WHICH INFORMATION MATTERS TO MARKET RISK SPREADING IN BRAZIL? VOLATILITY TRANSMISSION MODELLING USING MGARCH-BEKK, DCC, t-COPULAS

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Abstract

The objective of this article was to analyze the spillover effects and channels of volatility from and to Brazilian stock market (Bovespa) in the period that goes from 2014 to 2016. In this period, is marked as one of the most volatile periods since the subprime crisis. A political and economic crisis, followed by federal police investigation combined with a period of slow economic growth in the world, downtrend in commodities prices and unconventional monetary policies in the world, makes the task to identify the sources of price risk dubious. Using a MGARCH-BEKK, DCC and t-Copulas modelling, the main results of the article suggest US monetary policy and rebalancing of portfolios generates volatility to Brazil. However, Bovespa also generates volatility to commodity markets and US bonds market. This is explained by the role that Brazil plays as mediator of these markets when allocators diversify their positions with Latin America and in commodities.

Keywords: DCC, GARCH-BEKK, t-Copulas, Spillover, Market Risk.

1 Introduction

In his seminal work about volatility transmission, Engle, Ito e Lin (1988) explains the volatility process lies in an agile reaction to a contemporary information or in a sluggish information pricing by the market. Particularly, in Brazil, the period between 2014 and 2016, marked Brazilian financial Market as one of the most volatile periods since the subprime crisis. A political crisis, combined with the federal police investigation – called in a free translation as "Car Wash"-, and other geopolitical events as the BREXIT, expectations about monetary policy and presidential elections in USA generated volatility on markets.

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In the middle of this turbulence of information, it is difficult for portfolio managers to discern the relevant news. A correct understanding about the co-dependence between markets is critical to portfolio performance. Additionally, the technology advances in trading provides agility and easier access to international markets to traders. Consequently, strategies of international diversification, and arbitrage opportunities, are easier to implement. Solnik (1995) suggest that internationally diversificate portfolios perform better than domestically ones. Of course, as Markowitz (1952) formalized in his seminal work, the low correlation between assets reduces risk while improves return. However,Longin e Solnik (1995) shows that the correlation between countries tend to variate in time, and to become higher in level, as well.

In a highly-integrated world, both in an economical and a financial perspective, issues about temporal cross dependence of assets return gain importance. The recent literature recognizes the existence of financial co-volatility movements. Particularly, considering these features, they have the potential to carry out the best decisions of hedging, portfolio selection, pricing of assets and derivatives, and market risk management Bauwens, Laurent e Rombouts (2006). Engle (1982) pioneered the development in financial econometrics, that in advance allow to solve problems of aggregation of risk. Developing multivariate models as MGARCH, CCC, DCC or models with flexibilizations of normally distributed returns as copulas [1].

As noted by Bekaert, Hodrick e Zhang (2009), co-volatilities have received too much attention because of the highly-correlated risk that marked crises in emerging markets. These structural breaks in correlation patterns are termed as contagion. A profound discussion about this survey can be find in Dornbusch, Park e Claessens (2000); Calvo e Reinhart (1996); Forbes e Rigobon (2002); Marçal e Pereira (2009).

This article deals with well-known and expected effect of interdependence that occur between markets in periods of stability, as referred by Forbes e Rigobon (2002). The transmission of volatility in Brazil might occur, first in pathway channels that institutional investors (pensions funds, hedge funds) creates to gain exposure on commodities markets throughout Brazilian companies (such Vale and Petrobras) or other emerging markets highly correlated with Brazil, but with less liquidity. In this regard, Cardona, Gutiérrez e Agudelo (2017) attest to the leadership role played by capital market of Brazil in Latin America.

A second motive, relates to portfolio allocators pursuing emerging market shares to balance their risk and return strategies. Of course, it can't be ignored the existence of herd behavior in markets, that drives mainly contagion effect, but also, spillover of risk. The literature that understand the channels and what generates capital flow is too wide to survey here, a profound analysis can be found in Bonizzi (2016), Froot e Donohue (2002), and Hsieh et al. (2011).

The seminal paper of Engle, Ito e Lin (1988), stablished transmission effects in comparison with market efficiency. Modelling Yen/USD, to a wide group of markets, they tested the hypothesis of *Heat Waves* and *Meteor Shower*. The first relates to the fundamentals of an economy, which must not widespread to other markets. In contrast, the *Meteor Shower* hypothesis proposes the tendency of less efficient markets to widespread information. The recent literature on transmission effects still is concerned with the impact of events in economic variables, or about the identification of factors that spread waves of risk among existing channels and with the contagion effect in times of crisis, as well.

Ahmadi, Behmiri e Manera (2016) investigates the effects of different oil-related shocks on the volatility of agricultural prices using a sVAR. The main results suggest a significant impact of oil volatility in agricultural markets. Baldi, Peri e Vandone (2016) additionally uses a

[1] Patton (2009)presents a broad discussion about using Copula functions when modelling financial times series, and their desirable density distribution assumptions to risk modelling.

GARCH-BEKK model to identify transmission effects between $SP500$ and commodities market, finding a negative relationship in transmission effects. Beckmann e Czudaj (2014) adopts a different approach; using future markets they find out a spillover effect within commodity prices. Gozgor, Lau e Bilgin (2016) broadens the precedent literature by trying to measure the role of uncertainty and risk perceptions on commodity's volatility. However, the effects of risk perception and uncertainty are statistically robust just for few products. Particularly, oil plays a leadership role in world's economic activity. Broadstock, Cao e Zhang (2012) in a fama-french three factor model, oil prices changes can be interpreted as a systemic risk to related stocks from Chinese energy sector. In Broadstock e Filis (2014), the authors disentangled oil-prices into specific shock series (supply, demand, aggregate demand) and add US stock market. This approach is important to understand the existence of asymmetric specific shock responses depending on economic signals and sectors. Boldanov, Degiannakis e Filis (2016) expands the analysis to discern shocks in oil-exporting and oil-importing countries. Supply side shocks tend to affect both countries differently, whereas demand side tend to affect all countries positively.

The versatility of the Multivariate GARCH models is used to analyze the vulnerability that countries face about regional or global shocks. Alotaibi e Mishra (2015) studies the effects of volatility spillovers from regional and global factors over GCC stock markets attesting an asymmetry of responses. Cardona, Gutiérrez e Agudelo (2017) tested the hypothesis of decoupling between United States and Latin American Countries – such as Mexico, Brazil, Chile, Peru, Colombia, Argentina. They used a Multivariate GARCH-BEKK model to averiguate the spillover relationships between these markets. The aftermath of the study suggests that Brazil have a leadership role on the region since it transmits volatility to other countries. Additionally, the country is the only one to transmit volatility to the United States. However, the results do not provide support to the financial decoupling hypothesis though.

Liu, Hammoudeh e Thompson (2013) and Hammoudeh et al. (2013) disentangle economic, financial and political risk on BRICS countries. Using a MTAR and an ADRL framework they try to measure the transmission of risk by these factors.

