RBEE

Dynamic interdependence and volatility transmission in the American stock markets during the attacks of September 11: a retrospective

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Resumo: Este trabalho examina a interdependência dinâmica, a transmissão de volatilidade e a integração entre os mercados acionários dos Estados Unidos, México e Brasil durante os atentados terroristas de 11 de setembro de 2001, a partir de um modelo Vetor Autorregressivo com heterocedasticidade condicional autorregressiva exponencial generalizada (VAR-EGARCH). Os resultados sugerem que existe um efeito assimétrico significativo dentro dos próprios mercados, implicando que más notícias são avaliadas mais "racionalmente" pelos participantes do mercado e são refletidas nos preços dos ativos de forma menos abrupta, quando os retornos são negativos. Nas altas, parece haver um maior stress do mercado refletindo em uma magnitude maior da volatilidade dos retornos dos ativos. Os resultados ainda indicam que, desde que não sejam consideradas as interações entre os mercados, as correlações calculadas por um modelo restrito são superdimensionadas.

Palavras-chave: mercado de ações; interdependência dinâmica; volatilidade; VAR-EGARCH; ataques terroristas.

Abstract: This article examines the dynamic interdependence, volatility transmission and integration between the stock markets of the United States, Mexico and Brazil during the terrorist attacks of September 11, 2001, from a Vector Autoregressive Model with Exponential Generalized Autoregressive Conditional Heterokedasticity (VAR-EGARCH). The results suggest that there is a significant asymmetric effect within the markets themselves, implying that when return rates are positive, bad news is more "rationally" valued by market participants and affects asset prices less abruptly. At highs, there seems to be greater market stress reflecting a greater magnitude of the volatility of asset returns. The results also indicate that, when disregarding interactions between markets, the correlations calculated by a restricted model are oversized.

Keywords: stock markets; dynamic interdependence; volatility; VAR-EGARCH; terrorist attacks.

Classificação JEL: G15; C32; F65.

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1. Introduction

The 90s were marked by recurrent periods of economic and financial instability in emerging markets. Early in the first half of the 90s, the Mexican crisis brought serious financial difficulties to Latin American countries. Nevertheless, in subsequent years the major countries of Latin America (LA) implemented large fiscal adjustments accompanied by a relative success in controlling inflation.

Asian economies in strong growth suddenly reversed the cycle towards recession. In mid-1997, the Asian crisis, triggered by the devaluation of the Thai currency, caused a massive devaluation of Asian assets. This crisis affected several emerging countries also in LA, and worked as a test for the economic policy of inflation control via fixed exchange implemented by some countries in the region. After the Asian crisis, the Russian moratorium in 1998 again brought instability to Latin American markets.

These two economic and financial shocks have not been fully absorbed. Consequently, the fiscal imbalance and the high deficit in the balance of payments increased the pressure on the Brazilian currency and in January 1999 the Real suffered devaluation with the adoption of flexible exchange rates. In 2000, the Argentinian economy started showing vulnerabilities, triggering an unprecedented political and economic crisis.[3]

External facts to the economies of LA contributed to instability in the region's equity markets during 2001 and 2002. One in particular generated spasms in the stock market world - the terrorist attacks of September 11, 2001. On this date, two planes hit the twin towers of the World Trade Center in New York, considered the financial center of American capitalism. On the same day, a third plane hit the building that represents the U.S. national security, the Pentagon. This episode certainly had a direct impact on the U.S. stock market and the major world markets.[4]

This work presents an analysis of volatility transmission and dynamic interdependence between the two main stock markets of Latin America - Brazil and Mexico - in relation to the U.S. market before, during and after the terrorist attacks of September 11, 2001.

The term rationality used here refers to transactions in the stock market that take into account the fundamentals of the financial structure of listed companies, as well as long-term trends in the returns of each asset. When bad (or good) news is announced, such transactions may suffer bias in the short term, and such biases may stress the market and reduce the rational pattern observed in the absence of stressful news. In this article, when a formula refers to innovation, it means the news the study is analyzing.

