 data (2020).

At a global level, fluctuations in the world financial market resulting from the financial instability after the subprime crisis have led to an increase in volatility and a fall in asset prices. This fact caused an increase in the risk and uncertainties associated with the assets; in addition, it raised the degree of normal movements between stock markets due to the transmission of crisis shocks between countries, enhancing contagion episodes among economies worldwide. Ferrari Filho and Paula (2004) emphasize that, among the problems associated with financial globalization, the greater degree of interdependence between economies increases the possibilities of contagion of crises between countries and contributes to increased market volatility. Stiglitz (1999) states that one of the causes for contagion to occur is the excessive degree of capital mobility. Thus, especially after the Southeast Asian financial crisis and the subprime crisis, the term contagion has become relevant in the context of international transmission of financial market turmoil episodes.

This way, this article seeks to answer two questions. First, in the face of the subprime financial crisis, to what extent did the shocks that occurred in the US stock market affect the Brazilian stock market? Second, did these shocks affect the various stock sectors to the same extent? The hypothesis guiding the study is that the contagion arising from the subprime crisis had heterogeneous impacts on the various sectors of the Brazilian stock market given its differentiated insertion in the crisis in relation to the peculiar characteristics of each sector.

Studies focused on contagion in emerging markets are relevant, as shown by Stiglitz et al. (2006), as volatility in these economies tends to be higher than in developed markets in the context of international capital flow. This fact, together with the financial deregulation process, is one of the new challenges for developing countries in terms of macroeconomic policy, as suggested by Lann (2008). White (2000) states that the importance of studying crises lies in finding ways to prevent them, to act in the face of them, and to provide them with solutions.

Three points are highlighted in the literature regarding the importance of studying contagion related to crises in the financial market: i) implications for portfolio management and international risk diversification processes; ii) provision of subsidies to public policy makers; and iii) effectiveness of interventions by international financial institutions in crisis scenarios.

Some authors have sought to analyze the contagion effect for emerging economies, such as studies by Edwards (1998), Forbes and Rigobon (2000), Kim et al. (2002), Perobelli et al. (2013), and Almeida et al. (2018), among others. Specifically on the financial contagion resulting from the subprime crisis, Horta et al. (2010) carried out three tests to verify such hypothesis for European stock exchanges. The copula theory was used with data referring to the global, industrial, and financial indices of Portugal, France, Holland, and Belgium. The results suggested the occurrence of contagion for most of the analyzed markets, which were equally severe within the financial and industrial indices. Evidence similar to this was observed by Hwang et al. (2010) when using multivariate conditional volatility models for 38 developed and emerging countries. The authors found evidence of financial contagion for both emerging markets and developed economies during the subprime crisis. The study by Celik (2012) was also based on a sample

of both developed and emerging countries to analyze the existence of financial contagion. Not only do the results corroborate the conclusions of previous studies, but the author also argues that emerging markets may have been more influenced by the contagion effects resulting from the subprime crisis. Finally, the research by Kao et al. (2019) applied asymmetric cointegration structures to investigate the hypothesis of contagion between the Standard and Poor's 500 (S&P 500) index and a sample of 23 equity markets from Asia, Europe, and America. Using this methodology was important to identify the existence of heterogeneous contagion effects for Canada, western and northern European countries, and developed countries in Asia, in relation to developing countries in Asia, eastern Europe, and Latin America. A possible explanation for this fact, according to the authors, is that the degree of financial connection with the US market may have contributed to the occurrence of differentiated effects between countries.

Regarding the studies developed for the Brazilian economy on the international contagion as a result of the subprime crisis, Tabak and Souza (2009), for instance, focused on the contagion between the banking systems of 48 countries, and Santos and Valls Pereira (2011) analyzed the contagion between the financial market indices of the United States, Brazil, Japan, and England through the copula approach.

The present study differs from the others by carrying out a disaggregated analysis of the contagion between the various segments that make up the Brazilian stock market. Such innovation is relevant, for it allows the pattern of responses of various assets to contagion to be analyzed, serving as a guide for public policy makers regarding the possibility of different sectoral impacts, in addition to guiding the decision-making process of investors, and contributing to a better understanding of the national financial market in scenarios of financial instability. In agreement, Bernanke and Gertler (1999) emphasize the importance of the monetary policy reaction in times of great financial instability, in which the conduct of monetary policy should regard price stability and financial stability as highly complementary and mutually consistent objectives. As Apostoaie and Cuza (2010) point out, there are situations in which ensuring financial stability is more important than maintaining price stability.

2. GLOBALIZATION AND FINANCIAL INNOVATIONS AND THE SUBPRIME CRISIS

Several factors have potentialized the development of the financial globalization process in recent decades. The downfall of the Bretton Woods system in the early 1970s – marking the beginning of the floating exchange rate regime – as well as the development of the euro-market from the 1960s on were precursor factors for the rise and consolidation of the process of making finance globalized. Together with these events, the deregulation of financial markets (which began in the 1980s), the liberalization of capital flows, and the technological development of telecommunications and information technology (IT) were also crucial in such process. According to Minella (2003), the changes that have taken place in the financial system since 1980 have made it possible for capital to circulate more easily between countries.

The main transformations began in the US economy due to a combination of factors including policies adopted to ensure the dollar as the main currency in the international monetary and financial system, the economic and financial power of the country, and a developed banking

system (Prates, 2005). According to Wray (2009), the process of separating commercial banks from investment banks occurred more intensively in the US. Thus, the process observed was a transition from a regulated banking sector, directing its functions of traditional loans and deposits, towards financial institutions for the free market, since they have a wide choice of financial instruments, as the same author emphasizes.

In this process, in which the participation of non-banking institutions has increased substantially in the domestic financial systems, the emergence of new instruments, or financial innovations, has contributed to increasing asset liquidity at first, and to stimulating the global impacts of financial crises. In a microeconomic context, as shown by Cagnin (2009), these new instruments are a way to increase institutions' profits through competitive advantages. Another approach suggested by the author focuses on the macroeconomic environment, which, during an economic growth environment, financial innovations make it possible to increase the indebtedness of economic agents until moments of instability.