A few works focusing on Brazil's markets movements using MGARCH models can be found. Using DCC and GARCH-BEKK models, Chaine (2011) tested the spillover effect from the $S\&P500$ on the Bovespa index, along the subprime crisis. The hypothesis of transmission is attested, suggesting that during the crisis co-movement is highly positively correlated. Righi e Ceretta () splits the sample in before, during and after the financial crisis of 2008 to evaluate the transmission effect on Brazil's stock market. The results are illustrative as they reveal that Brazil index started to influence other indexes during the crisis, and after the crisis, its market emerged as more integrated to the world. Ferreira et al. (2012) analyzes the contagion effect on the same period under sectorial indexes, finding evidences of a rising co-volatilities, affecting mainly the real estate and financial sectors.

The stylized fact about non-normality of distributions in financial series is a motivation to use a more appealing modelling about this fact. Lee e Long (2009) proposes the use of a Copulas function modelling Multivariate GARCH models such DCC, BEKK and VC. Another approach in this sense is proposed by Christoffersen et al. (2011), that uses copula allowing to asymmetries and tail dependence combined with DCC and DECO models.

Empirical studies applied to Brazil that we had access test the interdependencies in periods of crisis. Therefore, they fit better to Forbes e Rigobon (2002) definition of contagion effects, instead of transmission effect. .Barroso, Silva e Sales (2016) attempt to provide evidence of a portfolio rebalancing effect due to unconventional monetary policies in US. To attest the effects of Quantitative Easing on capital inflows in Brazil, the authors built a counterfactual exercise. Their detailed analysis confirmed some intuitions about spillover effects from US monetary policy. Capital inflows led to exchange rate appreciation, stock market boom, and credit growth. Moreover, the results are as revealing as enlightening to the effects of capital flows to economic variables in Brazil.

The objective of this article is to analyze the transmission effects and channels of volatility from and to Brazilian stock market. The hypothesis tested here is the existence of these channels because of: i) Brazil is a mediator of perturbance and volatility of commodities (metals, energy, and agricultural) and Latin American markets; ii) The volatility of financial market in Brazil is highly dependent of international disturbances (politic, geopolitics, economic); iii) The fundamentals of the Brazilian economy explain by themselves the volatility in stock markets. The methodology chosen to test the transmission of volatility to Brazil is based on Cardona, Gutiérrez e Agudelo (2017), that uses a bivariate and a trivariate GARCH-BEKK and the estimation is based on Lütkepohl (2005) and Tsay (2013). Even though these models present difficulties to encounter significant parameters, their outcomes are intuitive and objective.

The difficulty to disentangle the sources of shocks in a country with political and fiscal instability as Brazil today is evident in the literature review. This factors shed light on the need to clarify the right channels of risk to the financial market in Brazil. Moreover, the lack of empirical applications directed to Brazil highlights the contribution of this article. Besides this introduction, this paper is organized in four additional sections. The next present the data main features. The third section discusses the methodology applied, followed by the fourth that presents and discusses the results. Finally, the fifth section is the conclusion.

2 Data

The times series used are daily logarithmic returns of Brazil and USA stock index; agricultural commodities as Corn, Sugar, Soybeans, Coffee and Etanol; other commodities are Iron ore and Brent Oil (is the most relevant to oil companies in Brazil); and financial products as Credit Default Swaps (CDS) of 5 years maturity, Brazilian and USA bonds of 10 years maturity, as well. The data was provided by Thomson Reuters Database, and the sample of study goes from January of 2014 to December of 2016.

Table 1 – Descriptive Statistics of returns – Period: jan/2014 to dec/2016

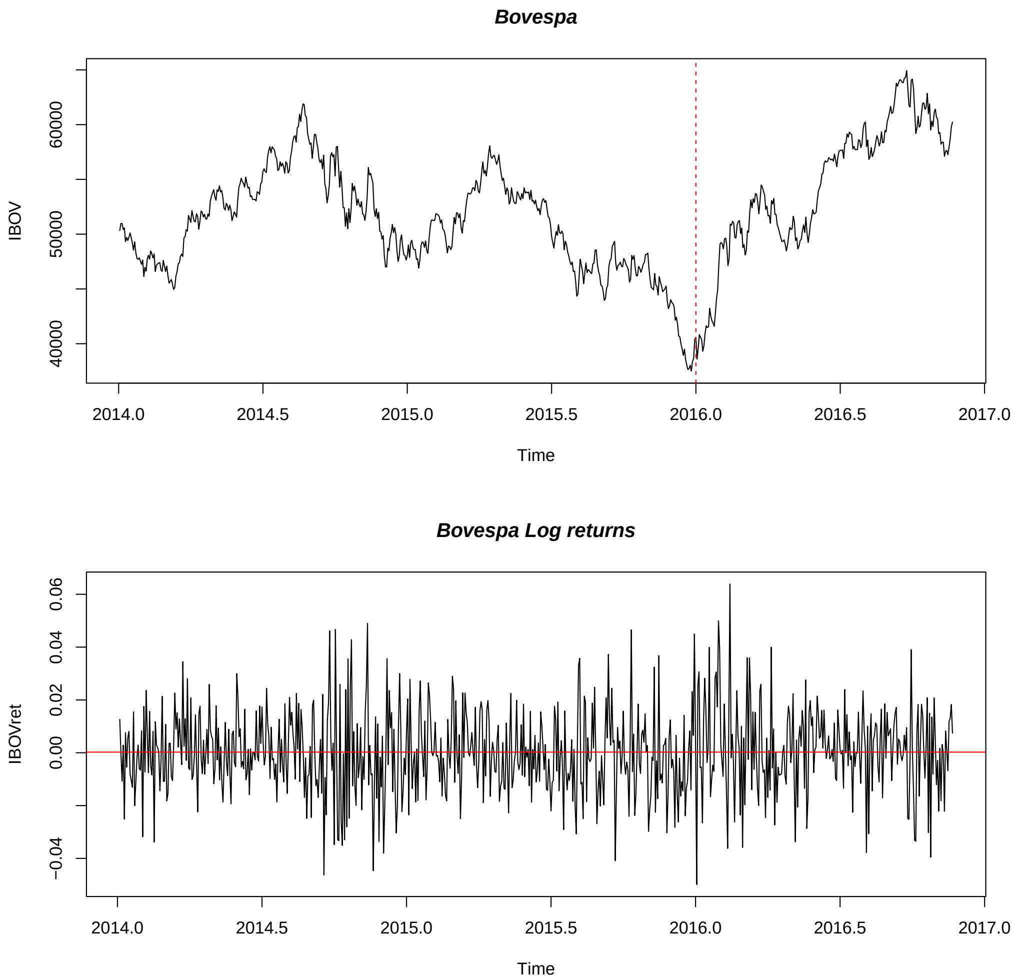
	Min.	Mean	Median	Max.	S.D.	C.V (%)	Kurtosis (excess)	J.B.
Bovespa	- 4.9880	0.0246	0.0103	6.3867	1.5925	64.573	0.5847	14.25(0.00)
SP500	- 4.2021	0.0282	0.0349	3.8291	0.8600	30.470	2.1609	160.63(0.00)
Gold	- 3.3842	- 0.0083	- 0.0574	4.6866	0.9440	-112.955	2.1496	135.52(0.00)
Iron	-15.8374	- 0.0764	0.0514	12.0955	1.8811	-24.593	-2.3083	148.74(0.00)
Brent	- 10.2449	- 0.0901	- 0.1785	10.3094	2.4907	-27.630	2.0159	33.01(0.00)
CDS5y	- 15.6975	0.0492	0.0000	14.1385	3.2812	66.623	2.2683	160.24(0.00)
BR Bonds10y	- 5.2182	- 0.0200	- 0.0398	4.6228	1.1464	-57.238	1.5400	74.25(0.00)
US Bonds10y	- 11.0214	- 0.0259	- 0.1455	10.7081	2.3485	-90.5484	1.5262	71.71(0.00)
Corn	- 5.5197	0.0071	- 0.0894	5.3725	1.3666	190.214	0.6684	19.42(0.00)
Sugar	- 4.7055	0.0358	0.0371	3.7537	1.1678	32.5624	0.2895	2.85(0.24)
Soybeans	- 7.6265	- 0.0441	0.0178	9.0971	1.3986	-31.7029	5.2865	876.69(0.00)
Coffee	- 9.3006	0.0320	0.0191	9.1640	2.1976	68.5139	1.5771	78.91(0.00)
Ethanol	- 5.8230	0.0113	0.0022	9.0269	14.5958	128.0351	2.8073	251.57(0.00)

