

## Contagion effect in the BRIC+M block: a MS-copula approach

Miriam Sosa\*

Christian Bucio\*\*

Alejandra Cabello\*\*\*

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### Abstract

This paper aims to analyze the contagion effect among the stock markets of the BRIC+M block (Brazil, Russia, India, China plus Mexico). The dependence is estimated through a dynamic bivariate copula approach over the period July, 1997 – December, 2015. Once the dependence is estimated, univariate (MS-AR) is used to determine whether dynamic dependence evolves according to different regimes: a low dependence regime and a high dependence regime. The high dependence regime indicates contagion effect. Empirical results show strong evidence of time-varying dependence among the BRIC+M markets and an increasing dependence relation, above all, during financial crisis episodes.

*Key words:* copula approach; markov switching- AR; BRIC; Mexico; stock Markets.

*Clasificación JEL:* G15; C58; D53.

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\* Profesora-investigadora en la Universidad Autónoma Metropolitana-Iztapala, México. <msosa87@hotmail.com>.

\*\* Profesor-investigador en la Universidad Autónoma del Estado de México. <cbuciop@uaemex.mx>.

\*\*\* Profesora-investigadora en la Universidad Nacional Autónoma de México. <acr2001mx@yahoo.com.mx>.

# Efecto contagio en el bloque BRIC+M: estimación vía MS-Cópula

## Resumen

La presente investigación analiza el efecto contagio entre los mercados de capitales del bloque BRIC+M (Brasil, Rusia, India, China y México). Para lograr dicho objetivo se estima la dependencia dinámica a través de cópulas biva-riadas durante el periodo julio 1997 – diciembre 2015. Una vez que se estima la dependencia dinámica, se complementa el análisis con el modelo Auto Regresivo con cambio de Régimen Markoviano (MS-AR) para determinar si la dependencia entre los mercados de valores evoluciona de acuerdo a dos regímenes: régimen de alta dependencia y régimen de baja dependencia, asociando los periodos de alta dependencia con el fenómeno de contagio bursátil. Los resultados señalan que la relación de dependencia entre los mercados de valores del bloque BRIC+M cambia a través del tiempo y que se hace mayor a partir de la crisis financiera global.

*Palabras clave:* estimación con cópula; modelo auto regresivo con cambio de régimen; BRIC; México; mercados de capital.

*Clasificación JEL:* G15; C58; D53.

## 1. Introduction

Since 2008 crisis, financial contagion has triggered severe domestic fiscal, financial and external imbalances in developed and emerging countries. These effects have impacted financial decisions related to risk management, asset allocation and investment strategies. In this sense, it is of outmost importance to analyze contagion in order to shed some light and increase the understanding about this phenomena.

Stock markets are a key financing source and allow to increase the investment, promoting economic growth. Capital markets keep deep relations with other markets, influencing the price level of commodities, currency and oil, to mention some of them. Because of the relevance of these markets, above all in emerging countries, it is important to study their behavior and the relationships among them.

Based on the previous mentioned, this paper investigates the contagion effect in the stock markets of the BRIC+M block. It presents how the degree of bilateral association between BRIC+M<sup>1</sup> stock markets changes over the period 1997-2015.

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<sup>1</sup> South Africa is not considered in this research because it officially joined to BRICS in 2011 and its economic weight is very low, only represents three percent for total GDP share of the group.

Contagion effect is defined as a significant increase in market co-movement after a shock to one country (Forbes and Rigobon, 2002); previous research suggests contagion occurred during recent crises: Asian crisis, Russian, dot.com crisis, subprime crisis, sovereign debt crisis and global financial crisis.

Empirical research around BRIC's markets are widespread; among these studies stand out those by Bekaert, Ehrmann and Fratzcher (2014) who present evidence about contagion from the US and the global financial sector. Dimitriou, Kenourgios and Simos (2013) study the linkages between the US market and BRICs' markets; their results show contagion effect for some of the BRICs' markets in 2009. Jin and an (2016) findings identify a significant contagion effect from the US to the BRICs' stock markets in the context of the 2007-2009 global financial crisis.

In this paper the dynamic linkages between BRIC+M stock markets are analyzed by using bivariate copula approach. Markov Regime Switching Autoregressive (MS-AR) is employed to determine whether dynamic dependence evolves according two different regimes: a low dependence regime and a high dependence regime. The presence of high dependence regime indicates contagion effect.

The main contribution of this paper is presenting a relatively innovative approach for the analysis of dependence in order to further on the understanding concerning dynamic dependence patterns in five of the most important emerging markets. Information about the relationship between stock markets is important to fund managers, traders and economic authorities to formulate portfolio decisions and economic policies.

The paper is organized as follows. The second section reviews previous literature, the third section presents the data and methodology, section 4 examines the empirical evidence, and finally, section 5 concludes the paper.

## 2. Literature review

The Global Financial Crisis (GFC)<sup>2</sup> has been one of the most damaging economic phenomena in the whole history, only comparable with the Great Depression of 1929. During crisis episodes, changes in stock market linkages are of utmost importance to assess adjustments needed concerning asset allocation and risk management, not only for practitioners and policymakers but also

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<sup>2</sup> There is no consensus about the global financial crisis period and duration. In this paper, the global financial crisis immediate effects period comprehends from 2007 to 2012: 2007-2010 subprime crisis, 2011-2012 sovereign debt crisis. However, during 2013-2014 stock markets presented global financial crisis remaining effects.

for academics. Because of that, empirical and theoretical literature about contagion and on the channels of contagion has been widely studied.

