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A study of co-movements between U.S. and Latin American stock markets: A cross-bicorrelations perspective

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Abstract
This work applies a test that detects dependence between pairs of variables. The kind of dependence is a non-linear one, and the test is known as cross-bicorrelation, which is associated with Brooks and Hinich [1]. We study dependence periods between U.S. Standard and Poor's 500 (SP500), used as a benchmark, and six Latin American stock market indexes: Mexico (BMV), Brazil (BOVESPA), Chile (IPSA), Colombia (COLCAP), Peru (IGBVL) and Argentina (MERVAL). We have found windows of nonlinear dependence and co-movement between the SP500 and the Latin American stock markets, some of which coincide with periods of crisis, leading to an interpretation of a possible contagion or interdependence.

Keywords: Financial crisis; cross-bicorrelations; nonlinear dependence; co-movement; financial markets.

Un estudio de comovimientos entre las bolsas de valores de Estados Unidos de Norteamérica y América Latina: Una perspectiva de la bicorrelación cruzada

Resumen
Este trabajo aplica una prueba para detectar dependencia entre pares de variables. Este tipo de dependencia es no linear, y la prueba es conocida como bicorrelación cruzada, la cual es asociada a Brooks y Hinich [1]. Estudiamos periodos de dependencia no-lineal entre el índice Standard and Poor's 500 (SP500) de EUA y seis índices de mercados accionarios latinoamericanos: México (BMV), Brasil (BOVESPA), Chile (IPSA), Colombia (COLCAP), Perú (IGBVL) and Argentina (MERVAL). Hemos encontrado ventanas de dependencia no-lineal y de co-movimiento entre el SP500 y los mercados accionarios latinoamericanos, algunas de las cuales coinciden con períodos de crisis, lo cual da paso a posibles interpretaciones de contagio o interdependencia.

Palabras clave: Crisis financiera; bicorrelaciones cruzadas; dependencia no lineal; co-movimiento; mercados financieros.

1. Introduction

The study of the transmission of shocks from one country to another and the correlations between several countries and co-movements that cannot be explained by strong economic arguments has attracted the attention of researchers in economics and finance, as well as of practitioners. Research on this topic has significant effects, on both asset pricing, allocation and forecasting, as well as on other elements cf. [2-4].

Recently, co-movements between financial markets have been studied, with emphasis on the return on stock market indexes, through econometric or time series models that allow for a better understanding of the behavior of markets, especially through periods of crisis. A lot of this research has studied interdependencies and co-movements from the point of view of contagion, cf. [5-10]. Several approaches are adopted to analyze the co-movements between financial markets, some of which use quantitative tools borrowed

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mostly from physics and computational sciences, cf. [11-13].

According to [6], if two markets are highly correlated, and the correlation does not increase in one of the markets after a financial crisis, but on the contrary, there is a continuous variation in its co-movement, then both markets are highly interdependent and contagion cannot be considered as the cause of the relationship between the two markets. Thus, for these authors the privileged dimension is a linear dependency. However, there is an important line of research that emphasizes the need for an empirical verification of nonlinear univariate and multivariate dependencies. Several arguments have been put forward in favor of this route of investigation, according to [14]. On the one hand, if after running a regression there is an indication of nonlinear dependence in the error terms of a standard model, the most common being the linear one, it can be argued that the standard model does not represent the data sufficiently well. On the other hand, if the evidence of nonlinear behavior is found in the first moment, the conditional mean, the formulation of a trading scheme built on this finding would be conceivable. This would ensure that benefits greater than a passive trading plan are obtained.

In order to explore these –less known and less obvious– nonlinear relationships between financial markets and how they co-move, in this work we use the Brooks and Hinich [1] nonlinearity test, that uses a measure of the dependence between pairs of variables called the cross-bicorrelations between time series, using bivariate autoregressive vectors in high frequency data. According to [15] these tests can be viewed as natural multivariate extensions of Hinich's portmanteau bicorrelation and whiteness statistics, but in this case the test examines nonlinear characteristics for pairs of variables. The advantage in using the cross-bicorrelation test is that it addresses the specific window frames in which the nonlinear dependence is present and also signals the direction of the nonlinear dependence, which is not provided by the Granger causality test

Both univariate [16-24] and multivariate [25-27] tests have been successfully applied to analyze the nonlinear behavior of different financial and economic time series. However, to the best of our knowledge, this is the first time that such a multivariate nonlinear test is used to uncover how stock markets co-move.