The descriptive statistics shows that some series present outliers, as US Bonds and Iron. The test of normality rejects the null hypothesis of normality to almost all the series. Additionnaly, is possible to identify that the agricultural commodities market has a more disperse distribution than the metals and financials. The excess of kurtosis different from zero suggests the adequacy of these series to a conditional heteroscedasticity modelling.

The political crisis in Brazil was one of the major features of the period of this study. In some way, have driven prices on financial markets due expectations relating conduction of economic policy. Moreover, the presidential election in 2014 was cutthroat, it expanded uncertainty and disturbed investor's portfolios.

In fact, is possible to observe on Figure 1 the uptrend since 2014, followed by a reversal movement that marks Brazilian stock market's phase of downtrend. Amorim (2016) highlights that the presidential election generated a polarized dispute between the candidate of Social Democratic Party (PSDB) Aécio Neves and the representant of Labor Party (PT) Dilma Rousseff. The expectations of a possible election of the first forced at that time a raising tendency of stock markets' prices until 2015. This pressure of buyers became known in a free translation as "bull election's market".

Figure 1 – Bovespa Prices and log returns – Period: jan/2014 to dec/2016



Afterwards, in 2015, the political climate worsens. As Globo (2014) pointed the elected president Dilma Rousseff peddled a lie on society when she changed all the economic team and pivoted to an austerity economic policy – meanwhile her proposals were about more fiscal expansion policies. Moreover, Almeida e Salto (2016) explain that is in this period that the problems about public debt becomes explicit. In the same period, the stock market's prices of the companies became more volatile.

August of the same year, the govern delivered to congress the budget of the next year in a deficit situation. This event is sparkled as the first time on the history of the country (GLOBO, 2015). It reinforces the fiscal problems that the country faces, what motivates a downgrade on credit rating by risk agencies Standard and Poor's and Fitch. Finally, at end of the year the leader of the government went to jail as suspect of bribery.

Nevertheless, this context conjectures a political crisis with consequences on Bovespa's (brazilizan stock exchange) volatility. Once an impeachment, in the prevailing political system in Brazil could solve the crisis (ABRANCHES, 1988). Just the raising probability of these event resulted in a bull market in Brazil. However, at the same period the international environment enhanced beginning an uptrend as well. Is possible to note when observing the trend of prices of Brent Oil, S&P500 index and the other commodities. The high correlation between them is explained by the highly dependence of Brazil of exports of primary products and due the dynamic of trading of certain commodities as oil and iron. Speculators and investors might prefer to reduce costs of trading by buy and sell financial products of companies highly associated with its markets as Vale and Petrobras. Its worsen analysis of portfolio managers making difficult to discern correlation from causality.

3 Methodology

Since Markowitz (1952), the analysis of risk is based on statistical measures. Sharpe (1964), Lintner (1965) and Mossin (1966) relativized in a linear relationship the notion of risk with the Capital Assets Pricing Model (CAPM). Problems of adherence to data experienced by this models motivated Ross (1976) to propose Arbitrage Price Theory (APT) to increase robustness of beta as measure of exposure to systemic risk.

However, Mandelbrot (1963) notes the misbehaving of models of risk measurement due to the inconsistency between the assumption of normally distributed returns and real world financial returns behavior. Financial times series tend to cluster, a problem solved by modelling the conditional heteroscedasticity. Proposed by Engle (1982) with the Autorregressive Conditional Heteroscedasticiy(ARCH) model. Bollerslev (1986) proposed a generalization with the Generalized ARCH(GARCH), pioneering a set of extensions trying to capture leverage effect of financial time series.

Moreover, as Cardona, Gutiérrez e Agudelo (2017) suggest, the aftermath of financial crisis led scholars to propose models allowing to predict idiosyncratic risk and their effects on other markets. Additionally, portfolio managers must base their decisions of allocation on cross-assets effects (DANÍELSSON, 2011). Policy makers must feed up their macroeconometric models with the interdependence between economic variable before taking a decision, as well. Although valuable, the positive definiteness and the excess of parameters generated by a multivariate model, requires imposing some restrictions (FRANCQ; ZAKOIAN, 2011).

Among them, the most direct generalization is the VEC Model proposed in Bollerslev, Engle e Wooldridge (1988), the use of additional constraints generates the BEKK model in Engle e Kroner (1995). A model relying on univariate GARCH is the Constant Conditional Correlation (CCC) Bollerslev (1990), an extension is the Dynamic Conditional Correlation(DCC) model proposed in Engle (2002) and Tse e Tsui (2002).

As Tsay (2013) stablish, the DCC is used modelling the conditional correlation matrix as

$$\rho = D_t^{-1} \sum_t D_t^{-1} \tag{1}$$

D_t is the diagonal matrix of the k volatilities at time t. The model uses marginal volatility series to extract the conditional correlation matrix of them. Supposing $\eta_t = (\eta_{1t}, \cdots, \eta_{kt})^{`}$ as the standardized innovation vector. In this regard, p_t is the volatility matrix of η_t. The model proposed by Engle (2002), differs from Tse e Tsui (2002) because instead of assuming the past correlation information just as feeding the model output, it considers the η_t.

Following the approach in Tsay (2013), is used a Copula function (C) to provide a better understanding about the dependence structure of the joint distribution of this variables.

The Copula links together marginal distribution functions to form joint distribution functions. Supposing a vector random variable $X = [X_1, X_2, \cdots, X_n]^{'}$, with distributions $F_1, F_2, \cdots, F_n$. Their joint distribution function F (PATTON, 2009). According Sklar (1959) theorem:

$$F(x) = C(F_1(x_1), F_2(x_2), \cdots, F_n(X_n), \forall x \in \mathbb{R}^n \tag{2}$$

As pointed by Patton (2009), extracting the marginal distributions from a multivariate function, is very useful for time series modelling, because the Copula function (C) does not requires the same distribution of all variables to extract information from the model. Additionally, when dealing with financial times series, the non-normality of them is a stylized fact. Therefore, this is an advantage when the shape and the adherence of the data is the main interest of the model. In this study, will be used a t-Copula function as suggested by Tsay (2013). Using the model based in Creal, Koopman e Lucas (2013) to describe the conditional volatilities and correlations in a manner analogous to a DCC model.