Securitization was one of the main forms of financial innovation that began in the American market in the 1980s. Its process allowed illiquid assets, such as subprime mortgages, to be grouped and transformed into liquid assets and traded with investors, allowing risk distribution to other agents. According to Wray (2009), securitization can be seen as a reflection of financial globalization, since there is the creation of assets traded across borders through securities organized by banks and passed on to global investors, a policy known as "originate and distribute" rather than to keep these illiquid assets in its liabilities.

In the subprime international financial crisis, the development of several new assets was observed. Competition between different financial institutions and the chance of increased liquidity through securitization led to the creation of new real estate bonds, for example Collateralized Mortgage Obligations (CMOs) and Collateralized Loan Obligations (CLOs). As suggested by Gomes (2011), it is possible to identify three stages in the American subprime crisis evolution. The first one is related to the conservative nature of the credit operations carried out, since the income flows expected by the debtors were enough to cover the debt services, as well as the amortization of the principal. The second one refers to the credits designed to facilitate the monthly payment of interest only, making it possible to settle the principal at the end of the mortgage maturity. Given this scenario, there was an increase in speculative operations by creating favorable conditions for the increase in residential prices, once the obligation to pay interest only allowed debtors to obtain a greater volume of credit from creditors. Finally, in the third stage, the appearance of exotic assets flooded the market with financial bonds that caused the incorporation of unpaid monthly interest expenses to the main amount borrowed. Consequently, at the end of the bond maturity, a debit balance higher than that initially agreed on was accumulated.

In short, the development of new financial instruments and the IT sector led to greater interconnection between financial markets, in addition to shedding light on the study of the financial contagion between markets hypothesis. It cannot be said, however, that markets are more susceptible to financial contagion because of this greater interconnection (Santos & Valls Pereira, 2011). Nevertheless, throughout the American subprime crisis in 2007 and 2008, it was observed that its effects were not concentrated only among developed countries, yet, in fact, they were spread to emerging economies as well (Cunha et al., 2009), bringing about the discussion on contagion again.

For many authors, including Edwards (2000) and Rigobon (2002), the study of the financial contagion was conducted concurrently with the outbreak of financial market crises of emerging

countries in the 1990s. The severe stress such emerging countries went through during financial crises, and consequently the financial contagion hypothesis, have since been addressed in several studies in the economic literature.

Another issue that emerged after the international subprime financial crisis regards the central banks involvement in ensuring price stability and financial stability. As pointed out by Gameiro et al. (2011), such crisis showed that monetary stability alone does not assure financial stability and that the processes of liberalization and financial innovation have given a more important role to financial factors in macroeconomic dynamics. According to Papademos (2009), a consensus after the crisis is that the main responsibility of central banks is to preserve price stability, but they have the greater role of promoting financial stability.

3. METHODOLOGY AND DATABASE

The empirical analysis proposed in this article is based on conditional volatility models, notably the multivariate GARCH (General Autoregressive Conditional Heteroscedasticity) model. According to the specification proposed by Baba-Engle-Kraft-Kroner, the BEKK-GARCH models are estimated for studying the financial contagion between the American stock market and the Brazilian stock market sectors, whose proxies are the S&P 500 index and sector indices of the B3 Stock Exchange, respectively. The indices referring to the Brazilian stock market are: Electricity (IEE), Telecommunications (ITEL), Consumption (ICON), Industrial sector (INDX), Real Estate (IMOB), and Financial sector (IFNC). As emphasized by Bauwens, Laurente and Rombouts (2006), a study through the multivariate approach leads to more consistent analyzes and empirical models when compared to the univariate approach.

It should be noted that each empirical technique used is linked to one of the definitions of the term contagion. Thus, the GARCH family models have been used in studies investigating contagion presence via changes in the structure of dependence between a set of financial market returns, which is a definition proposed by Chang and Majnoni (2002). According to Dungey et al. (2004), contagion has the effect of causing structural changes during crisis periods in conditional variances and covariances. Hence, this hypothesis can be tested by comparing the structure of the covariances between pre-crisis and subprime crisis periods.

3.1. MULTIVARIATE BEKK-GARCH MODEL

Aiming to eliminate the deficiencies on the imposition of strong restrictions to ensure the positivity of the variance and covariance matrix of the residuals, Engle and Kroner (1995) formalized a specification of multivariate volatility known in the literature as the Baba-Engle-Kraft-Kroner – the BEKK model (Tsay, 2010).

The specification of the multivariate BEKK-GARCH model is given by:

$$H_t = C'C + \sum_{k=1}^K A'_k \varepsilon_{t-k} \varepsilon'_{t-k} A_k + \sum_{k=1}^K B'_k H_{t-k} B_k \quad (1)$$

in which H_t is a covariance matrix $N \times N$, between the returns of the Brazilian stock market indices and the US stock market index, defined as positive and measurable in relation to the set of information over time $t-1$. The residuals of the vector error correction, or innovation vector, are given by ε_t , C is a lower triangular matrix, and A_k and B_k are matrices of $N \times N$ parameters. Decomposing the constant term C into a product of two triangular matrices ensures that H_t is positive.

A parsimonious specification where $k = I$, as in Kasch-Haroutounian and Price (2001), was adopted in this study. This hypothesis eliminates the identification problem arising from models in which $k > I$. Because of the use of such a model, the variances and conditional covariances of asset prices in each market are related, and the estimation of many parameters is not required.