Seminal works analyzing Latin American stock markets as [24] and [22] use the univariate test, as is the case of the bicorrelation. In our case, we implement a bivariate test, the cross-bicorrelation that allows us to study co-movement between pairs of variables. Thus, the cross-bicorrelation is a multivariate extension of the bicorrelation, and the cross-bicorrelation can capture most types of dependence between pairs of series of the third-order statistics.

In this paper, we use the non-linearity test proposed by [1] in order to uncover the cross-covariances and cross-correlations between U.S. Standard and Poor's 500 (SP500), used as a benchmark, and six Latin American stock market indexes: Mexico (BMV), Brazil (BOVESPA), Chile (IPSA), Colombia (COLCAP), Peru (IGBVL) and Argentina (MERVAL). We found windows of nonlinear dependence between the SP500 and the Latin American stock markets, some of which coincide with periods of crisis, leading to an interpretation of possible contagion or interdependence.

Table 1.
Summary statistics for the returns

	Mean	**Min**	**Max**	**Std-Dev**	**Skew-ness**	**Kurtosis**	**JB**
SP500	0.03	-9.47	10.96	1.23	-0.32	14.15	15727
BMV	0.06	-7.27	10.44	1.27	0.06	9.24	4905
BOVESPA	0.06	-12.10	13.68	1.79	-0.07	7.94	3073
IPSA	0.05	-7.17	11.80	1.03	-0.03	13.19	13100
COLCAP	0.08	-13.25	18.13	1.36	-0.12	23.85	54822
IGBVL	0.07	-13.29	12.82	1.54	-0.52	13.18	13191
MERVAL	0.10	-12.95	10.43	1.99	-0.57	7.03	2216

Source: The authors used data from *Bloomberg*.

The organization of the document is the following: Section 2 presents the information collected. Section 3 describes the methodology used. Section 4 reports the empirical results. Finally, the main conclusions are presented in Section 5.

2. The data

For this study we consider daily returns of seven stock market indexes, namely the U.S. Standard and Poor's 500 (SP500) is taken as a baseline market for comparison against six Latin American stock market indexes: Mexico (BMV), Brazil (BOVESPA), Chile (IPSA), Colombia (COLCAP), Peru (IGBVL) and Argentina (MERVAL). Daily closing prices from January 2nd, 2003 to January 8th, 2015, for a total of 3025 observations of each index were obtained from *Bloomberg*. The data was sampled for this period of time in order to capture the effects that the U.S. might have had on the Latin American equity markets during the sub-prime financial crunch and to have a broad view of other possible cross-bicorrelation phenomena. Prices were converted into a continuous rate of returns, taking natural log differences between consecutive daily closing prices of equity markets. Table 1 presents summary statistics for these returns. The statistics are consistent, as expected, with some of the characteristic particularities of financial variables [28,29]. In particular, the kurtosis indicates that return distributions are leptokurtic. Furthermore, the Jarque-Bera statistic (JB) confirms returns not normally distributed. Although the results of the KPSS test for seasonality are not listed, it does not reject the null hypothesis of seasonality or the results of the ADF and PP tests, under the null hypothesis of a unit root. Both tests with a 5% significance level are available upon request.