However, to understand the direction of the flow of shocks and volatilities the GARCH-BEKK model is appealing and intuitive, even though it presents some difficulties of estimation.Resende (2015) proves that a stochastic sequence of a variable $X = (\epsilon_t)_{t\in N}$ is a GARCH-BEKK model if:

$$\begin{cases}\epsilon_t = (H_t)^{\frac{1}{2}}\eta_t\end{cases}$$

$$H_t = \Omega + \sum_{i=1}^{q}\sum_{k=1}^{K} A_{ik}\epsilon_{t-i}\epsilon_{t-1}^{'}A_{ik}^{'} + \sum_{j=1}^{p}\sum_{k=1}^{K} B_{jk}H_{t-j}B_{jk}^{'} \tag{3}$$

Francq e Zakoian (2011) defines this relation as a strong GARCH process. Where K is an integer, Ω, A_{ik} and B_{jk} are square mxm matrices, and ω is positive definite; η_t is an i.i.d sequence. The specification ensures positive definites to H_t.

Francq e Zakoian (2011) derives the vector form of the equation specification H_t:

$$vech(H_t) = vech(\Omega) + \sum_{i=1}^{q} D_m^{+}\sum_{k=1}^{k}(A_{ik}\otimes A_{ik}^{'})D_m vech(\varepsilon_{t-i}\varepsilon_{t-i}^{'}) + \sum_{i=1}^{p} D_m^{+}\sum_{k=1}^{k}(B_{ik}\otimes B_{ik}^{'})D_m vech H_{t-j} \tag{4}$$

Beeing the matrix in the form (mxm), in a diagonal vector representation, are also positive semi-definite matrices. Then exists A_{ik} and B_{ik} and the parametrization is equivalent to a vec (FRANCQ; ZAKOIAN, 2011).

Engle e Kroner (1995) shows that the BEKK in the bivariate case becomes:

$$H_t = \Omega\Omega' + \begin{bmatrix} a_{11}^* & a_{12}^* \\ a_{21}^* & a_{22}^* \end{bmatrix}^{'} \begin{bmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{2,t-1}\varepsilon_{1,t-1} \\ \varepsilon_{2,t-1}\varepsilon_{1,t-1} & \varepsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11}^* & a_{12}^* \\ a_{21}^* & a_{22}^* \end{bmatrix} + \begin{bmatrix} g_{11}^* & g_{12}^* \\ g_{21}^* & g_{22}^* \end{bmatrix}^{'} H_{t-1} \begin{bmatrix} g_{11}^* & g_{12}^* \\ g_{21}^* & g_{22}^* \end{bmatrix} \tag{3}$$

Suppressing the time subscripts and the GARCH terms, it becomes:

$$H_{11} = \Omega + a_{11}^2\varepsilon_1^2 + 2a_{11}^*a_{21}^*\varepsilon_1\varepsilon_2 + a_{21}^2\varepsilon_2^2$$
$$H_{12} = \Omega + a_{11}^*a_{12}^*\varepsilon_1^2 + (a_{21}^*a_{12}^* + a_{11}^*a_{22}^*)\varepsilon_1\varepsilon_2 + a_{21}^{*2}\varepsilon_2^2 + a_{21}^*a_{22}^*\varepsilon_2^2$$
$$H_{22} = \Omega + a_{12}^2\varepsilon_1^2 + 2a_{12}^*a_{22}^*\varepsilon_1\varepsilon_2 + a_{22}^2\varepsilon_2^2$$

This model becomes more parsimonious than a vec specification as it economizes on parameters (ENGLE; KRONER, 1995). As stated by (TSAY, 2013), even though the framework provided by the BEKK model produces some positive-definite volatility matrices and attractive representations. It has problems of application, whereas their parameter are constantly non-significant at 5% level. To encounter a good estimation, the model should be used at maximum three variables.

The process of estimation of the MGARCH-BEKK model in this article will follow Cardona, Gutiérrez e Agudelo (2017) proposal, and the approach of (LÜTKEPOHL, 2005) and (TSAY, 2013). First, we encounter the stationary series applying the tests of unit root as Dickey-Fuller, Phillips Perron, and KPSS. Then, the series are grouped in pairs with the Bovespa, and the estimation process will follow the CRAN Package 'MTS', developed by Ruey Tsay. To estimate the DCC and t-Copula dynamic correlation. First, smoothing the covariance returns of the series using a Vector Autorregressive (VAR) model. Then, their residuals are fitted to capture the conditional heteroscedastic process in a univariate GARCH model. Finally, these uncorrelated residuals will be used as input of a DCC and t-copulas process, to capture the cross-dependence of this series. described in this section.

Thereafter, the Portmanteau Test select the models considered to analysis. Table **??** in the appendix provides the test results of all Bivariate estimation done. This rigorous treatment with the residuals of this series is justified because it will be followed by a structural analysis. The ARCH parameter will be interpreted as a shock or a perturbance in the cross relation of the series. Whereas the GARCH term represents the volatility transmitted to the other country. The direction of this process is determined by the position of the coefficients, the magnitude and their significance.

4 Results

4.1 Dynamics of Volatility in Brazil

The analysis of the parameters of the model fitted describe the dynamic of the series studied. Intuitively they provide understanding about the velocity of reaction of the market to a given news and the persistence of this disturbance in time. Additionally, modelling to capture skewness of series allow to adjust the model differently to negative and positive news.

Table 2 – Parameters of family GARCH estimation to Bovespa – Period: jan/2014 to dec/2016

	ARCH(3)	GARCH(1,1)	EGARCH(2,2)	TGARCH(1,1)
μ	0.0000 7.78(0.00)	0.0000 3.88(0.00)	-0.3162 -1.02(0.30)	0.000 1.01(0.31)
α_1	0.0000 0.00(0.99)	-	0.1001 -1.67(0.09)	0.0002 0.02(0.96)
α_2	0.2091 2.95(0.09)	-	-0.1793 -2.90(0.00)	-
α_3	0.0946 1.66(0.09)	-	-0.1793 -2.90(0.00)	-
β_1	-	0.9292 63.17(0.00)	0.4083 10.15(0.00)	0.9621 88.3(0.00)
β_2	-	-	0.5534 535.1(0.00)	-
γ_1	-	-	10.33 -1.22(0.21)	0.0722 2.71(0.00)
γ_2	-	-	0.2251 2.48(0.01)	-

Note: Estimation of ARCH/GARCH model, following Daníelsson (2011) and Morettin (2008).

All the models were chosen based on the methodology of the section 3, thus just the most robust ones are showed in this section. Comparing the models is possible to observe that the EGARCH (2,2) has a higher reaction, being it negative. This might be due the leverage effect, when negative returns tend to generate more panic, consequently, faster movements. In contrast the TGARCH (1,1) presents almost zero reaction.