It is important to point out that, emerging markets have aroused interest of investors and risk managers because portfolio investments in these countries are more profitable and volatile than developed markets. In consequence, extensive literature has been developed around emerging markets, particularly; research dealing with the BRIC countries has been rapidly increasing. Most studies have emphasized either their interdependence (Patel, 2019; Verma & Rani, 2016; Singh & Kaur, 2014; Mostafa & Stavroyiannis, 2016) or else about their increased dependence with other markets (Kocaarslan, Soytas, Sari & Ugurlu, 2018; Bergmann, Securato, Savoia & Contani, 2015; Chittedi, 2014; Bianconi, Yoshino & De Sousa, 2013).

Among closely related literature stands out Kenourgios, Samitas & Paltalidis (2011) who analyze contagion effect in the BRIC block, the US and the U. K. using multivariate copula regime-switching model to capture non-linear relationships during the Asian, Russian, Tech bust and Brazilian financial crisis. Their results contribute to the evidence about an asymmetric increase in dependence among stock markets during all five crises. However, they estimate copula parameters on a static basis, for certain periods, but not over the whole period, as it is estimated in this study.

Likewise, Zouhair, Lanouar & Ajmi (2014) investigate stock market co-movements and financial contagion in the BRIC block and the US. during the subprime financial crisis, using a class of Markov-switching models to distinguish among periods of high, medium, and low volatility. Their results reveal the presence of high degree of interdependence between the US and the BRIC countries, particularly in high volatility periods. Zouhair *et. al* (2014) apply a different approach to analyze interdependence, only over the subprime crisis period.

This paper contributes to the empirical literature on modeling co-movement in financial markets by considering the case of Brazil, Russia, India, China and Mexico (BRIC+M block, hereafter). Its aim is analyzing the time-varying behavior (dynamic dependence) between those stock markets, using copula with a rolling window estimation. Moreover, Markov Regime Switching Autoregressive (MS-AR) is applied to identify whether or not dynamic dependence evolves according to different regimes (high and low dependence regimes) to prove contagion effect, during the Asian, Russian, dot.com, Brazilian, subprime, sovereign debt and global financial crises.

The new methodology employed here also measures dependence between stock markets during crisis periods. However, this approach is based on dynamic copula functions with Markov switching models. These functions provide an interesting tool to model nonlinear dependence, when normality and symmetry do not hold.

### 3. Data and methodology

As previously mentioned, to test contagion effect among the BRIC+M stock markets, data includes daily prices of the BRIC+M stock indexes in US dollars, that is, IBOVESPA (Brazil), RTS (Russia), BSE SENSEX (India), HANG SENG (China) and IPC (Mexico) from July 1997 to December 2015. Stock market series were obtained from yahoo finance and exchange rate series from Oanda web site.

Following closely a previous paper by Sosa, Bucio and Cabello (2015), Copula approach applies rolling window estimation. Although there exist a good number of copula families, the family of Archimedean copula were chosen for this paper due to its benefits. Archimedean copulas allow modeling dependence in arbitrarily high dimensions with only one parameter, governing the strength of dependence (Grover, 2015). Among the Archimedean copulas, Clayton copula is estimated because it is adequate to describe negative skewness which is an important feature of stock markets return series (Nelsen, 1999).

#### 3.1. Archimedean copulas

The bivariate distribution from the Archimedean copulas family is represented as:

$$C_{\alpha}(u_1, u_2) = \phi_{\alpha}^{-1}[\phi_{\alpha}(u_1) + \phi_{\alpha}(u_2)], 0 \leq u_1, u_2 \leq 1 \quad (1)$$

where  $\phi_{\alpha}$  is convex and decreasing such as  $\phi_{\alpha} \geq 0$ . This function:  $\phi_{\alpha}$  offers the copula  $C_{\alpha}$  and the opposite  $\phi_{\alpha}^{-1}$  generator is the Laplace's transformed from an unrealized variable denoted as  $\gamma$ , and that induces  $\alpha$  dependence. Through this the selection of a generative process result different copulas from the Archimedean family. Three copulas from the Archimedean family are well known: The Clayton copula, the Gumbel copula and Frank copula.

#### 3.2. Dependence measurements via copulas

Each of the multiple families of copulas are characterized by a parameter or a parameter vector. These parameters measure the dependence of marginals, and they are called dependence parameters  $\theta$ . Here is important to note that the relation between this dependence parameter and Kendall's Tau concordance measure is as follows.

Let  $X_1$  and  $X_2$  two random variables with marginal continuous distribution  $F_1$  and  $F_2$  and coordinated distribution function  $F$ . The typical concept of dependence,  $\tau$  Kendall can be expressed in terms of copula for  $F$ .

Kendall correlation is given by:

$$\tau(X_1, X_2) = 4 \iint_0^1 C(u_1, u_2) dC(u_1, u_2) - 1 \quad (2)$$

It can be observed that the  $\tau$  Kendall is functioning with the copulas  $X_1$  and  $X_2$ . In the case of the analyzed copulas in this work, that is Archimedean copulas, there is a relation between rank correlations and linear correlations. This work is focused especially on the relation with the  $\tau$  Kendall.