Recent research has explored the interdependencies between asset markets in terms of the second moment of returns distribution. Although most of these studies examine the equity markets of the United States, Japan and Europe, Singh, Kumar and Pandey (2009) study markets in three continents, America, Europe and Asia, researching the interdependency between 15 global markets. The authors use Vector Autoregressive models to spillovers analysis among the return on equity indexes, as well as the Autoregressive model GARCH to check volatility spillovers between markets. The authors find evidence of a strong spillover between the markets of Europe and Asia.

By examining the relationship of interdependence among stock markets, Brooks and Henry (2000) model the transmission of shocks between the stock markets of the U.S., Japan and Australia to check an existence of volatility linear and non-linear transmission between them. They find an asymmetric multivariate GARCH formulation that can explain almost any causality between these markets.[5] Koutmos and Booth (1995) analyze the transmission of asymmetric volatility and its impact among the stock markets of New York, Tokyo and London. Using a multivariate model of Vector Moving Average with EGARCH, the results suggest strong evidence that the transmission of

[3] The Argentinian crisis was practically limited to its own domestic economy, and by June 2002 the Argentinian Peso had dropped from one to a quarter of the US Dollar.

[4] Other facts that have disturbed the world stock markets were cases of accounting fraud detected in the balance sheets of large U.S. corporations (Enron, WorldCom, Xerox e Merck) between the end of 2001 and the middle of 2002.

[5] An alternative application of the test causality in variance between markets, based on cross-correlation function of the waste (FCC), is demonstrated in the work of Cheung and Ng (1996). According to the results, the FCC proposed test has good empirical results and provides useful information about the temporal dynamics and the interaction between two time series.

volatility in a given market is much more pronounced when the news originated in the latter market is adverse.

The literature review indicates a lack of studies related to the interdependence and volatility transmission between the two major Latin American markets and the main U.S. market. It is worth noting studies that adopt models similar to the one presented here, such as Pericli Christofi (1999) who apply the Vector Autoregressive EGARCH to five leading Latin American stock markets - Argentina, Brazil, Chile, Colombia and Mexico. Another example is Ortiz and Arjona (2001) who analyze the nature of volatility applying GARCH type models and their extensions to the six largestmarkets in Latin America. The authors include the stock market in Venezuela, however using weekly data for the period 1989 to 1994.

Working in the field of economics of crime, Nedelescu and Johnston (2006) studied the impacts of two major terrorist events that occurred in the 2000s[6], on financial markets. The authors also study the management of the crisis generated by these attacks. Drakos (2010), used the Pooled Panel GARCH model to verify the integration between markets, discussing on the determinants of terrorists shocks' cross-market transmission, considering the two terrorists attacks. His results indicate that the terrorist events had diffuse effects of different magnitude among the 68 countries studied. The author finds empirical support for three channels that determine the transmission of the effects of "terrorist shocks" when analyzed separately.

This work simply replicates the model used by In et al. (2001) to check the interdependence and volatility transmission between two stock markets in Latin America - Brazil and Mexico - and between them and the stock market in the United States. Using a Multivariate Autoregressive Vector model with exponential generalized autoregressive conditional heteroscedasticity (VAR-EGARCH), the research intends to verify the integration between asset markets selected before and after the terrorist attacks of September 11, 2001.

This article is structured as follows: in the next section, data and preliminary statistical analyzes are presented. Section 3 presents the model multivariate VAR-EGARCH. Section 4, shows the results from the empirical model and discuss the implications of these results. Finally, section 5 presents the conclusions and final remarks.

2. Database and Descriptive Statistics

This study uses the main indices of the U.S. stock market (Dow Jones Industrial Average - DJIA), Brazil (Index of the Stock Exchange of São Paulo - IBOVESPA) and Mexico (Index of the Stock Exchange of Mexico City - INMEX).

Daily series were used, considering closing prices in U.S. dollars and the period from 02 April 2001 to 12 July 2002, which included 335 observations. This period was chosen to analyze the relationship between the indexes before, during and after the period of shock represented by the attacks of September 11, 2001. The prices of those assets come from the database Economatica In the absence of a note on a given trading day, we used the arithmetic mean between the closing immediately anterior and posterior to fill the missing value.