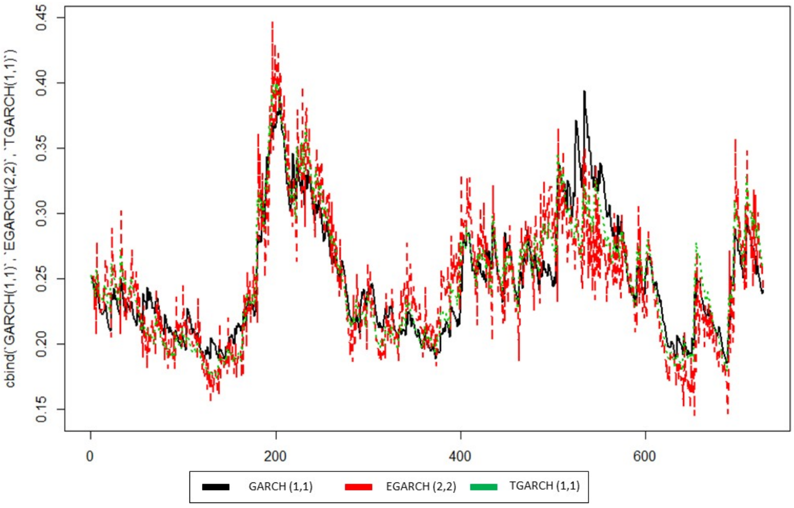
Table 3 – Half-Life of volatility shocks in Brazil – Period: jan/2014 to dec/2016

ARCH(3)	GARCH(1,1)	EGARCH(2,2)	TGARCH(1,1)
0.53	33.17	20.12	42.44

Note: Based on the parameters estimated.

The persistence of the brazilian is of 33 days when considering a GARCH(1,1) specification, of 42 and 20 days, respectively seeing a TGARCH(1,1) and EGARCH(2,2) specification. In words, this suggest that a shock given by any information that hit the market, lasts in these number of days to return to their unconditional average volatility.

Figure 2 – Comparative of Volatility Models applied to Bovespa – jan/2014 to dec/2016



4.2 Dynamic Correlation

A preliminary analysis on tables 3, 5 and 6 shows that in average, the most volatile Variable is the CDS(58%), followed by Brent(38%), US treasury Bonds(36%) and Iron(29%). The first differs from others because is a derivative. However, all of them are important variables to Brazilian stock market. Reflecting monetary policy, world's economic activity and, political and default uncertainty in Brazil.

Table 4 – Dynamic Correlation of Bovespa vs US Bonds, Stocks and CDS Brazil

				Bivariate		
		Bovespa	SP500	US Bonds 10y	BR Bonds 10y	CDS 5y
Anualized Volatility (%)		24.89	12.98	36.97	17.69	58.64
DCC - GARCH (Engle) (%)			45.36	- 40.10	- 4.76	2.46
	Q_{1}		11.97(0.28)	9.15(0.51)	26.23(0.00)	8.16(0.61)
	Robust Q_{1}		34.07(0.73)	38.61(0.53)	30.09(0.87)	45.57(0.25)
DCC - GARCH (Tse & Tsui)			44.32	- 37.47	- 4.79	2.51
	Q_{1}		11.97(0.28)	8.71(0.55)	26.23(0.00)	8.10(0.61)
	Robust Q_{1}		34.07(0.73)	33.38(0.76)	30.09(0.87)	45.43(0.25)
				Trivariate		
t Copulas - GARH		45.36	3.14	- 40.81	- 3.33	2.92
	Q_{1}	11.97(0.28)	14.89(0.13)	14.89(0.13)	21.05(0.02)	6.05(81.80)
	Robust Q_{1}	34.07(0.73)	98.29(0.25)	98.29(0.25)	109.15(0.08)	128(0.00)

Table 5 – Dynamic Correlation of Bovespa vs Metals

			Bivariate			
		Bovespa	Brent	Iron	Gold	Copper
Anualized Volatility (%)		24.89	38.78	29.68	14.84	19.88
DCC - GARCH (Engle) (%)			2.46	7.74	2.04	7.58
	Q_{1}		8.16(0.61)	3.52(0.96)	11.90(0.29)	11.78(0.29)
	Robust Q_{1}		45.57(0.25)	55.61(0.05)	43.37(0.32)	42.80(0.35)
DCC - GARCH (Tse & Tsui)			2.51	8.08	2.04	7.52
	Q_{1}		8.10(0.61)	3.34(0.96)	11.90(0.29)	12.27(0.26)
	Robust Q_{1}		45.43(0.25)	64.91(0.00)	43.37(0.32)	39.61(0.48)
			Trivariate		Trivariate	
t Copulas - GARH			2.92	9.05	4.06	7.73
	Q_{1}		6.05(81.80)	6.05(81.80)	21.05(0.02)	13.10(0.21)
	Robust Q_{1}		128(0.00)	128(0.00)	109.15(0.08)	84.17(0.65)

Table 6 – Dynamic Correlation of Bovespa vs Agriculturals

		Bovespa	Corn	Sugar	Ethanol	Soy	Coffee
Anualized Volatility (%)		24.89	21.46	-	22.56	21.24	36.67
DCC - GARCH (Engle) (%)	Diagnostic Test		0.09	-	- 0.21	3.46	- 2.64
	Q_1		15.29(0.12)	-	4.30(0.93)	4.40(0.92)	9.62(0.47)
	Robust Q_1		26.22(0.95)	-	52.07(0.00)	40.86(0.43)	48.48(0.17)
DCC - GARCH (Tse & Tsui) (%)			0.09	-	- 0.06	3.46	-2.62
	Q_1		15.70(0.10)	-	4.74(0.90)	4.40(0.92)	9.68(0.46)
	Robust Q_1		26.11(0.95)	-	49.25(0.14)	40.84(0.43)	48.89(0.16)
			-				
t Copulas - GARH (%)			2.32	2.42	0.04	5.20	0.01
	Q_1		15.59(0.11)	4.13(0.93)	8.42(0.58)	4.13(0.93)	8.42(0.58)
	Robust Q_1		74.82(0.87)	88.05(0.53)	98.27(0.25)	88.05(0.53)	98.27(0.25)

The analysis of the correlations show that just the *S&P* 500, and the Treasury bonds of Brazil are highly correlated with the Bovespa Index. The first presents an average of 45% when considering the DCC (Engle), 44% when considering the DCC(TseTsui), and 46% when considering the t-Copulas. Whereas the second presents a negative correlation with the stock market index.

These results are important because is expected that the US stock market affects the Brazil(BR) stock market, directly or indirectly. As referred in the introduction section 1, important money flow channels are encountered in portfolio balancing due unconventional monetary policies in US (see Barroso, Silva e Sales (2016). In the following sections this results become clear.

Another important result is that the average dynamic correlation with the stock market in Brazil is low. Suggesting a good potential of diversification of the index, as well as, the Bovespa has low vulnerability to commodities market. In the figure 5, is possible to note that the agricultural commodities are in a downtrend of correlation in the mid-term. Moreover, especially in high volatile variables(Brent and CDS), the correlation is more unstable on time.

Comparing the different models, whereas that in average correlation, the t-Copulas model is more volatile than the DCC's. Intuitively, this model considers in a higher precision, tail movements in the joint distribution of the series.