The matrix form of the model estimated in the present study is given by:

$$\begin{aligned}
 & \begin{bmatrix} h_{11,t} & \cdots & h_{17,t} \\ \vdots & \ddots & \vdots \\ h_{71,t} & \cdots & h_{77,t} \end{bmatrix} \\
 &= \begin{bmatrix} C_{11} & & \\ \vdots & \ddots & \\ C_{71} & \cdots & C_{77} \end{bmatrix} \times \begin{bmatrix} C_{11} & \cdots & C_{17} \\ & \ddots & \\ & & C_{77} \end{bmatrix} \\
 &+ \begin{bmatrix} A_{11,1} & \cdots & A_{17,1} \\ \vdots & \ddots & \vdots \\ A_{71,1} & \cdots & A_{77,1} \end{bmatrix} \times \begin{bmatrix} \varepsilon_{1,t-1}^2 & \cdots & \varepsilon_{1,t-1}\varepsilon_{7,t-1} \\ \vdots & \ddots & \vdots \\ \varepsilon_{7,t-1}\varepsilon_{1,t-1} & \cdots & \varepsilon_{7,t-1}^2 \end{bmatrix} \times \begin{bmatrix} A_{11,1} & \cdots & A_{17,1} \\ \vdots & \ddots & \vdots \\ A_{71,1} & \cdots & A_{77,1} \end{bmatrix} \\
 &+ \begin{bmatrix} B_{11,1} & \cdots & B_{17,1} \\ \vdots & \ddots & \vdots \\ B_{71,1} & \cdots & B_{77,1} \end{bmatrix} \times \begin{bmatrix} h_{11,t-1} & \cdots & h_{17,t-1} \\ \vdots & \ddots & \vdots \\ h_{71,t-1} & \cdots & h_{77,t-1} \end{bmatrix} \times \begin{bmatrix} B_{11,1} & \cdots & B_{17,1} \\ \vdots & \ddots & \vdots \\ B_{71,1} & \cdots & B_{77,1} \end{bmatrix}
 \end{aligned} \tag{2}$$

The initial procedure for estimating the multivariate BEKK-GARCH models consists of pre-filtering the data so as to remove the serial correlation existing at the first moment of the series. This way, to meet this objective, a VAR(p) model was estimated for the equations of the averages of the seven indices considered, and the presence of autocorrelation in the residuals was analyzed using the Lagrange Breusch-Godfrey Multiplier test.

To define the order of the VAR(p) model to be estimated, the procedure suggested by Alexander (2005) and Tsay (2010) was adopted, according to which the most parsimonious specification possible for the average equation was sought. At first, the orders indicated by the Akaike and Schwarz criteria were used. If autocorrelation was found, an autoregressive term (AR) was added to the initial equation, and the process was repeated to verify the serial correlation in the residuals of the new equation. The incorporation of AR terms was carried out until the residuals of the mean equation were free of autocorrelation.

The second step was to confirm if the residuals of the mean equation presented conditional heteroscedasticity, a fact named ARCH effect in the literature. The verification of such an effect occurred through the Lagrange Multipliers (LM) Test proposed by Engle (1982), whose null hypothesis refers to the non-existence of ARCH effect in the series.

After performing the previous procedures, the next one was the estimation of the conditional variance equation in the multivariate context.

3.2. TESTING THE HYPOTHESIS OF CONTAGION VIA STRUCTURAL BREAK IN CORRELATIONS

Almeida (2000) reinforces the importance of correctly identifying financial contagion based on volatility transmission between markets. According to the author, contagion episodes cause changes in the movements between markets whose reflexes are the increased interconnection between them. In this sense, the procedure proposed by Wooldridge (1990,1991) was used to verify whether there was the evidence of structural break associated with the subprime financial crisis or not.

The procedure in question tests the predictability of a given variable on the estimated model residuals. According to what Marçal and Pereira (2008) described, the test was performed by defining the generalized residuals by $\phi_t = \frac{\varepsilon_t^2}{h_t} - 1$; by λ_{gt-1} as the indicator variable as being the

candidate variable to have predictive power over the residuals; and $E(\nabla_{\theta} h_t) \equiv \frac{\nabla_{\theta} h_t}{h_t}$, as the expected value of the gradient of the generalized residuals of the estimated model calculated in the null hypothesis. Once the variables to be used to test the contagion hypothesis were presented, the following steps had to be used to obtain the test statistics:

- From a consistent estimate of θ , the residuals were calculated as suggested above, in addition to the gradient and the indicator variable;
- Regression of the indicator variable (λ) in the gradient was performed by calculating the respective residuals;
- The regression of a vector of ones was carried out in the product of the generalized residual by the residual of the regression of item (ii) by calculating $T \times R_u^2 = T - SQR$.

These statistics have an asymptotic chi-square distribution with a degree of freedom equal to the number of indicator variables used in step (ii).

The indicator variable $\lambda_{1,t} = [D_{subprime}]$ was used in the specification test to verify the presence of instability in the correlation structures during the subprime crisis period. Thus, $D_{subprime}$ is a dummy variable referring to the international financial crisis. Concerning the initial date, 09/15/2008 was chosen because it refers to the date of the bankruptcy of Lehman Brothers. For the end of the crisis, an *ad-hoc* date – 03/13/2009 – was selected based on the stabilization of the volatility of the indices.

3.3. DATA DESCRIPTION AND SOURCE

The database used in the research is composed of the logarithmic returns (r_t) of the Brazilian and American stock market indices defined as $r_t = \ln\left(\frac{P_t}{P_{t-1}}\right)$. The indices are the IEE, ITEL, ICON, INDX, IMOB, and IFNC for the Brazilian stock market, and the S&P 500 index for the US stock market. The daily observations regard the period 01/03/2007 - 12/30/2010, resulting in 1,042 observations. All data series in relation to the indices for the Brazilian and American markets were obtained from the websites https://www.b3.com.br/pt_br/ and <https://www.spglobal.com/en/>, respectively, where the methodologies for calculating the indices are also available.

Because financial series from two different markets – from Brazil and the US – were used, it was decided to combine the dates of observation of the two countries, in order to have a complete and joint sample of the information contained in the indices of these markets. Hence, dates that did not contain observations for both markets simultaneously were eliminated from the sample, which ultimately resulted in 964 observations.

4. RESULTS AND DISCUSSION

Initially, it was necessary to define the period of the international financial crisis. Table 1 presents a summary of the dates.