3. Methodology

Brooks and Hinich [1] claim that the cross-bicorrelation test would allow a researcher identify any existence of nonlinear dependence between two pairs of variables. The size of the sample series is *N*, with two stationary variables $x(t_k)$ and $y(t_k)$. As we are working with the first percentual logged differences and small sub-samples of the total series, to assume stationarity is more than reasonable. Each series is separated into equal length non-overlapping moving time windows or frames, where *t* is an integer and *k* represents the *k*-th window and, both series are jointly covariance stationary, which have been standardized. The test's null hypotheses states that the two variables $x(t_k)$ and $y(t_k)$ have no dependence and in fact are pure white noise. The alternative hypothesis states that the series have cross-covariances, $C_{xy}(r)$ defined as $E[x(t_k)y(t_k+r)]$ or any of the cross-bicovariances, $C_{xxy}(r,s)$ defined as $E[x(t_k)x(t_k+r)y(t_k+s)]$, different from zero.

Under the null hypothesis, $C_{xy}(r)$ and $C_{xxy}(r,s)$ are zero for every r,s except when $r=s=0$. According to the test, there is dependence between a pair of variables if $C_{xy}(r) \neq 0$ or $C_{xxy}(r,s) \neq 0$ for at least one value of r or a pair of values of r and s, respectively. Next, we present the statistics that give the r sample xy cross-correlation and the r,s sample xxy cross-bicorrelation, respectively

$$C_{xy}(r) = (N-r)^{-1} \sum_{t=1}^{N-r} x(t_k)y(t_k+r), \qquad (1)$$

for $r \neq 0$, and

$$C_{xxy}(r,s) = (N-m)^{-1} \sum_{t=1}^{N-m} x(t_k)x(t_k+r)y(t_k+s) \qquad (2)$$

where $m = \max(r,s)$.

We can interpret the cross-bicorrelations as the degree of relation of the value of one variable with the value of the cross-correlation of the two variables. The second-order test does not include current elements, and is executed on the errors terms of an $AR(2)$ fit to clean out the univariate autocorrelation arrangement. Thus current correlations will not be reason for rejecting the null hypothesis. To perform the third-order test, we apply the test on the errors terms of a $VAR(2)$ model having a current term in one of the equations (the order p of the $AR(p)$ and $VAR(p)$ models is chosen to optimize the Schwartz (BIC) criterion). The pre-whitening step is grounded on the elimination of any presence of linear correlation or cross-correlation. Therefore any outstanding dependence between the variables should be classified as nonlinear. Let $L = N^c$ where $0 < c < 0.5$ (for our case of study we use $c = 0.4$, $N = 3025$, and thus we have 121 non-overlapped windows of length 25 days). The corresponding test statistics for non-zero cross-correlations and cross-bicorrelations are

$$H_{xy}(N) = \sum_{r=0}^{L} (N-r)C_{xy}^2(r) \qquad (3)$$

And

$$H_{xxy}(N) = \sum_{s=-L}^{L} \sum_{r=1}^{L} (N-m)C_{xxy}^2(r,s), \qquad (4)$$

for $-s \neq -1,1,0$, respectively. In these statistics L is the number of times that the correlations are verified and $L(2L-1)$ is the number times that the cross-bicorrelations are probed. Following [15], we state that H_{xy} and H_{xxy} are asymptotically χ^2 with L and $L(2L-1)$ degrees of freedom, respectively, as $N \to \infty$.

Table 2.
Number and percentage of significant (at the 5% level) cross-bicorrelation windows and correlations between *xxy* and *yyx*, and values of most significant bicorrelations. All cross-correlations and correlations are against SP500.

Series	**Significant cross-bicorrelation windows**	**Correlations (*xxy, yyx*) for all windows**	**Correlation (*xxy, xy*) for largest window**
BMV	20 (16.5%)	0.79	0.19
BOVESPA	34 (28.1%)	0.70	0.12
IPSA	18 (14.9%)	0.75	0.08
COLCAP	17 (14.0%)	0.73	0.10
IGBVL	29 (24.0%)	0.74	-0.01
MERVAL	31 (25.6%)	0.55	0.50

Source: The authors.