4.3 Bivariate Risk Transmission Analysis

Table shows the main results found in the estimation of a Bivariate GARCH-BEKK. In the agricultural group of commodities, were maintained just soybeans. Sugar, corn and ethanol did not fit well in the model, presenting serial autocorrelation. Therefore, they were excluded of the part of the bivariate estimation.

A structural analysis in the table 5 estimation, given the significance of the parameters, reveals that gold, iron ore, brent oil and US long term bonds cause a perturbance to Bovespa, without persistence. Meanwhile, Brazil's index does not affect other variables. The interdependence in volatility generates a bidirectional channel with copper, soy and unidirectional from monetary policies in US.

Table 7 – Estimation of the Bivariate – BEKK(1,1) relative to Bovespa – Period: jan/2014 to dec/2016

	S&P500	US Bonds10y	Gold	Iron	Brent Oil	Copper	Soybean
Shock from Bovespa	0.0276	0.0036	-0.0457	-0.0457	6.3867	1.5925***	-0.0309
Shock from Bovespa	0.0408	0.2250***	0.1633***	0.2331***	3.8291	0.8600	-0.0022
Volatility from Bovespa	0.0022	-0.0049	0.0215	-0.0215	4.6866	0.9440	0.0066*
Volatility from Bovespa	-0.0018	-0.0543**	-0.0283	-0.0283	12.0955	1.8811	-0.0011
Portmanteau Test	1.54(0.76)	2.26(0.81)	7.82(0.16)	0.10(0.99)	0.55(0.45)	0.09(0.75)	3.57(0.61)
Portmanteau – Rank Based	7.98(0.15)	2.58(0.76)	10.33(0.06)	12.83(0.02)	0.23(0.62)	1.56(0.21)	3.36(0.64)

Note: The estimation of the model follows the methodology applied in Tsay (2014). Significance of the parameters: *, **,***; corresponds respectively to 10, 5 and 1% of confidence level.

Even though Brazil generates volatility to copper prices, the magnitude on the other direction is stronger ($-0.0039 vs 0.037$). Therefore, the use copper, as a main input in many real state business in China, and in the production of electronics, is recently highly associated with the economic activity in the world. The results of Gold suggest as it is a precious metal used mainly as reserve of value by investors in a kind of flight to security, that the movements of gold that affect the Bovespa are related to risk aversion behavior, not implying a problem in the fundamentals of the economy. Extreme events tend to increase volatility of Gold, what per se affect the willingness by allocators to rebalancing their portfolio. These kinds of events tend to have less persistence (ENGLE; ITO; LIN, 1988).

Extending the findings of Barroso, Silva e Sales (2016), where unconventional monetary policies in US leads to an exchange rates appreciation, stock market's boom and credit growth. Whereas he suggests the existence of strong propagation channels based on inflow of excess monetary supply from US to Brazil, the analysis here reinforce this channel as a path of risk spreading to stock's markets. In this regard, there is a portfolio rebalancing implication in carry trade portfolios because there is a wealth effect on the economy given the QE policy. However, as Gunes (2012) propose, 'fear factors' incorporated on the Volatility Index (VIX), have strong implications in carry trade balancing.

The results found with iron ore, brent oil and none relationship with SP500 is not consistent to what is expected to capital market in Brazil. The index is mainly constituted by metals companies such CSN and Vale, a big player in the oil market as Petrobras and some banking companies. Thus, the significance of these commodities is expected. Might exist some limitations in a bivariate analysis, whereas it does not consider arbitrage effects among stocks exchange along the world. Different markets closing and opening are sufficient to traders seek opportunities generated by the same news in different stock exchanges. In his seminal work, Engle, Ito e Lin (1988) has an intuitive illustration about this:

> "[...]when the monetary supply statistics are announced in the market in New York at 4:10pm of Thursday, there are less than thirty minutes to trade actively in New York. If all traders do not share the common belief about the meaning of the announced money supply, then it takes a few hours of actual trading to settle the difference in traders' priors. [...]some types of technical analysis behavior could have this characteristic. Suppose that there was a large yen appreciation in the Tokyo maket. If the shock creates the expectation of more appreciation , then the speculation may take place in the European markets of the same day and not wait until the Tokyo market of the next day" (ENGLE; ITO; LIN, 1988, p. 5).

This article also intends to test the channel of investment flows due to costs reduction – invest in a pathway created by the high correlation of Petrobras and Vale with such commodities. To accomplish this objective, the analysis will be expanded to a trivariate model, being: i) Bovespa, Brent Oil, and Petrobras; ii) Bovespa, Iron Ore, SP500; iii) Bovespa, SP500 and BR Bonds 10y.

4.4 Trivariate Risk Transmission Analysis

In contrast with bivariate models, the parameter of trivariate of the relationships arised as dubious when treated in a direct manner. The first insightful result is that the perturbance from Bovespa to Brent Oil becomes significant when Petrobras is introduced. Even though the effect of Oil on stock market is stronger ($0.085 vs - 0.037$), what suggests that Bovespa plays an indirect role on the oil market. This conclusion is reinforced by the dynamic assumed by Petrobras and Brent Oil. While Brent oil causes shocks on Petrobras, the persistence waves of risk are spread to oil market by Petrobras. This result deserves further study, because the company does not play just the role of a big state oil company, but, recently have been target of investigations about corruption. In some way, Petrobras is today a proxy of political stability in Brazil. Furthermore, a more profound understanding about the interdependence between oil companies around the world in a scenario of low oil price – EBITDA margins are harder to obtain.

A similar effect is found in the interconnection between Vale and Iron Ore market given by the significance of the parameters. Observing the vector containing SP500, Iron Ore and Bovespa, both indexes become relevant to explain codependences in the Iron Ore market. Additionally, Brazil's index appears to have more vulnerability to disturbances of the commodity. This interdependence becomes even more stronger when considering the vector of Bovespa, Iron Ore, and Vale. Bovespa plays a bidirectional role with Iron Ore ($-0.0190 vs 0.1181$ respectively). The intuition is that the index act as mediator in the transmission effect to Vale, as the company has a persistence of covolatility caused by the commodity.