To sum up, if  $(X_1, X_2)$  have an elliptical or Archimedean bivariate copula and random continuous marginal, the  $\tau$  Kendall is:

$$\tau = (\alpha - 1)/(\alpha + 1) \quad (3)$$

### 3.3. Clayton copula

The bivariate copula from the Clayton family is:

$$C_a(u_1, u_2) = \{u_1^{1-a} + u_2^{1-a} - 1\}^{1/(1-a)}, a > 1 \quad (4)$$

With generative  $\phi_\alpha(t) = t^{1-\alpha} - 1$ , and transformed from Laplace's:  $\phi_\alpha^{-1}(s) = (1 + s)^{1/(1-\alpha)}$ .

#### *Copula parameters estimation*

There are several methodologies for estimating the parameters associated with copula. This work employs maximum likelihood. This mechanism can be applied to estimate any copula family because the estimation of copula parameters can be obtained by maximizing its log-likelihood function, as explained below:

Let  $C$  be a copula, such that,

$$F(x_1, \dots, x_n) = C(F_1(x_1), \dots, F_n(x_n)) \quad (5)$$

with density function,

$$f(x_1, \dots, x_n) = c(F_1(x_1), \dots, F_n(x_n)) \cdot \prod_{j=1}^n f_j(x_j) \quad (6)$$

Therefore, the maximum likelihood estimation mechanism can be defined as:

Let  $X$  a r.v.i.i.d. vector with multivariate distribution function  $F$  and continuous marginal distribution function  $F_1, \dots, F_n$ ; the log-likelihood function is defined as:

$$l(\theta) = \sum_{j=1}^n \ln c(F_1(x_{j,1}), \dots, F_n(x_{j,n})) + \sum_{j=1}^n \sum_{i=1}^d \ln f_i(x_{j,i}) \quad (7)$$

where  $\theta$  are the parameters set for both marginal and copula. Thus, given the marginal set and a copula; the log-likelihood function can be maximized obtaining the maximum likelihood estimator,

$$\hat{\theta}_{MLE} = \max_{\theta \in \Theta} l(\theta) \quad (8)$$

### MS-AR Model

Once dynamic dependence between stock markets returns is estimated, time varying dependence series are modeled, using a regime switching approach, to prove if stock markets dependence evolves according to two different regimes (high and low). This analysis allows to confirm contagion effect, above all, during the GFC period.

A time-series variable  $y_t$  can be modeled by a Markov switching autoregressive of order  $p$  (MS-AR), with regime shifts in mean and variance. It is represented as follows (Hamilton, 1989).

$$y_t = \mu(s_t) + \left[ \sum_{i=1}^p \varnothing_i (y_{t-1} - \mu(s_t)) \right] + \sigma(s_t) \varepsilon_t \quad (9)$$

Where  $\varnothing_i$  are the autoregressive coefficients  $\mu$  and  $\sigma$  are the mean and standard deviation depending on the regime  $s_t$  at the time  $t$ .  $y_t$  represents the stock market returns of the BRIC+M countries. This MS-AR model detects potential regime shifts in the stock market returns and enables to estimate the impact of crises on the stock market dependence (Chkili and Nguyen, 2014).

The MS-AR model provides an accurate estimation of the potential regime shifts in the stock returns dependence, above all during the turbulent period analyzed in this study. The inclusion of structural breaks in the financial time-series analysis is crucial to avoid mistaken conclusions related to the dynamic behavior of stock markets and relationships between them.

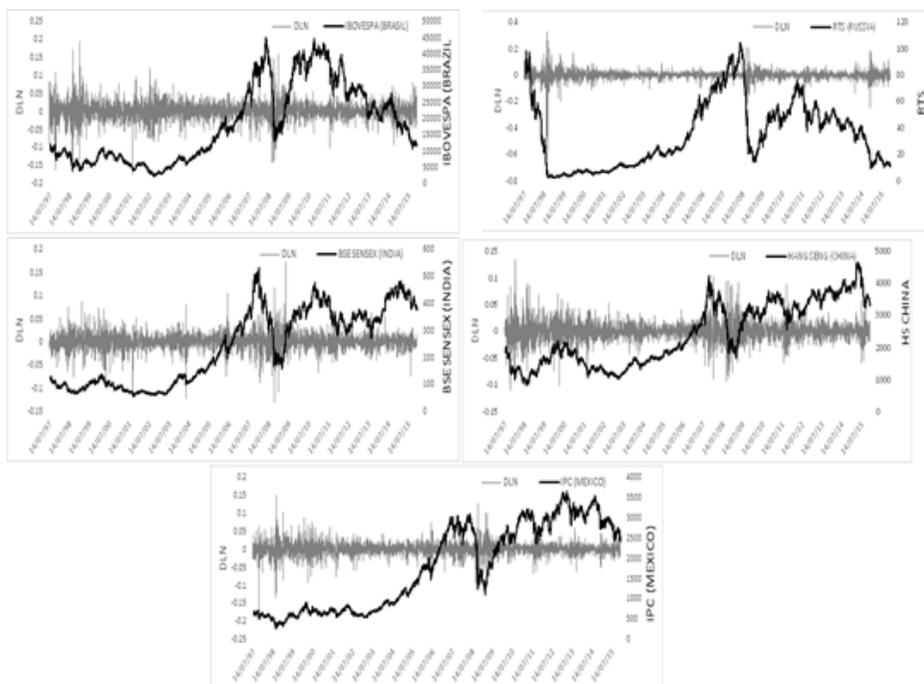
## 4. Empirical evidence

As previously stated, empirical analysis employs the representative stock indexes from BRIC+M stock markets on a daily basis: IBOVESPA (Brazil), RTS

(Russia), BSE SENSEX (India), HANG SENG (China) and IPC (Mexico) from July 1997 to december 2015. To have a similar sample given the dissimilar calendar of these markets, the data sets were accordingly homogenized considering only common trading days. Also given the importance of international portfolio investment, indices were homogenized into a single currency, the US dollar.