4. Empirical results

In Table 2, we report the results for the cross-bicorrelation test. All tests are run taking SP500 as the benchmark for comparison, since the effects of the U.S. on Latin America are the ones we wanted to test. We present the number and percentage of significant (at the 5% level) cross-bicorrelation windows, correlation for all windows and the correlation for the largest window. As can be seen, the countries with the most significant cross-bicorrelation windows are Brazil (BOVESPA), Argentina (MERVAL) and Peru (IGBVL), with 28.1%, 25.6% and 24.0% of significant windows, respectively. On the other hand, Colombia (COLCAP), Chile (IPSA) and Mexico (BMV) are the countries with less significant windows (14.0%, 14.9% and 16.5%, respectively). As for the correlations for all windows, most countries present a correlation between 0.70 and 0.79, with the exception of Argentina (0.55). Furthermore, the country with an episode of largest correlation (0.50) was Argentina, whereas the one with the lowest correlation for a single episode was Peru (-0.01). These results shed light on the degree of dependence and co-movement between economies.

In Table 3 we present the dates of significant cross-bicorrelation windows between the SP500 benchmark and the six Latin American stock market indexes, labeled in the following way: BMV (A), BOVESPA (B), IPSA (C), COLCAP (D), IGBVL (E) and MERVAL (F). All windows are of 25 labor days of length, for a total of 121 windows. During 2003, Brazil and Argentina showed significant cross-bicorrelation windows with the U.S. For the years of 2004 to April 2007, the markets do not co-move, with the exception of a significant window from 6/26 to 7/31 between SP500 and BMV. In the middle of 2007 the effects of the U.S. are visible on some Latin American countries: Mexico, Brazil and Peru are affected earlier than Chile, Colombia and Argentina. However, the effects of the sub-prime financial

Table 3.
Dates of significant cross-bicorrelation windows between SP500 and the corresponding Latin American stock market, labeled as follows: BMV (A), BOVESPA (B), IPSA (C), COLCAP (D), IGBVL (E) and MERVAL (F). All windows are of 25 labor days of length, for a total of 121 windows. The numbers in the A-F columns represent the corresponding window that is significant.

Year	Starting date	Finishing date	A	B	C	D	E	F
2003	1/3	2/7		1			1	1
2003	2/10	3/17		2				2
2003	3/18	4/22		3				3
2003	5/29	7/2						5
2003	7/3	8/7						6
2003	9/15	10/17						8
2006	6/26	7/31	36					
2007	1/31	3/7						
2007	3/8	4/12						
2007	5/18	6/22					45	
2007	7/31	9/4	47	47		47	47	
2007	10/10	11/13		49				49
2007	11/14	12/19	50	50	50		50	50
2008	12/20	1/28	51	51	51		51	
2008	1/29	3/4		52	52		52	
2008	3/5	4/9	53	53	53	53	53	53
2008	4/10	5/14		54		54		
2008	5/15	6/19		55				55
2008	6/20	7/25		56		56	56	56
2008	7/28	8/29		57			57	
2008	9/2	10/6	58	58	58	58	58	58
2008	10/7	11/10	59	59	59	59	59	59
2008	11/11	12/17	60	60	60	60	60	60
2009	12/17	1/23	61	61	61	61	61	61
2009	1/26	3/2	62	62	62	62	62	62
2009	3/3	4/6	63	63	63	63	63	63
2009	4/7	5/12	64	64	64	64	64	64
2009	5/13	6/17	65	65	65		65	65
2009	6/18	7/24	66		66	66	66	66
2009	7/24	8/27		67				67
2009	10/5	11/6	69	69				
2010	1/22	2/26					72	
2010	4/6	5/10					74	
2010	5/11	6/15	75	75	75		75	75
2010	6/16	7/21		76				76
2010	8/26	9/30					78	
2011	2/24	3/30					83	
2011	5/6	6/10					85	
2011	7/19	8/22	87	87	87	87	87	87
2011	8/23	9/27	88	88	88	88	88	88
2011	9/28	11/1	89	89	89	89	89	89
2011	11/2	12/7	90	90	90	90	90	90
2012	12/8	1/13		91				91
2012	1/17	2/21		96				
2013	3/28	5/2					104	
2013	6/10	7/15		106				
2014	1/13	2/18		112				112
2014	9/23	10/27		119				119
2015	12/3	1/8				121		121