Regarding the beginning of the impacts of the subprime crisis on the Brazilian market, information from daily newspapers was used to establish its starting point, which is a date related to the collapse of the American investment bank Lehman Brothers on 09/15/2008. This date was also used in other studies in the literature, for instance Kao et al. (2019) and Longstaff (2010).

As for the end of the crisis, there was no hard fact suggesting its end, so the date 03/13/2019 was chosen *ad-hoc* based on the volatility stabilization of the Brazilian and American indices, the same practice used by Carvalho (2011).

4.1. PRELIMINARY ANALYSIS

Table 2 shows the correlation matrix between the sector indices of the Brazilian stock market and the S&P500 index between 2007 and 2010. The results revealed a divergent behavior

10

Table 1*Definition of the periods analyzed*

Description	Beginning	End	Number of observations
Pre-crisis	01/03/2007	09/14/2008	408
Subprime Crisis	09/15/2008	03/13/2009	120
Post-Crisis	03/14/2009	12/30/2010	436
Total period	01/03/2007	12/30/2010	964

Source: Self elaboration.

between the American index and the Brazilian market indices, as there is a high correlation with the IMOB index and negative one with the IEE index. It is also worth mentioning the intermediate association between the S&P500 and the INDX indices in the period analyzed. Such results seem to indicate heterogeneous relationships between the US stock market and the different sectors of the stock market in Brazil.

With the preliminary objective of analyzing the variance behavior in the period covered by the research, the returns of the series were calculated as described in the methodology. Figure 1 presents the values of the financial returns of each index analyzed.

Through the visual analysis of Figure 1, the increase in the volatility of returns is observed in all the indices evaluated during the period of the international financial crisis, and the highest volatilities are found for IMOB and IFNC. The representative index of the American stock market, the S&P 500, proved to be less volatile compared to the Brazilian ones. These results preliminarily indicate the vulnerability of the Brazilian stock market in relation to capital outflows in times of international financial instability, such as what happened in the 2008 crisis. In this context, Akyüz and Cornford (1999) warn of the most significant effects on emerging economies' financial markets faced with potentially destabilizing capital flows.

Table 2*Correlation matrix of stock indices*

	ICON	IEE	IFNC	IMOB	INDX	ITEL	SP500
ICON	1.00	–	–	–	–	–	–
IEE	0.84	1.00	–	–	–	–	–
IFNC	0.95	0.93	1.00	–	–	–	–
IMOB	0.32	-0.15	0.16	1.00	–	–	–
INDX	0.83	0.60	0.77	0.41	1.00	–	–
ITEL	0.83	0.81	0.86	0.17	0.80	1.00	–
SP500	0.28	-0.23	0.08	0.85	0.55	0.15	1.00

Legend: ITEL – Telecommunications Sector Index, IEE – Electricity Sector Index, INDX – Industrial Sector Index, ICON – Consumption Sector Index, IMOB – Real Estate Sector Index, and IFNC – Financial Sector Index, and SP500 – Standard and Poor's 500 index.

Source: Self elaboration.

Consequently, given such evidenced vulnerability of the stock market in Brazil, it becomes relevant to analyze the financial contagion to the Brazilian stock market and identify which sectors were most impacted.

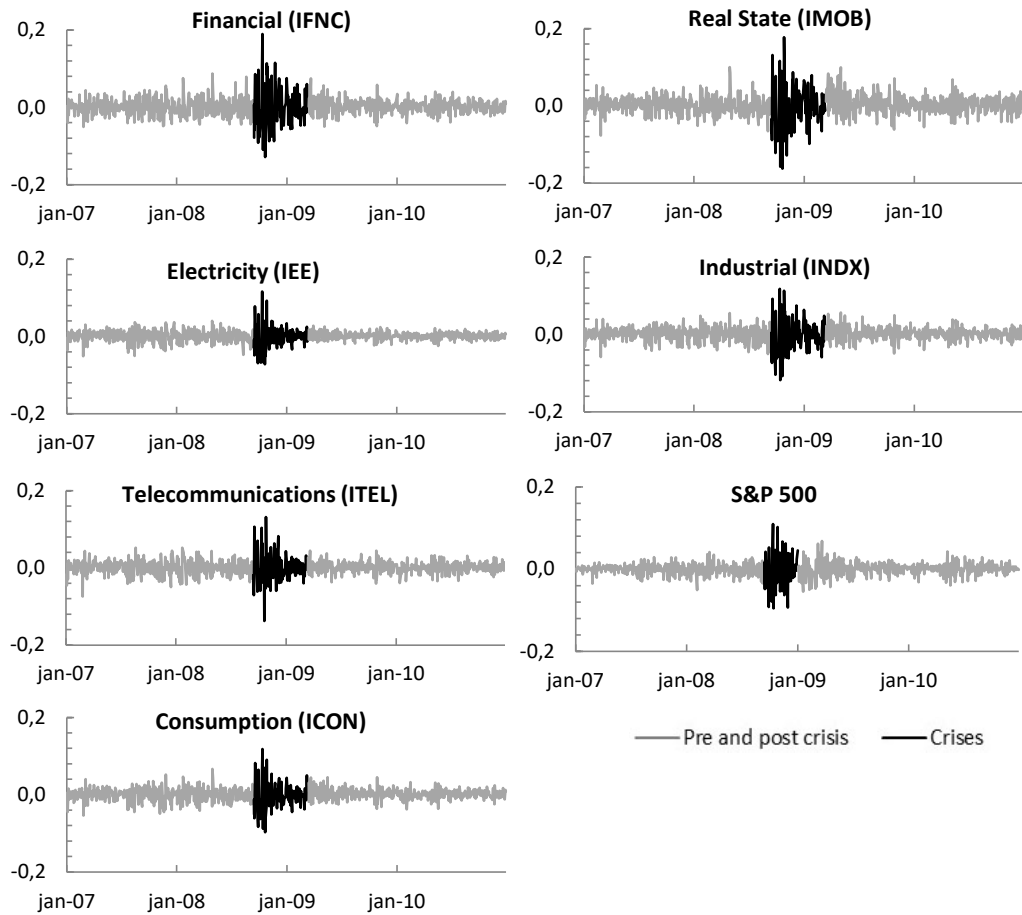


Figure 1. Evolution of the daily returns of the indices ITEL, IEE, INDX, ICON, IMOB, IFNC and S&P500 from 01/03/2007 to 12/30/2010

Source: Results of the research.