Figure 1 shows the behavior of the equity markets from Brazil, Russia, India, China and Mexico. Figure 1 allows us to observe the historical levels and returns of the stock indexes of the countries under study. Returns are characterized by higher changes (increasing volatility) and volatility clusters, during the crisis periods (1997-1998, 2001 and 2007-2012) compared to the stability periods. Besides, the series show signals about the presence of heteroscedasticity presence and an unforeseeable behavior, particularly no Gaussian.

Series in levels shows that stock indexes retained an upward trend until the second quarter of 2008, reaching a particularly low level during the first quarter of 2009, when the trend was reversed. It is important to note that the Russian and Brazilian markets exhibited a negative performance since the last quarter of 2011 and over the rest of the sample period.



Source: own elaboration based on Yahoo Finance and Oanda data

Figure 1

Stock indexes from Brazil, Russia, India, China and Mexico (levels and returns)

Table 1  
Descriptive Statistics

	Mean	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Probability
BSE	0.000295	0.018117	-0.115297	9.272147	6636.079	(0.00)*
HANG SENG	0.000148	0.017513	0.087517	8.314804	4763.627	(0.00)
IBOVESPA	-2.37E-06	0.025575	-0.238078	8.837966	5779.566	(0.00)
IPC	0.000355	0.018249	-0.292115	11.70325	12817.65	(0.00)
RTS	-0.000494	0.035362	-2.799855	55.49752	469551.7	(0.00)

\*Values within parentheses indicate probabilities

Descriptive statistics of BRIC+M countries equity markets are presented in table 1. Standard deviation, mean, kurtosis, skewness and Jarque Bera measures are included. It can be observed that the Russian market has the highest volatility, measured by the standard deviation, compared to markets from the rest of the sample. The average return of the major part of the sample is very low and positive, except for the Russian and Brazilian markets.

The distribution of returns is negatively skewed, except for the Chinese market that is positively skewed, indicating the presence of asymmetry. This fact reinforces the afore mentioned use of the Clayton copula. The values concerning kurtosis suggest that the distribution is leptokurtic, with a high concentration on the central values (higher peak) and the presence of heavy tails. Finally, the probabilities of Jarque-Bera testing reported in Table 1 favors rejecting of the hypothesis of a normal distribution at the 1% level. Thus, analysis performed under the assumption of normality lack appropriate support; it leads to spurious results. Therefore, the methodology proposed in this paper is copula theory which as previously explained yields more consistent estimates about the behavior of financial series.

Considering the nonlinearity of returns a mechanism that optimizes dissimilar situations of linearity and non-linearity becomes necessary. Copula methodology helps abating such mishaps generating unbiased estimates. Pertinent to this study are Archimedean copulas which comprehend the non-linearity and asymmetry study.

#### 4.1. Copula results

To confirm the importance and magnitude of the relationship among the BRIC+M share markets, figure 2 shows the results obtained using Archimedean copula, particularly Clayton. It is important to point out that, dynamic copula estimates are obtained applying rolling windows of 251 days, which corresponds to

a full one-year stock market cycle. Copula approach is preferred over linear methods because its goodness of fit. Besides, related studies have proved that linear correlation overestimates relationships among markets (Sosa, Bucio & Cabello, 2015; Ortiz, Bucio & Cabello, 2016).

Figure 2 illustrates dynamic dependence estimation employing Clayton copula. It can be observed that there is a time varying dependence over the period under study. Dynamic copula dependence fluctuates at levels below 0.2 during the decade of the 1990's. It is in 2008 when the GFC effects impact dependence among stock markets and increases to 0.4, taking values above 0.45 in the case of Brazil-Mexico and China-India dependence. This suggests that there is not an interdependence phenomenon among capital markets of BRIC+M, but contagion effect, cannot be discarded since there are episodes of high and low dependence. This evidence is enhanced with the Markov Regime Switching Model results.

Figure 2 shows that the highest dependence relation is sustained by Brazil- Mexico (0.36 average) follows by China-India (0.26 average). The stock markets with the lowest dependence relation are India-Brazil and India-Mexico. It can be explained by geographic location and trade and financial relations among those countries.