Source: The authors.

crisis were felt on all countries from September 2008 lasting till July 2009 (Table 3 (cont.)). From August 2009 to June 2011, there was not much co-movement, Peru being the exception with significant cross-bicorrelation windows during these years. Another block of co-movement was visible from July to December 2011, which might have happened due to the European sovereign debt crisis and some of the concerns over the U.S.'s slow economic growth and its credit rating being downgraded. From 2012 to January 2015, the countries that continued to show significant cross-bicorrelations with the U.S. were Brazil and Argentina.

In Fig. 1 and Fig. 2, we plot the $(1-p)$-values of the significant cross-bicorrelation windows between SP500 and Mexico, Brazil and Colombia (Fig. 1), and Chile, Peru and Argentina (Fig. 2). These windows correspond to the ones reported in Table 2 and 3. It is clear how there are two main periods of nonlinear dependence between U.S. and Latin American stock markets: 2008-2009 and 2011. Brazil and Argentina showed cross-bicorrelations with the U.S. in 2003.

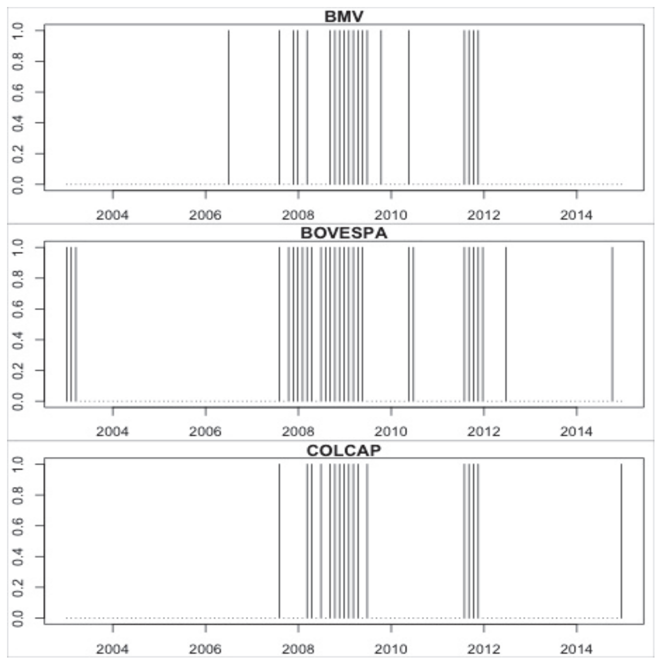

Figure 1. $(1-p)$-values of the significant cross-bicorrelation windows between SP500 and Mexico, Brazil and Colombia, respectively.
Source: The authors.

In Fig. 3 we plot the normalized prices for the SP500, BOVESPA and COLCAP indexes. The SP500 is the benchmark and it is compared with BOVESPA that presents the most significant cross-bicorrelation windows (28.1%) and COLCAP that presents the least significant percentage of windows (14.0%). We also plot the returns and the $(1-p)$-values of the significant cross-bicorrelation windows. As can be seen in the prices and returns plots, it is clear how for the year 2008 and the year 2011, the SP500 falls in prices and has a higher volatility before the other indexes.