The returns were calculated according to equation (1):

$$R_t = 100 \cdot (\log I_t - \log I_{t-1}) \qquad (1)$$

where It is the closing price on t.

[6] Terrorist attacks of September 11 in New York and Washington and March 11 in Madrid.

Table 1. Descriptive statistics of stock indexes daily returnable 8.

Statistic	DJIA	IBOVESPA	INMEX
Mean	-0.015512	-0.066491	0.010690
Median	-0.016504	-0.027780	-0.009627
Maximum	1.898702	2.683579	3.112536
Minimum	-1.941342	-4.774417	-3.026453
Standard Deviation	0.526788	1.036114	0.642000
Variance	0.276669	1.070297	0.410922
Asymmetry	0.101128	-0.404473	0.197208
Kurtosis	4.264103	4.475589	5.914915
JB	22.67095	39.17265	119.6901
	(0.000012)	(0.000000)	(0.000000)
AR(1)	0.040	0.141	0.199
	(0.468)	(0.010)	(0.000)
LB(10) to R_t	16.238	11.022	21.596
	(0.093)	(0.356)	(0.010)
LB(10) to R_t^2	45.082	30.127	7.3427
	(0.000)	(0.001)	(0.693)

Note: LB(n) is the Ljung-Box statistic for up to n lags, distributed as χ^2 with n degrees of freedom; JB is the normality test of Jarque and Bera; AR(1) is the autocorrelation coefficient of first order, the values in brackets represent the p-value.

Source: Own elaboration

Table 1 summarizes the descriptive statistics of stock indexes daily return. In the period studied, where the terrorist attacks took place, only the sample mean of INMEX is positive, implying that the other indexes experienced negative returns over the period. The worst is the IBOVESPA average, with a rate of -0066%, followed by DJIA, with -0.015%. The minimum variance was obtained by the DJIA (0.27) and the maximum IBOVESPA (1.07).

The measures of kurtosis and skewness are presented to evaluate where daily returns are normally distributed or not. If kurtosis values are greater than 3, the distribution of daily returns is higher and shorter tails than in a normal distribution. The statistic of Ljung-Box (LB) for up to 10 lags, calculated for the series of returns and squared returns, suggests the presence of significant linear and nonlinear dependence. The value at 1% of LB for returns in INMEX is relevant and suggests the presence of linear dependence. Likewise, there is a quadratic dependence highly significant for the DJIA and IBOVESPA, suggesting the presence of autoregressive conditional heteroscedasticity.

Table 2. Correlation matrix of the stock indexes daily returns

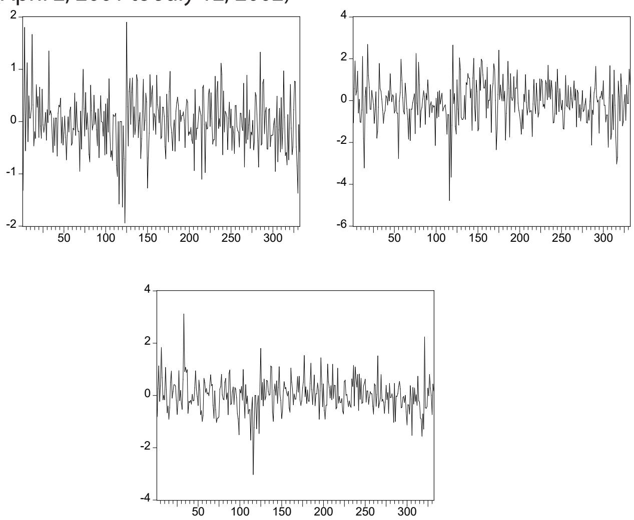
	DJIA	IBOVESPA	INMEX
DJIA	1.000000	0.433733	0.476452
BOVESPA		1.000000	0.365103
INMEX			1.000000

Source: Own elaboration

Except for Canada, the correlation structure between these markets is probably the most important of the Americas from the standpoint of investors, where diversification and hedging strategies invariably involve some degree of correlation. According to Table 2, the strongest correlation is observed between the DJIA and INMEX (0.47), followed by the DJIA and IBOVESPA (0.43). The correlation IBOVESPA and INMEX is the weakest (0.36), and it is clear that the DJIA has the most important role in the integration of the markets studied here.