4.2. STUDY OF THE CONTAGION BETWEEN FINANCIAL ASSETS

Table 3 shows the results of the contagion test for the Brazilian stock market indices based on the structural break of the dynamic correlations estimated by the multivariate BEKK-GARCH model.

Based on the P-value of the structural break test statistics associated with the subprime financial crisis, the null hypothesis of no contagion was rejected for all stock market indices in Brazil, at a significance level of 5%. This result shows that during the subprime crisis there was a break in the structure of the estimated correlations between the American and Brazilian stock markets. Therefore, the hypothesis of financial contagion from the US stock market to the sector indices of the Brazilian market was confirmed. In Figure A.1, in the annexes, the correlations estimated by the multivariate BEKK-GARCH model (1,1) between the returns of the S&P500 and the returns of the sector indices of the Brazilian stock market are presented.

In this context, the systemic character of the subprime crisis acquired after the bankruptcy of Lehman Brothers led the markets to present a greater degree of association that facilitated the financial contagion of the American market towards the Brazilian indices. Möler and Callado

Table 3*Contagion test between the S&P 500 index and Brazilian stock indices during the subprime crisis*

Index	Statistics	P-value
IEE	839.6891	0.00
ITEL	635.6430	0.00
ICON	869.186	0.00
INDX	907.4741	0.00
IMOB	847.6458	0.00
IFNC	879.7133	0.00

Legend: ITEL – Telecommunications Sector Index, IEE – Electricity Sector Index, INDX – Industrial Sector Index, ICON – Consumption Sector Index, IMOB – Real Estate Sector Index, and IFNC – Financial Sector Index.

Source: Results of the research.

(2007) highlight that the deregulation of the Brazilian capital market not only had an influence on the capital inflow into the stock market but also contributed to net capital outflows from this market in times of crisis. Still according to the authors, the changes in the flows of foreign investments in the stock portfolio statistically influenced the IBOVESPA in the sense of causing an increase in the volatility of this index. Thus, the significant capital flight from the Brazilian stock market during the worsening of the subprime crisis resulted in an increase in the asset volatility in this market.

Once the contagion was identified, analyzing the specificities inherent to each association structure estimated between the sector indices became relevant. This way, it was possible to identify the pattern of co-movements between the analyzed indices through the estimation of the conditional covariance between the markets. Next, the graphs referring to the covariances estimated by the multivariate BEKK-GARCH model between the US market index and each Brazilian market index are presented. Figure 2 shows the graph containing the estimated covariances between the S&P 500 and the Financial indices.

Among the sector indices analyzed, the financial one showed the highest estimated covariance with the American index during the 2008 financial crisis, thus, suggesting a greater contagion for this index. The average increase in covariance between the pre-crisis and crisis periods was approximately 316%, corroborating the effects caused by the sudden reversal of capital inflows into the Brazilian economy during the subprime crisis due to the risk aversion movements and liquidity preference by international investors.

Restrictions on domestic and international credit are key factors in emerging economies, and it influences mainly the banking sector. As reported by Freitas (2009), not only the freezing of interbank and international financial markets but also the devaluation of the Real throughout the subprime crisis led to the rapid deterioration of banks that had received the credit and restricted liquidity. According to Central Bank of Brazil (BACEN, 2009), one of the effects of the crisis on Brazil was the reduction of international credit lines offered to the country. This study also describes that the pass-throughs of external credits by the institutions of the National Financial System revealed a reduction in their balances from US\$ 46.8 billion, in June 2008, to US\$ 31.5 billion, in December 2009. Subsequently, the restriction of internal and external liquidity impacted the financial institutions that make up the IFNC portfolio, in which an intense participation of

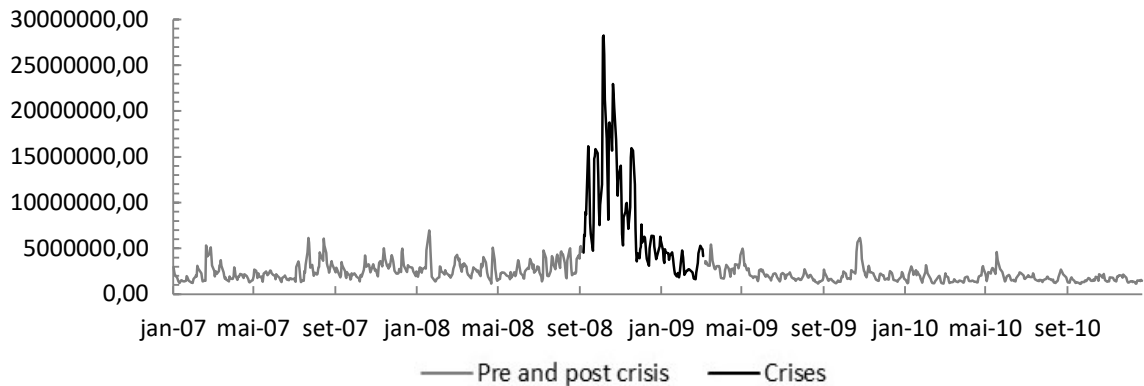


Figure 2. Covariance estimated by the multivariate BEKK-GARCH model (1,1) between the returns of the S&P500 and IFNC indices from 01/10/2007 to 12/30/2010

Source: Research results.

intermediary financial institutions can be observed composed mostly of shares of private banks (Banrisul, Itaú, Bradesco, and Santander), according to B3 data (2020).

Figure 3 presents the estimated covariance between the S&P 500 and Real Estate indices, so it is possible to verify the behavior of the association between them in such period.