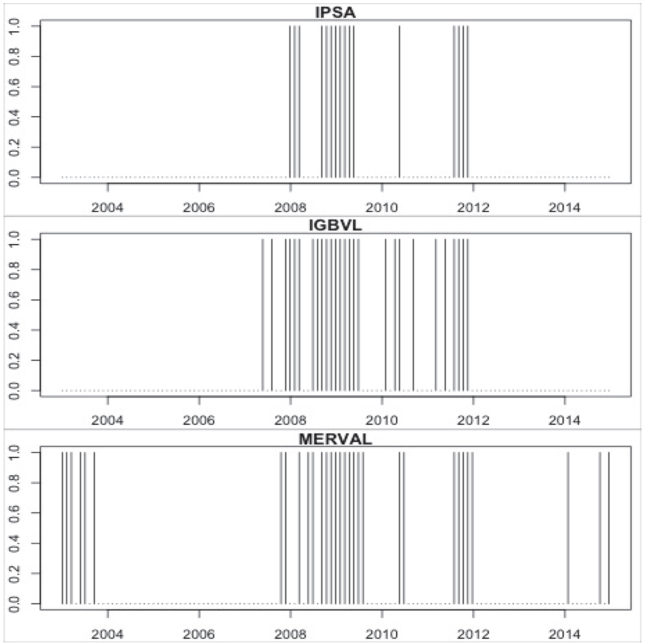

Figure 2. $(1-p)$-values of the significant cross-bicorrelation windows between SP500 and Chile, Peru and Argentina, respectively.
Source: The authors.

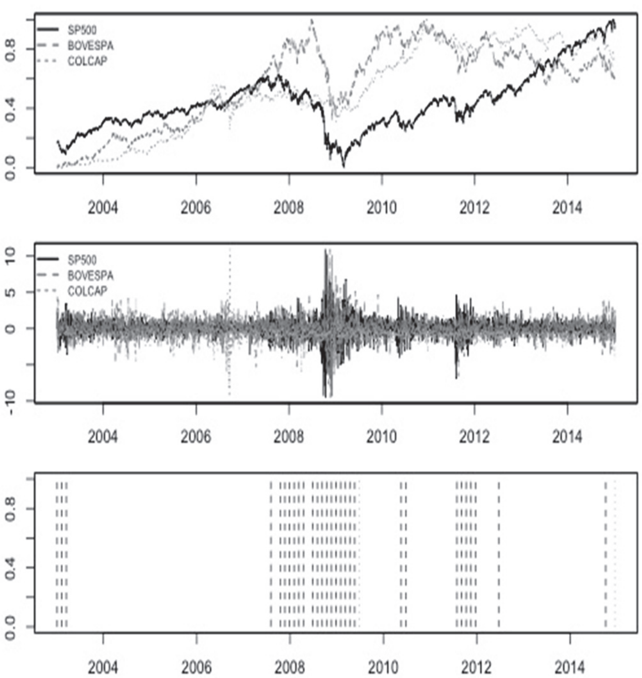

Figure 3. Plot of normalized prices, returns and $(1-p)$-values of the significant cross-bicorrelation windows (top, middle, bottom, respectively) for SP500, BOVESPA and COLCAP.
Source: The authors.

5. Conclusions

In this document we have successfully applied the Brooks and Hinich [1] cross-bicorrelation test to uncover the cross-covariances and cross-correlations between U.S. Standard and Poor's 500 (SP500), used as a benchmark, and six Latin American stock markets indexes: Mexico (BMV), Brazil (BOVESPA), Chile (IPSA), Colombia (COLCAP), Peru (IGBVL) and Argentina (MERVAL). We found windows of nonlinear dependence between SP500 and the Latin American stock markets, some of which coincide with periods of crisis, giving way to an interpretation of possible contagion or interdependence. Using a different but related methodology, [23] found that there are several periods where there were international financial crises that present strong univariate nonlinearity for several Latin American financial markets.

This nonlinearity test presents several advantages, since it would be capable of detecting any form of nonlinear dependence of the third-order statistics between two pairs of variables. Furthermore, it offers a helpful tool for academics to study the functional form of the nonlinear association between the pairs of variables by defining in which direction the cross-bicorrelations flow and which of the lags are important. Given that this test allows the researcher to determine the third-order nonlinear dependency forms between pairs of series, it can be used as a supplementary instrument to the Granger causality test.

We have identified some moments of cross-bicorrelations that might be interesting to explore from a deeper economic point of view and it is left as a work in progress. Furthermore, following [23], it would be interesting to run a test including overlapped windows in a rolling scheme. Thus, like [23] it would be possible to identify the start, the end, the intensity and persistence of the cross-bicorrelation instead of just the bicorrelation.

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