Figura 1. Daily returns of indexes DJIA, IBOVESPA and INMEX

(April 2, 2001 to July 12, 2002)



Data source: BM&F BOVESPA

3. Multivariate VAR-EGARCH model

Recently, many studies have explored the interdependencies between stock markets in terms of the second moment of return distribution, basing their analysis on multivariate GARCH models. Karolyi and Stulz (1996), for example, analyze the key factors affecting the cross-correlations between asset return using a multivariate-GARCH model. The results suggest that the correlation and covariance between asset markets of the United States and Japan are high in periods of significant market movements. By examining the dynamic interdependence and volatility transmission between Asian asset markets, In et al. (2001) define a multivariate VAR-EGARCH model in order to study the impact of financial crises that occurred in Asia in 1997 and 1998.

The use of multivariate EGARCH models in an attempt to capture the level of integration between asset markets has certain advantages and some distinctive aspects. First, the market interactions can be studied and analyzed by a single step estimation procedure, avoiding problems related to estimated regressors and increasing at the same time, the efficiency and power of the tests (Koutmos and Booth, 1995). Second, multivariate VAR-EGARCH can explicitly test the hypothesis that the 'innovation' in the market itself and between markets influences the volatility asymmetrically.[7] In many cases, volatility transmissions are considered asymmetric in the sense that bad news generated in a market has a greater effect on the volatility of another market than good news. This information produced in a market can be evaluated in terms of signal and magnitude in another market.

Thus, the methodology proposed in this work consists of the estimation of a

[7] The asymmetric impact of past 'innovations' on current volatility of asset return is attributed to the so-called "leverage effect", considered statistically significant in the literature (Cheung and Ng, 1992; Koutmos, 1992; Poon and Taylor, 1992). For details on "leverage effect", see Enders (2010, p. 155-57).

multivariate VAR-EGARCH aiming to investigate the integration and transmission of volatility between asset markets of the United States, Brazil and Mexico.

The multivariate VAR-EGARCH model used in this study is defined as follows:

$$R_{i,t} = b_{i,0} + \sum_{i=1}^{3} b_{i,j} R_{j,t-1} + \varepsilon_{i,t} \tag{2}$$

$$\sigma_{i,t}^2 = \exp\left\{ a_{i,0} + \sum_{j=1}^{3} a_{i,j} F(h_{j,t-1}) + \gamma_i \ln(\sigma_{i,t-1}^2) \right\} \tag{3}$$

$$F(h_{j,t-1}) = \left| h_{j,t-1} \right| - E\left(\left| h_{j,t-1} \right| \right) + \delta_j h_{j,t-1} \tag{4}$$

Where: Ri,t is the return; i = 1, 2, 3 (1 = DJIA, 2 = IBOVESPA, 3 = INMEX); $\mu_{i,t}$ and $\sigma^2_{i,t}$ is the conditional mean and the conditional variance respectively; $\varepsilon_{i,t}$ is innovation at time *t* (ie, $\varepsilon_{i,t}=R_{i,t}-\mu_{i,t}$) and $h_{i,t}$ is the standardized innovation (ie, $h_{i,t}=\varepsilon_{i,t}/\sigma_{i,t}$).

Equation (2) describes the returns of the three markets as a VAR model, in which the conditional mean in each market is a function of its own past returns and the past returns of other markets. The coefficient $b_{i,j}$ measures the direct effect that a change in the return of the *j*th market will have over the *i*th market.

The process of the conditional variance is given by equation (3), following a procedure that allows EGARCH to extend standardized innovations, as well as the innovations that patterned an asymmetric impact from i market to j market volatility. According to the EGARCH representation, the conditional variance of returns in each market is an exponential function of its own past, cross standardized innovations between markets, and own lagged conditional variance. The last term expresses the persistence of volatility and is measured by the coefficient γ_i of equation (3)[8].