Regarding the contagion for the Real Estate Index, the estimated covariance between such index and the S&P 500 was the second highest during the subprime crisis, as shown in Figure 3. Its average increase between the pre-crisis and crisis periods was about 170%.

The drop in real estate sales in the period, along with the lack of available market credit for the civil construction industries, among other factors, caused sharp losses for Brazilian companies in the sector. According to data from the ABECIP (2012), the volume of real estate credit intended for construction, acquisition, renovation, and construction material decreased by 21.43% between September and November 2008. A study conducted by the consultancy PricewaterhouseCoopers (2008), based on interviews carried out among Executive Directors, Directors, and Financial Superintendents of publicly traded companies and large corporations, reported that the civil

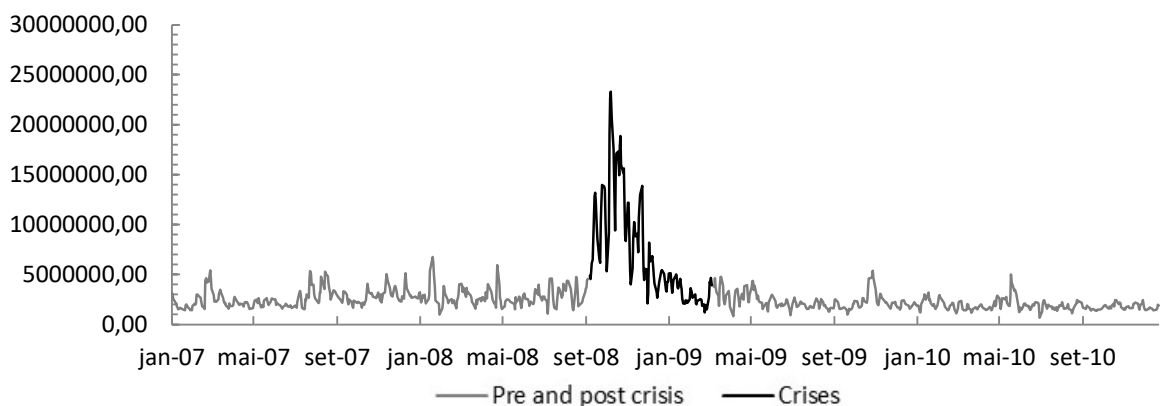


Figure 3. Covariance estimated by the multivariate BEKK-GARCH model (1,1) between the returns of the S&P500 and IMOB indices from 01/10/2007 to 12/30/2010.

Source: Research results.

construction sector was one of the five most impacted by the subprime crisis, and the drop in investments in such sector was highlighted as a strong potentiator for such effects. Thus, the shares of companies in this sector were prone to strong losses in this scenario.

In short, the drop in real estate sales and the reduction in credit can be pointed out as potential facts that boosted the contagion to the IMOB Index, composed, on average, by 60% of shares of companies related to Construction and Engineering, according to B3 data (2020).

The other Brazilian stock market indices (Industrial, Consumption, Electricity, and Telecommunications) had less financial contagion from the US market because the estimated covariances between the indices were lower during the 2008 international financial crisis.

Figure 4 presents the estimated covariance between the S&P 500 and Industrial (INDX) indices.

Among all the indices evaluated, the Industrial one is the most diversified since it consists of shares of companies that operate in several sectors of both domestic and foreign markets. As for contagion, the average increase in covariance between the pre-crisis and crisis periods was about 182%. The 29.6% Real depreciation between September and October 2008, according to BACEN data (2011), caused many companies using foreign exchange derivatives to accumulate high losses. Also, there are the effects for industries linked to Metallurgy and Steel, with a high composition of shares in the index, due to the drops in steel production as a result of the downturn in world demand and the price reduction of mineral commodities.

However, the Food and Beverage segments, together representing the largest share in the INDX, may have mitigated part of the international crisis effects for the Industrial Sector Index: the first

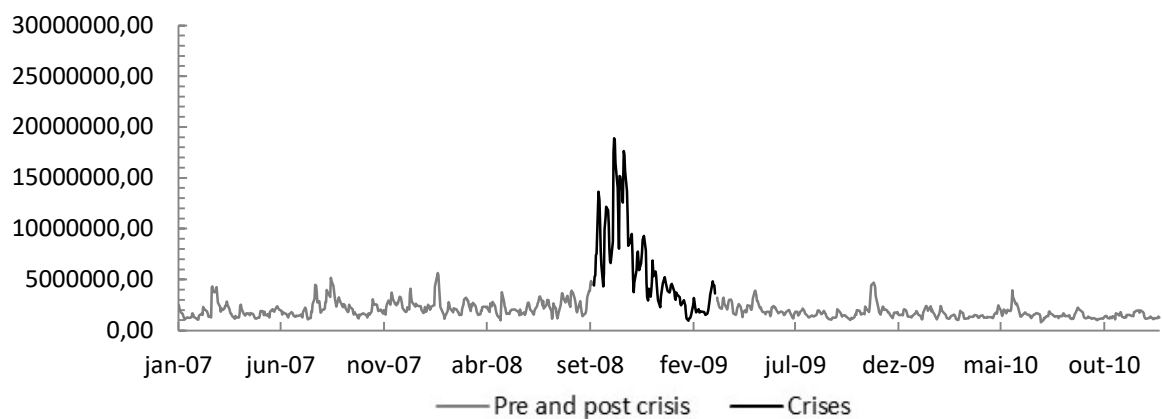


Figure 4. Covariance estimated by the multivariate BEKK- GARCH model (1.1) between the returns of the S&P 500 and INDX indices from 01/10/2007 to 12/30/2010.

Source: Research results.

one because of its essential nature in the composition of baskets of goods, and the second one for it is one of the only segments in the industry to show growth in 2009, about 7.1% according to IBGE data (2020). This way, the contagion to the Brazilian industrial stock segment was significant, yet on a smaller scale compared to the IFNC and IMOB Indices.

Figure 5 shows the estimated covariances between the S&P 500 and Consumption indices from January 2007 to December 2010.