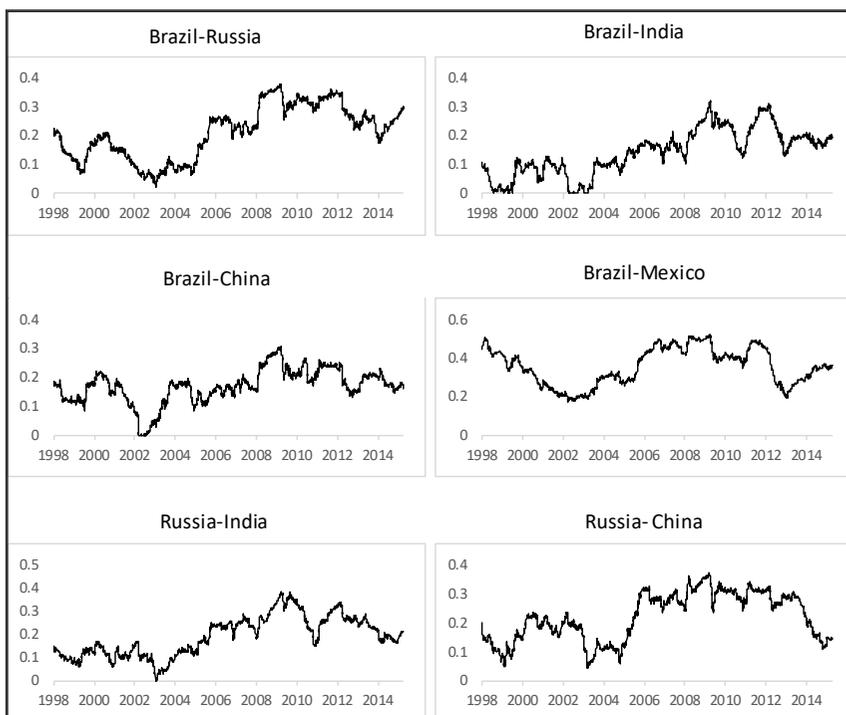
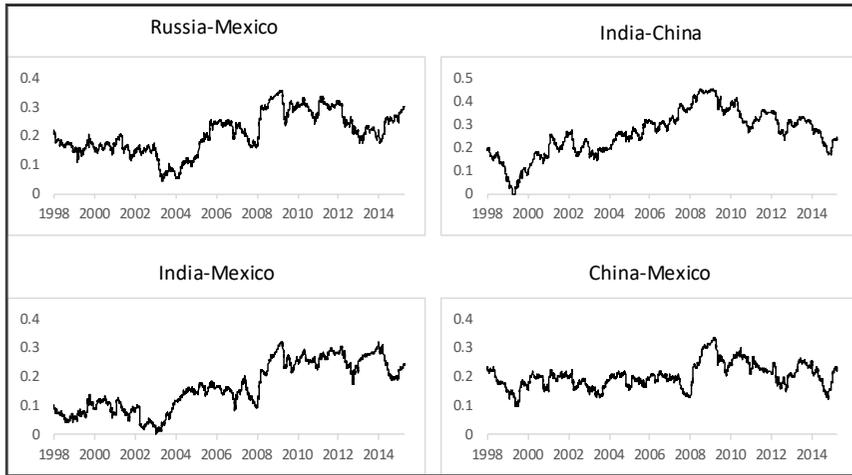


Figure 2  
Rolling window 251- days archimedean copula (kendall tau)



Source: own elaboration based on the results obtained

Conclusión. Figure 2  
 Rolling window 251- days archimedean copula (kendall tau)

Table 2  
 Average dependence during stability and crisis periods  
 among BRIC+M stock markets

	Asian Russian Crisis (1997-1998)	Stability period (1999-march 2000)	Dot.com crisis** (2000-2001)	Stability period (2002-2006)	GFC* (2007-2012)	Stability (2013-2015)
Kendall	0.162328	0.138229	0.165455	0.166061	0.285469	0.230646

Source: own elaboration based on the empirical evidene. \*GFC global financial crisis (immediate effects). \*\* From march 11, 2000 to december 31 2001. Kendall is the archimedean copula parameter.

Table 2 shows the average dependence during calm and crisis periods, it is important to point out that, although the dependence levels among BRIC+M markets are low, it can be observed important relative changes during crisis periods in relation with stability periods. The Global Financial Crisis (GFC) effects stand out because dependence increased in 70%, during the GFC period in relation to the four previous years. After the GFC period, the dependence measure diminishes slowly. This suggests that contagion among BRIC+M markets occurred during the GFC, but not over previous crisis episodes.

### 5.2. MS-AR Results

As Hamilton (2005) points out, financial time series occasionally exhibit dramatic breaks in their behavior, associated with events such as financial crises.

Markov regime switching model is suitable to estimate how abrupt changes in the international financial scenario affect asset prices (Ang and Bekaert, 2002; Garcia, Luger, and Renault, 2003; Dai, Singleton, and Wei, 2003). In this sense, abrupt positive changes in markets correlation are identified as contagion effect (Bekaert, Ehrmann, Fratzcher & Mehl, 2014; Dimitriou, Kenourgios & Simos, 2013; Hemche, Jawadi, Maliki, & Cheffou, 2016).

Following the previous idea, to confirm contagion effect among BRIC+M block during the period (1997-2015), particularly the GFC impact, MS-AR model is used to analyze whether stock markets dependence (non-linear correlation) evolves according to two different regimes: a low dependence regime and a high dependence regime. High dependence regime indicates contagion effect periods.

To begin with, the condition of stationarity is checked applying the ADF test. Results suggest that the null hypothesis about the presence of a unit root is rejected; values of dynamic dependence are greater than the critical MacKinnon value at a 1% level. Therefore, it is confirmed that the series are stationary.