Table 8 – Estimation of the Trivariate – BEKK(1,1) relative to Bovespa – Period: jan/2014 to dec/2016

Bovespa - Brent Oil - Petrobras		Bovespa - Iron Ore - Vale	
Shock from Bovespa to Brent Oil	-0.0371*	Shock from Bovespa to Iron Ore	-0.0958***
Shock from Brent Oil to Bovespa	0.0885**	Shock from Iron Ore to Bovespa	0.1233
Volatility from Bovespa to Brent Oil	0.0041	Volatility from Bovespa to Iron Ore	-0.0190***
Volatility from Brent Oil to Bovespa	-0.0119	Volatility from Iron Ore to Bovespa	0.1181***
Shock from Bovespa to Petrobras	-0.1161***	Shock from Bovespa to Vale	-0.1682***
Shock from Petrobras to Bovespa	0.0060	Shock from Vale to Bovespa	-0.2781**
Volatility from Bovespa to Petrobras	0.0273***	Volatility from Bovespa to Vale	0.0426***
Volatility from Petrobras to Bovespa	-0.0570***	Volatility from Vale to Bovespa	-0.0802
Shock from Brent Oil to Petrobras	-0.0757***	Shock from Iron Ore to Vale	0.0901***
Shock from Petrobras to Brent Oil	0.0885	Shock from Vale to Iron Ore	0.0694
Volatility from Brent Oil to Petrobras	-0.0128	Volatility from Iron Ore to Vale	-0.0077
Volatility from Petrobras to Brent Oil	0.0626***	Volatility from Vale to Iron Ore	-0.0169***

Bovespa - Iron Ore - SP500		Bovespa - SP500 - US Bonds10y	
Shock from Bovespa to Iron Ore	-0.0475**	Shock from Bovespa to SP500	-0.0935
Shock from Iron Ore to Bovespa	-0.0245	Shock from SP500 to Bovespa	0.0719***
Volatility from Bovespa to Iron Ore	-0.0036***	Volatility from Bovespa to SP500	0.0127
Volatility from Iron Ore to Bovespa	0.0121	Volatility from SP500 to Bovespa	-0.0162***
Shock from Bovespa to SP500	0.0263	Shock from Bovespa to US Bonds10y	-0.0141
Shock from SP500 to Bovespa	0.0363	Shock from US Bonds10y to Bovespa	0.0662***
Volatility from Bovespa to SP500	-0.0076	Volatility from Bovespa to US Bonds10y	0.0066***
Volatility from SP500 to Bovespa	-0.0071	Volatility from US Bonds10y to Bovespa	0.0201***
Shock from Iron Ore to SP500	0.0349	Shock from SP500 to US Bonds10y	-0.0065
Shock from SP500 to Iron Ore	-0.0012	Shock from US Bonds10y to SP500	0.0246
Volatility from Iron Ore to SP500	0.0979	Volatility from SP500 to US Bonds10y	0.0201***
Volatility from SP500 to Iron Ore	-0.0141***	Volatility from US Bonds10y to SP500	-0.0048

Note: The estimation of the model follows the methodology applied in Tsay (2014). Significance of the parameters: *, **,***; corresponds respectively to 10, 5 and 1% of confidence level.

All these results emphasize the first channel of risk spreading proposed in this article. Bovespa serves as pathway throughout fund managers open and close positions on commodities. A different perspective to the position of the Brazil in the international financial market system is that it plays a role of a negatively correlated asset to portfolio allocators. Solnik (1995) proposed the benefits that managers could accomplish in this approach. The intuitive interpretation when observing the connections between Bovespa, SP500 and US treasury bonds, differently than the bivariate analysis, now the relation between SP500 and Bovespa is significant with a unidirectional effect from SP500. Additionally, the US treasury bonds tend to affect Bovespa, in both generating perturbance and volatility. This results are aligned with the recent literature about portfolio and of capital flow.

Barroso et al. (2013) and Barroso, Silva e Sales (2016) suggested that QE policies affects portfolio rebalancing, generating flow of capital to Brazil. Bonizzi (2016) attested the eagerness of international investors for risk-return balancing. Gunes (2012) shed lights on the importance waves of risk in a carry trade portfolio. All these arguments reinforce the result found about transmissions channel between US bonds and stock markets and Brazil's stock market due portfolio rebalancing.

5 Conclusion

The objective of this article was to analyze the transmission effects and channels of volatility from and to Brazilian stock market. The hypothesis tested here is the existence of these channels because of: i) Brazil is a mediator of perturbance and volatility of commodities (metals, energy, and agricultural) and Latin American markets; ii) The volatility of financial market in Brazil is highly dependent of international disturbances (politic, geopolitics, economic); iii) The fundamentals of the Brazilian economy explain by themselves the volatility in stock markets. The dynamic correlation models suggest that just US stock markets and Brazil treasury bonds are highly correlated (positive and negative respectively) with Brazil stock index. Commodities in general are low correlated with Bovespa, and the agricultural ones have a downtrend association with the index.The empirical results suggest that the stock market in Brazil is strongly affected by monetary policies noises from US, and world economic activity. Additionally, receives shocks of risk due risk aversion moves. In the trivariate analysis, the evidences imply that Brazil is a mediator of waves of volatility, to and from Brent Oil, Iron Ore and US treasury Bonds.

This is explained by the role that Brazil plays as mediator of these markets when allocators build positions on Latin America and in commodities. The literature review conjecture the existence of portfolio rebalancing of fund managers investing in Latin America. Risk-return allocation and effects of unconventional monetary policies are appointed as determining money flow to Brazil. Additionally, there are evidences that Brazil is a pathway to intermediate trading in commodities such iron and brent oil. This article contributes identifying the propagation of risk among these channels, helping traders, fund managers and scholar's, to identify the information that matters.

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Appendix

Table 9 – Autocorrelation test to White Noise Proccess – Period: jan/2014 to dec/2016

	Pormanteau Test	
	m=5	m=10
S&P500	2.54(0.76)	7.62(0.66)
Gold	10.33(0.06)	15.56(0.74)
Iron	0.10(0.99)	0.02(0.88)
Brent	5.55(0.35)	10.75(0.37)
Copper	9.01(0.10)	16.18(0.70)
CDS5y	97.67(0.00)	116.56(0.00)
BR Bonds10y	70.21(0.00)	26.10(0.00)
US Bonds10y	2.26(0.81)	-0.0259
Corn	72.30(0.00)	124.19(0.00)
Sugar	-	-
Soybeans	3.57(0.61)	4.72(0.90)
Coffee	5.14(0.39)	10.52(0.39)
Ethanol	54.30(0.00)	84.91(0.00)

Figure 3 – Time series of returns Bonds and Agricultural Commodities Period: jan/2014 to dec/2016