As it can be seen in Figure 5, ICON showed a pattern of behavior similar to that observed for the INDX Index. The increase in average covariance during the subprime crisis was 181.84%. Such similarity can be accounted for by the index composition.

The ICON is made up of shares of two types of consumer segments: cyclical (clothing, car, and hotel) and non-cyclical (food, beverage, and health) ones. Since the greatest part of the index

consists of shares of companies in the Processed Foods and Beverages segment, both with a large participation in the INDX, these tend to present the same behavior.

Therefore, because of the less expressive impacts of the crisis for food and beverage companies, a lower contagion was expected for the ICON Index compared to the IFNC and IMOB Indices.

Figure 6 shows the estimated covariances between the S&P 500 and Electricity indices.

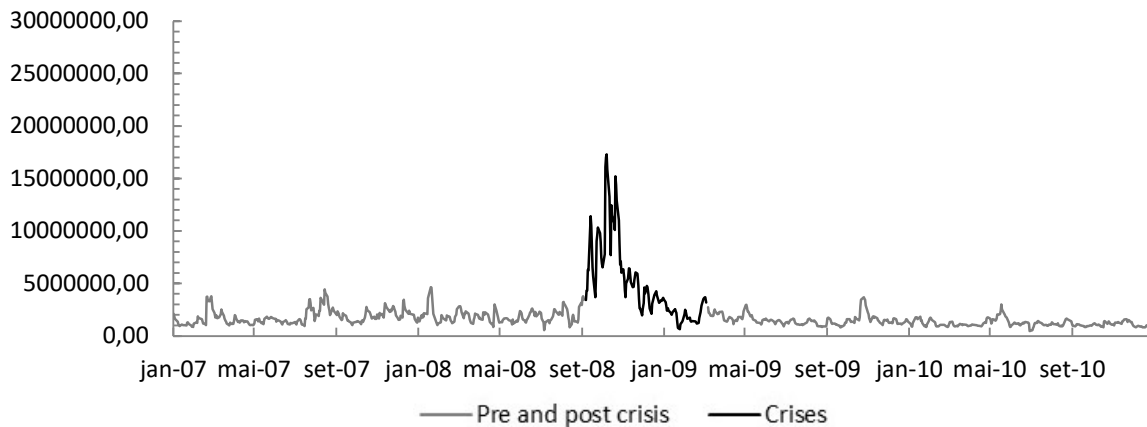


Figure 5. Covariance estimated by the multivariate BEKK-GARCH model (1,1) between S&P 500 and ICON indices returns from 01/10/2007 to 12/30/2010.

Source: Research results.

As evident in Figure 6, despite the financial contagion being lower than that recorded for the other indices, there was a significant increase (approximately 181%) in the covariance between the pre-crisis and crisis periods.

Certain particularities have made the IEE, whose share portfolio consists entirely of companies related to the supply of electricity, less sensitive to the effects of the subprime crisis. As highlighted by Lucon and Goldemberg (2009), the financial crisis has resulted in a reduction in economic activity closely related to electricity consumption. Nevertheless, the reduction in this consumption was not felt significantly by the sector. The study by EPE (2008), which is a company linked to the Ministry of Mines and Energy, points out that in October 2008 the international financial crisis had not yet been reflected in the demand for electricity.

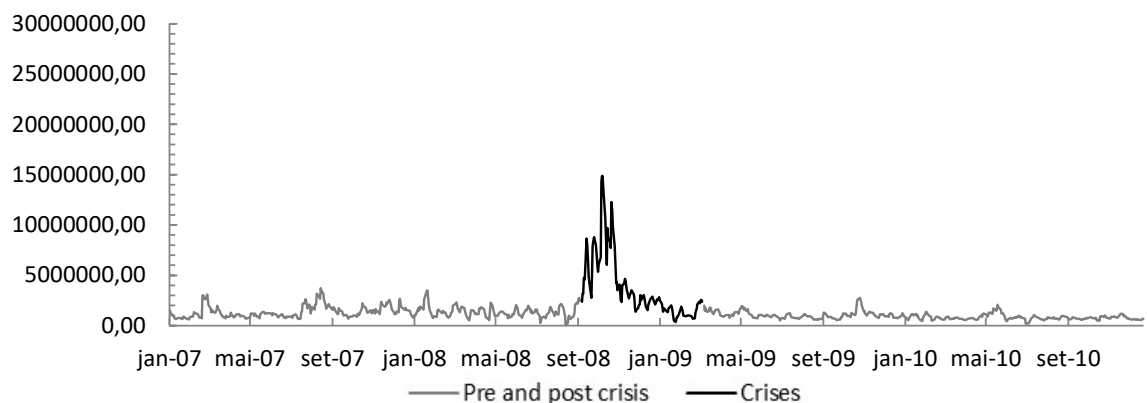


Figure 6. Covariance estimated by the multivariate BEKK-GARCH model (1,1) between the S&P 500 and IEE returns from 01/10/2007 to 12/30/2010.

Source: Research results.

Another factor that reduces the sensitivity of this sector to financial instabilities is the fact that the sales prices charged by distributors are not related to the quantity demanded but are fixed by contracts. Thus, the greater ability to predict the profitability of companies in the energy sector attracts investors who seek these shares in unstable scenarios. Such explanation also corroborates the lower volatility of the returns presented by the IEE, as shown in Figure 1.

Lastly, it is worth analyzing the financial contagion of the subprime crisis to the Telecommunications sector index, which is presented in Figure 7.

Based on Figure 7, there was a 158% increase in the estimated covariance between the two indices. Comprised mainly of shares of landline phone companies, some factors support the fact that the ITEL index, as well as the IEE analyzed above, presents a lower contagion in relation to the other Brazilian indices.