Table 3  
Unit root test (ADF)

	Brazil- Russia	Brazil- India	Brazil- China	Brazil- Mexico	Russia- India	Russia- China	Russia- Mexico	India- China	India- Mexico	China- Mexico
T- statistic	-0.99*	-1.45*	-1.90*	-1.43*	-1.41*	-1.57*	-1.27*	-1.30*	-1.38*	-2.62*

Reported values are statistical significance levels of \* 1%

### 5.3. Testing for volatility regime switch behavior

In order to confirm that BRIC+M stock markets dependence presents regime-switching behavior, the log likelihood test (LR) is employed to test the null hypothesis of homoscedasticity, that means that a linear model could be more suitable, against the alternative hypothesis of regime switching model (MS-AR) reproduces better the stock markets behavior (Garcia and Perron, 1996). This test is estimated as follows

$$LR = 2 \times |\ln L_{MS-AR} - \ln L_{AR}|$$

where  $\ln L$  is the log likelihood of the contrasting models. The best-fitted model is selected through Davies (1987) critical values. This test has been used in several studies (Kanas, 2005; Wang and Theobald, 2008; Chkili and Nguyen, 2014) to prove that other emerging markets exhibit a time-varying behavior, which responds to local circumstances and to the effects of crises transmission.

To reinforce the tests results, the Akaike Information Criteria (AIC) is also introduced. Table 4 shows the results of both tests.

Table 4  
LR and AIC tests statistics results

	LnL(AR)	LnL(MS-AR)	LR	AIC (AR)	AIC(MS-AR)
Brazil-Russia	16007.83	16635.52	1255.38	-8.44	-8.77
Brazil-India	15882.61	16598.28	1431.34	-8.38	-8.75
Brazil-China	15862.48	16508.81	1292.66	-8.37	-8.70
Brazil-Mexico	16138.78	16788.77	1299.98	-8.51	-8.85
Russia-India	15930.09	16559.66	1259.14	-8.40	-8.73
Russia-China	15941.87	16565.45	1247.16	-8.41	-8.73
Russia-Mexico	15945.39	16541.07	1191.36	-8.41	-8.72
India-China	15938.97	16632.71	1387.48	-8.41	-8.77
India-Mexico	15849.81	16582.50	1465.38	-8.36	-8.74
China-Mexico	15888.81	16553.80	1329.98	-8.38	-8.73

Reported values are statistical significance levels of \* 1%.

Table 4 indicates that the log-likelihood value of the MS-AR is significantly higher than the linear AR model in all the markets. The rejection of the null of no-volatility regime switch is equivalent to the rejection of the AR in favor of the alternative MS-AR model. The Akaike Information Criterion (AIC) endorses this results, thus it is also in favor of the MS-AR model in all cases.

### 5.3. MS-AR Results

Once proved that stock markets dependence evolves according to regime-switching behavior, the MS-AR models are estimated; their results are described in table 5. Standard deviations ( $\sigma_1^2$  and  $\sigma_2^2$ ) are statistically significant at 1% and their values suggest the presence of two regimes. The first regime is a low dependence level while the second regime presents a high dependence level. Russia-Mexico and Russia-China are the markets who exhibit the highest dependence level in the low dependence regime and India-China and Brazil-India present the highest dependence in the high dependence regime.

Table 5 also presents the probability of being in each regime. As it was expected, the probability to be in a high dependence regime ( $P_{22}$ ) is lower than the probability to be in the low dependence regime ( $P_{11}$ ), in all cases. This evidences that the low dependence regime is more persistent than the

high dependence regime. The relationship between India and Mexico's equity market is the linkage with the highest level of persistence in both low (0.87) and high dependence regime (0.59) followed by Russia-Mexico ( $P_{11}=0.87$ ,  $P_{22}=0.55$ ) and Brazil-India ( $P_{11}=0.86$ ,  $P_{22}=0.52$ ).

Evidence on the average duration for each regime ( $d_1$  and  $d_2$ ) confirm the presence of two regimes. The average duration of the high dependence regime ( $d_2$ ) between Brazil and Russia markets is 2.4 days, for Brazil-India 2.06 days, Brazil-China 1.82 days, Brazil-Mexico 1.87 days, Russia-India 1.96 days, Russia-China 1.98 days, Russia-Mexico 2.22 days, India- China 1.4 days, India-Mexico 2.45 days, China-Mexico 1.8 days. In contrast, the average duration of the low dependence regime ( $d_1$ ) between Brazil and Russia markets is 6.5 days, for Brazil-India 7.3 days, Brazil-China 6.3 days, Brazil-Mexico 6.1 days, Russia-India 6 days, Russia-China 5.5 days, Russia-Mexico 7.6 days, India- China 5.4 days, India-Mexico 7.6 days, China-Mexico 6.3 days.