The asymmetry is modeled by equation (4). The ARCH effect is an asymmetric function of past standardized innovations and measures both the magnitude and the signal effect. The term ($|h_{j,t-1}|$)-E($|h_{j,t-1}|$) measures the effect magnitude. For example, if the magnitude of the term $|h_{j,t-1}|$ is greater than its expected value, E($|h_{j,t-1}|$), impact of $|h_{j,t-1}|$ in $\sigma^2_{i,t}$ is positively larger, providing a positive coefficient $a_{i,j}$. The term $\delta_j h_{j,t-1}$ measures the effect signal. For example, if δ_j is negative, the *j* asset market declines ($h_{j,t-1} < 0$) and will be followed by a volatility greater than when the market advances ($h_{j,t-1} > 0$) (Koutmos, 1996). Thus, the parameter δ_j measures the mechanisms of transmission of asymmetric volatility. If δ_j is negative, when a *j* market declines, this implies an increase in volatility greater than if it rises. If δ_j is positive, when a *j* market declines, this implies a lower volatility that would occur when the market rises. If $\delta_j = 0$, then a positive shock has the same effect as a negative shock of the same magnitude; if $-1 < \delta_j < 0$, then a negative shock leads to a greater increase in volatility than a positive shock; if $\delta_j <-1$, a negative shock actually increases volatility, while a positive shock reduces volatility.

Additionally, dividing the term of equation (3) into a sum of two parts for assessing the asymmetry, the first representing function module *F*, the second, a dummy variable representing signal F. Thus, if necessary, we can divide the analysis of the ARCH effect for the magnitude and sign of function F, which takes the following form:

$$F(h_{j,t-1}) = \left[\left| h_{j,t-1} \right| - E\left(\left| h_{j,t-1} \right| \right) \right] + \left[\delta_j h_{j,t-1} \right] = (af_{j,t-1} + daf_{j,t-1}) + (av_{j,t-1} + dav_{j,t-1}) \tag{5}$$

4. Result Analysis

The method used by In et al. (2001) and Koutmos and Booth (1995) was applied here to verify the importance of the interdependence of markets, i.e., the directions of the relations between returns (lead-lag relationships), interaction of volatility, and test the joint significance of the interactions in terms of the first and second time using statistical ratio of likelihood.

[8] R The unconditional variance is finite if $\gamma_i < 1$, but,if $\gamma_i = 1$, then there is no unconditional variance, and conditional variance follows an integrated process of order one (Nelson, 1991).

Table 3. Parameters estimated by maximum likelihood of restricted model

DJIA			IBOVESPA			INMEX		
	Coefficient	*p-value*		Coefficient	*p-value*		Coefficient	*p-value*
$b_{1,0}$	-0.020967	0.4395	$b_{2,0}$	-0.070791	0.1992	$b_{3,0}$	0.001724	0.9520
$b_{1,1}$	0.006078	0.9111	$b_{2,1}$	0.161573	0.0102	$b_{3,1}$	0.214891	0.0000
$a_{1,0}$	-0.039697	0.1628	$a_{2,0}$	-0.137564	0.0547	$a_{3,0}$	0.043769	0.0105
$a_{1,1}$	-0.010136	0.8110	$a_{2,1}$	0.170381	0.0545	$a_{3,1}$	-0.091536	0.0000
γ_1	-0.126012	0.0000	γ_2	-0.199336	0.0011	γ_3	-0.047971	0.0001
δ_1	0.966425	0.0000	δ_2	0.777724	0.0000	δ_3	0.972976	0.0000

Source: Own elaboration

The parameters shown in Table 3 were calculated restricting all coefficients between markets, prices and volatility transmission measures, as well as cross-correlation coefficients (assumed to be zero) as in the model presented below.

$$R_{i,t} = b_{i,0} + b_{i,j} R_{j,t-1} + \varepsilon_{i,t} \tag{6}$$

$$\sigma^2_{i,t} = \exp\left\{a_{i,0} + a_{i,j} F(h_{j,t-1}) + \gamma_i \ln(\sigma^2_{i,t-1})\right\} \tag{7}$$

$$F(h_{j,t-1}) = \left|h_{j,t-1}\right| - E\left(\left|h_{j,t-1}\right|\right) + \delta_j h_{j,t-1} \tag{8}$$

This restriction reduces the multivariate model to three univariate EGARCH models. The restricted model is used as a reference model. According to Table 3, the autocorrelation coefficient $b_{i,j}$ is statistically significant for Brazil and Mexico. In the restricted model, the conditional variance is described as a function of past innovations and past conditional variance. The relevant coefficients $a_{i,j}$ and γ_i are statistically significant, except for $a_{1,1}$, relaxing the significance to up to 6%. The coefficient δ_i measure the leverage effect or the asymmetric impacts information passed on to current volatility, being significant statistically for all countries. The persistence of volatility as measured by γ_i, in all cases is statistically significant.