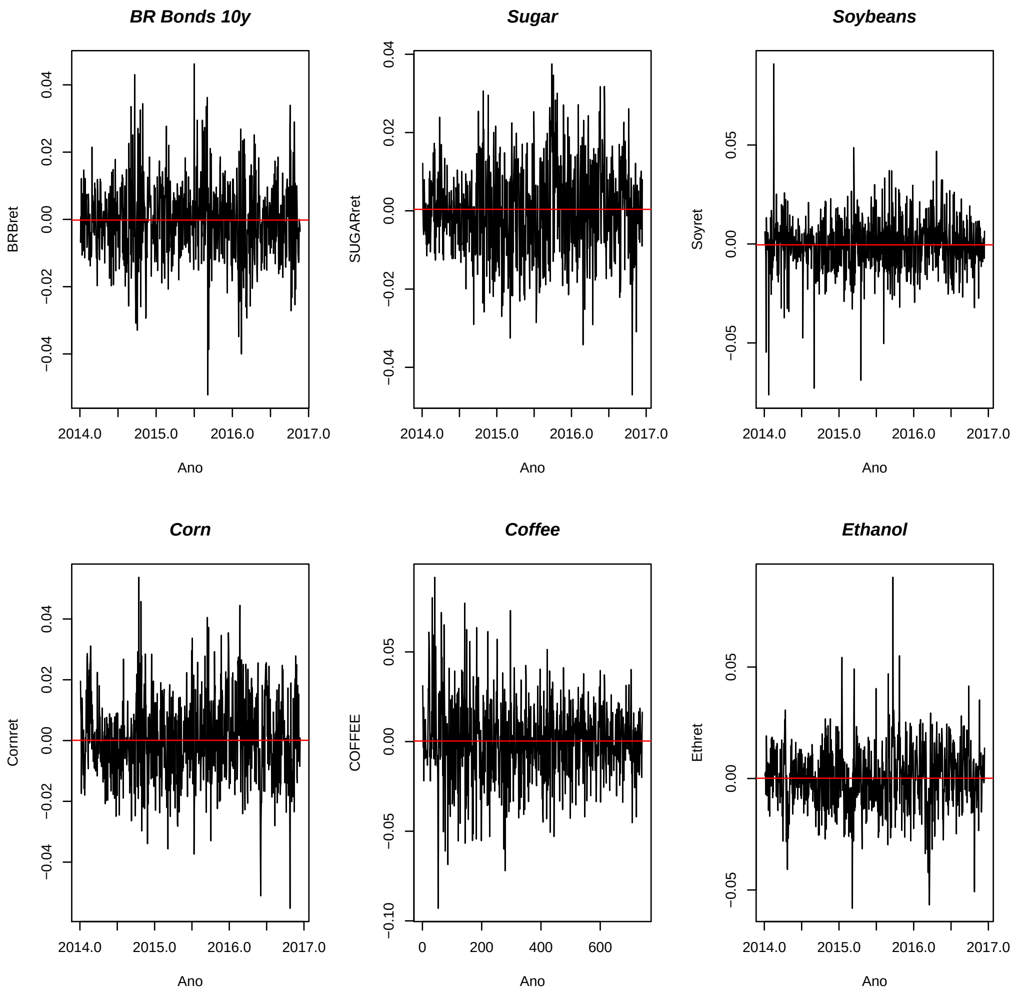

Figure 4 – Time series of returns Bonds, CDS and Metals Period: jan/2014 to dec/2016

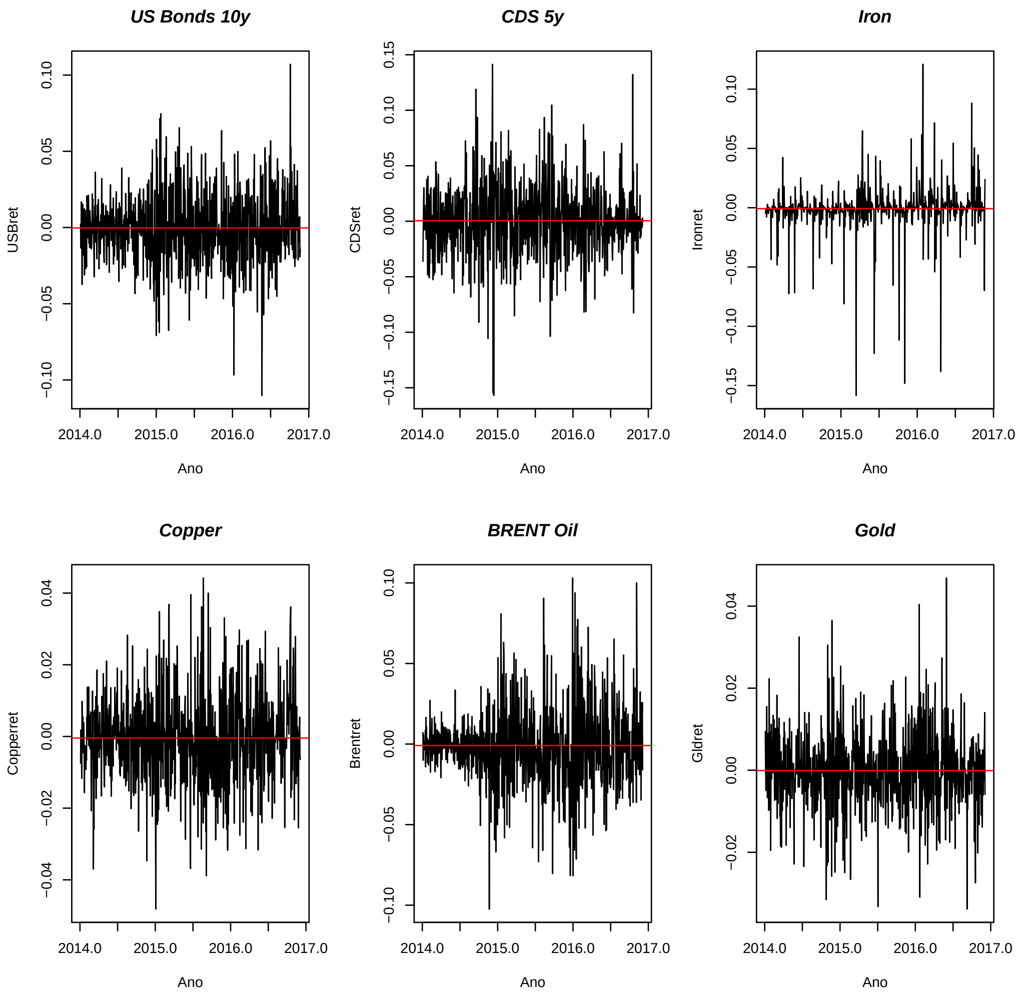

Figure 5 – Dynamic Correlations of all variables vs Bovespa - Period: jan/2014 to dec/2016

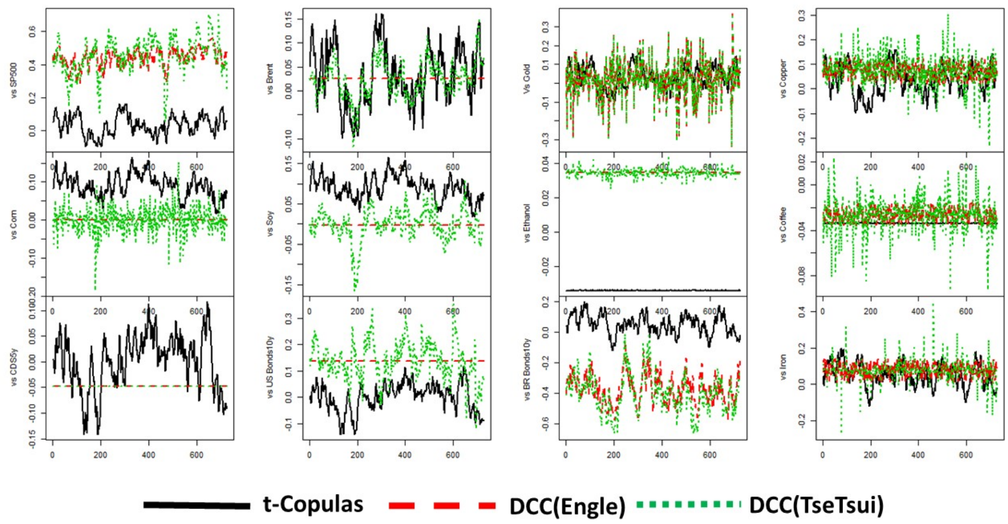

Figure 6 – Univariate GARCH Volatilities of all variables- Period: jan/2014 to dec/2016