Table 5  
MS-AR Model Results

	BRAZIL-RUSSIA		BRAZIL-INDIA		BRAZIL-CHINA		BRAZIL-MEXICO		RUSSIA-INDIA	
Const(1)	0.211524*	(0.012658)	0.143463*	(0.017410)	0.169297*	(0.013356)	0.356723*	(0.006152)	0.196442*	(0.012258)
Const(2)	0.211375*	(0.012653)	0.143430*	(0.017413)	0.169144*	(0.013384)	0.356634*	(0.006156)	0.196430*	(0.012264)
AR1	1.000265*	(0.000417)	0.999908*	(0.000489)	0.998580*	(0.000658)	0.999562*	(0.000386)	0.999709*	(0.000473)
$\sigma_1^2$	-6.317093*	(0.027773)	-6.247460*	(0.030353)	-6.226796*	(0.030514)	-6.319605*	(0.026937)	-6.267840*	(0.027917)
$\sigma_2^2$	-5.090790*	(0.031789)	-4.973275*	(0.037204)	-4.981938*	(0.037259)	-5.067902*	(0.034519)	-5.034169*	(0.033283)
$P_{11}$	0.845522		0.863202		0.841370		0.835876		0.833685	
$P_{22}$	0.583096		0.516251		0.453524		0.464358		0.490156	
$d_1$	6.473402		7.310057		6.303983		6.092956		6.012696	
$d_2$	2.398634		2.067189		1.829905		1.866920		1.961383	

	RUSSIA-CHINA		RUSSIA-MEXICO		INDIA-CHINA		INDIA-MEXICO		CHINA-MEXICO	
Const(1)	0.220383*	(0.00917)	0.209577*	(0.01239)	0.262423*	(0.009334)	0.165614*	(0.02873)	0.203036*	(0.014123)
Const(2)	0.220452*	(0.009173)	0.209478*	(0.012393)	0.262559*	(0.009336)	0.165757*	(0.028743)	0.202979*	(0.014126)
AR1	0.999791*	(0.00047)	0.999854*	(0.000561)	0.999883*	(0.000407)	0.999771*	(0.000493)	0.999841*	(0.000928)
$\sigma_1^2$	-6.305183*	(0.02929)	-6.203945*	(0.032325)	-6.253131*	(0.027244)	-6.275936*	(0.026108)	-6.239766*	(0.03457)
$\sigma_2^2$	-5.064914*	(0.03191)	-5.018189*	(0.039593)	-4.958317*	(0.038694)	-4.999294*	(0.033488)	-4.980282*	(0.051328)
$P_{11}$	0.817279		0.867799		0.815099		0.869358		0.840438	
$P_{22}$	0.496348		0.548582		0.284654		0.592077		0.441716	
$d_1$	5.472833		7.564251		5.408291		7.654495		6.267166	
$d_2$	1.985499		2.215244		1.397925		2.451443		1.791203	

Reported values are statistical significance levels of \* 1%. Standard deviations are reported in parentheses

### 5.3. Graphic Analysis: Smooth Probabilities

Regime switching approach offers additional information through a graphic resource about what regime market is in a specific date  $t$  based on observation obtained through a later date  $T$ . These are referred to as “smoothed” probabilities; according to Hamilton (2005) is an efficient algorithm for whose calculation was developed by Kim (1994).