The fact that Brazil Telecom was bought by Oi in 2008 and the record number of cell phones in Brazil – 150 million devices in December that year – according to the National Telecommunications Agency data (ANATEL, 2008) were events to further consolidate this sector in the Brazilian economy after its privatization in the mid-1990s. Furthermore, as reported by the Sustainable Development Indicators – IDS, calculated by the IBGE (2010), the proportion

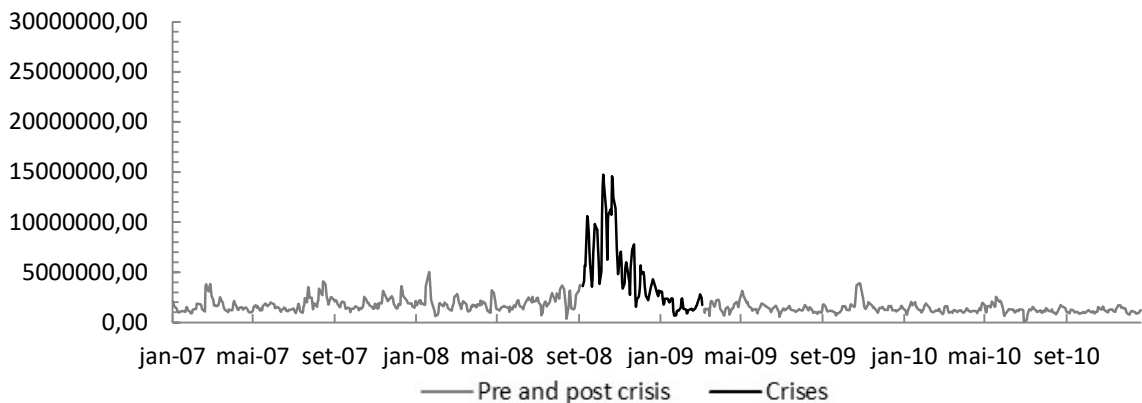


Figure 7. Covariance estimated by the multivariate BEKK-GARCH model (1,1) between the S&P 500 and ITEL returns from 01/10/2007 to 12/30/2010.

Source: Research results.

of Brazilian private households with permanent internet access increased from 8% in 2001 to approximately 24% in 2008.

As a result, greater stability for this sector in general was observed throughout the instability scenario due to the subprime crisis. Such stability, added to the growth of the sector in the domestic market and the mergers and acquisitions that took place, made the shares of these companies less sensitive to the impacts of the crisis compared to the other ones.

In summary, the co-movements verified between the Brazilian and US stock markets can be divided into three distinct periods, according to the estimated covariance. The first one, referring to the pre-crisis period, was characterized by lower covariances compared to the crisis period. The second one was during the financial crisis, when a significant increase in co-movements between the American market and the Brazilian stock indices was detected; however, financial contagion

did not occur in a similar way between the indices analyzed. The third one refers to the period of economic recovery from mid-2009 to 2010, which was marked by the covariance reduction in all the indices analyzed, returning to values close to those verified in the pre-crisis period.

In this context, it is worth emphasizing the importance of the countercyclical measures adopted by the Brazilian government to minimize the impact of the global economic crisis in several sectors. As for monetary and credit policies, the reduction in compulsory deposits by banks, the basic interest rate (Selic) reduction, and the credit supply expansion by public banks aimed to encourage investment and private consumption. As for fiscal policy, both the reduction of some tax rates and the reduction of the government's primary surplus target focused on the expansionary impact on not only the aggregate demand but also the level of employment. Finally, the various actions to mitigate the impacts of the crisis on the exchange rate sought to maintain a minimum liquidity level in this market at the height of the crisis (TCU, 2009).

5. CONCLUSIONS

The analysis of financial contagion for emerging economies such as Brazil is vital in a context of risk aversion and liquidity preference by international investors. The present study aimed to analyze the financial contagion of the subprime crisis to the Brazilian stock market by analyzing the major stock market indices, which represent important sectors of the real economy.

The subprime crisis contagion to the Brazilian stock market was studied with the use of multivariate BEKK-GARCH conditional volatility models. In general, the structure of the estimated covariances between 2007 and 2010 showed clear evidence of contagion in all the indices, as structural breaks were identified in the estimated dynamic correlations between the Brazilian market indices and the US index in the period characterized by the international financial crisis. Furthermore, the estimated covariances between the indices corroborated the contagion, since increases in this association were observed during the subprime crisis.

However, sectoral differences were important in the behavior of the estimated covariance between the Brazilian market indices and the S&P 500 index. The Real Estate and Financial indices showed the highest contagions among all the ones analyzed. The sharp losses of the civil construction industries, as well as the scarcity of internal and external credit which mainly harmed financial institutions, can be identified as crucial factors for such phenomenon.

For the other indices analyzed – Electricity, Industry, Consumption, and Telecommunications – the covariance with the US market during the global financial crisis was lower, showing a lower contagion of the crisis for these indices. Factors such as the lower elasticity of energy prices in relation to fluctuations in demand, the stock portfolio composition of some indices by assets of companies in the food and beverage sector, which were less sensitive to the effects of the crisis, and the increase in the number of cell phones and in the broadband service were important to mitigate the financial contagion on these stock indices.

Studies such as this one in the current context of debate on the various necessary reforms in the structure of the international financial system are highly important, as they provide subsidies for the understanding of how crises can propagate to emerging markets in an economy that is more and more globalized and financially integrated; moreover, they serve as a guide for government action and international institutions in the sectors of the economy and the stock market that are more sensitive to the contagion of financial crises.

As suggestions for future research, studies related to the impacts of adopting an international interest rate in relation to capital flows to emerging economies and financial contagion are relevant in the context of the reform and restructuring of the national and international financial architecture. Another extension of this study refers to the construction of an asset portfolio that takes into account the different effects of financial contagion on sector indices, and accordingly, in the comparison of performance with other asset portfolios during scenarios of stability and financial crises.

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Figure A.1. Correlation estimated by the multivariate BEKK-GARCH model (1,1) between the return of the S&P500 and the returns of the Brazilian stock indices from 01/03/2007 to 12/30/2010

Source: Research results.

AUTHOR'S CONTRIBUTION

All authors contributed equally to the elaboration of the article.


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CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest in this publication.

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