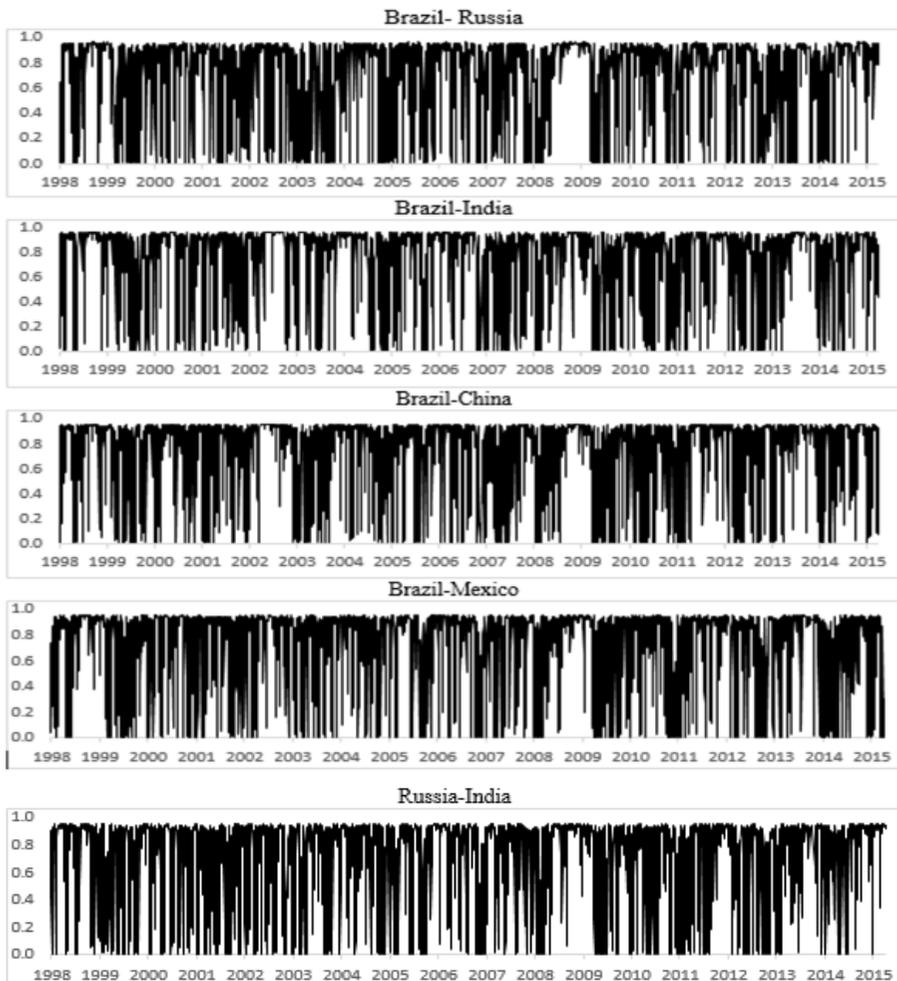
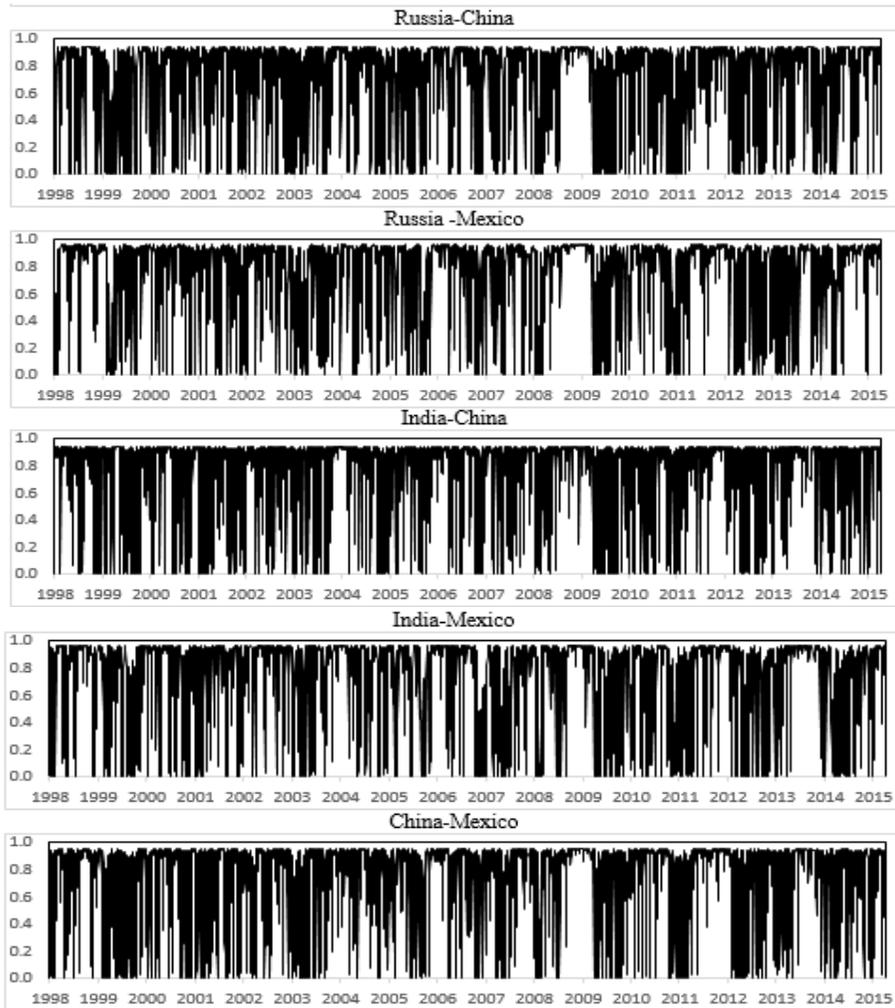


Figure 3  
Smooth Probabilities Regime 2



Conclusión. Figure 3

Source: own elaboration with copula series estimated.

Figure 3 presents the smooth probabilities of being in regime 2 (high dependence regime). In this study, it is used as a graphic test to identify contagion periods between stock markets. It allows to compliment the copula analysis, reinforcing contagion study. The smooth probability of being in the high dependence regime ( $S(P2)$ ) indicates the presence of several common high dependence episodes, stands out some periods: 1998-1999 (Russian crisis), 2002-2003 (Brazilian and dot com crisis secondary effects), 2008-2009 (subprime crisis), 2011-2012 (sovereign debt crisis) and 2013-2014 (global financial crisis residual effects).

Smooth probabilities analysis contributes with important evidence about the contagion effect among the BRIC+M stock markets, above all, during the global financial crisis period.

## 6. Conclusion

In recent years, important financial phenomena have motivated theoretical and empirical research about contagion effect. This paper analyzed dynamic linkages across daily national stock indices of five of the most important emerging countries, the BRIC block and Mexico, over the period 1997-2015.

In this sense, a new approach is proposed using a non-linear and asymmetric framework. Empirical analysis includes:

- i) a dynamic bivariate copula approach to estimate the time-varying dependence and
- ii) Markov Regime Switching Autoregressive (MS-AR) model which is used to determine whether dynamic dependence evolves according to different regimes: a low dependence regime and a high dependence regime.

The empirical findings yield evidence about contagion effect during crisis episodes, above all, during the subprime, sovereign debt and global financial crises. Dynamic dependence indicates that there is not an interdependence phenomenon, but there is a contagion effect among BRIC+M block. In general, both methodologies are complementary and enhance the robustness of results.

Findings have important implications to investors, risk managers and policy makers and suggest that new strategies should be taken since international diversification seems not to work in practice, at least, not during turmoil periods. Further research may be developed on other emerging markets (Latin American, Asian and Arabian) to contrast results and contributing with further evidence about the financial contagion phenomena. In the same way, new research may also apply this methodology on other financial markets (commodities, debt, foreign exchange and equity markets).

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