Table 4. Correlation matrix of the standardized innovations - model restricted

(April 2, 2001 to July 12, 2002)

	DOW	IBOV	INMEX
DOW	1.000000	0.454481	0.447188
IBOV		1.000000	0.334808
INMEX			1.000000

Source: Own elaboration

The pairs of estimated conditional correlations, as described in Table 4, presented similar results from the estimates shown in Table 2. The correlation between DJIA and IBOVESPA increased from 0.43 to 0.45, while the correlation between DJIA and INMEX decreases from 0.48 to 0.45 and between IBOVESPA and INMEX dropped from 0.36 to 0.33. This result is consistent with empirical observations of Koutmos (1996), except for the correlation between DJIA and IBOVESPA. That is, when disregarding the conditional heteroscedasticity, correlation estimates become overvalued, since changes in the values of the correlation matrix are attributed to resulting from the use of the EGARCH model.

Table 5. Diagnosis of restricted model based on the residuals
(April 2, 2001 to July 12, 2002)

Statistic	DOW	IBOV	INMEX
Mean	0.006993	0.009433	0.013915
Variance	0.983461	1.002815	1.087570
Asymmetry	0.113140	-0.299605	0.261969
Kurtosis	3.104541	3.642726	4.388401
LB(10) to Z_t	9.6684	4.9045	8.1502
	(0.470)	(0.897)	(0.614)
LB(10) to Z_t^2	1.8058	6.0783	2.2968
	(0.998)	(0.809)	(0.994)

Note: LB(*n*) is the Ljung-Box statistic for up to *n* lags, distributed as χ^2 with *n* degrees of freedom; the values in brackets represent the p-value.

Source: Own elaboration

The maximum likelihood estimates for the complete VAR-EGARCH model (equations 2, 3, 4 and 5) are presented in Table 6. Observing the parameters related to the conditional mean in each market, it is possible to observe that there are only two statistically significant coefficients, $b_{2,1}$ e $b_{3,3}$. That is, the current returns of IBOVESPA are correlated with past returns of the DJIA, whereas returns of INMEX are influenced only by their own past returns. According to the results, it is evident that the returns of the DJIA are not influenced by past returns of IBOVESPA and INMEX, or their own past returns. The relationship between the returns of the Brazilian and U.S. markets is unidirectional.

Table 6. Parameters estimated by maximum likelihood of VAR-EGARCH model
(April 2, 2001 to July 12, 2002)

	DJIA			IBOVESPA			INMEX	
	Coefficient	*p-value*		Coefficient	*p-value*		Coefficient	*p-value*
$b_{1,0}$	-0.032440	0.2260	$b_{2,0}$	-0.103053	0.0535	$b_{3,0}$	0.016108	0.6126
$b_{1,1}$	-0.008879	0.7703	$b_{2,1}$	0.173066	0.0135	$b_{3,1}$	0.008399	0.8312
$b_{1,2}$	-6.32E-05	0.9992	$b_{2,2}$	-0.084877	0.4939	$b_{3,2}$	0.063041	0.4193
$b_{1,3}$	0.003298	0.9420	$b_{2,3}$	0.061457	0.5663	$b_{3,3}$	0.132974	0.0255
$a_{1,0}$	-0.135950	0.1804	$a_{2,0}$	-0.275168	0.1690	$a_{3,0}$	-0.174361	0.2485
$a_{1,1}$	-0.205128	0.0000	$af_{2,1}$	0.204834	0.0173	$af_{3,1}$	0.263892	0.0014
$af_{1,2}$	-0.042726	0.3185	$a_{2,2}$	0.115258	0.2008	$af_{3,2}$	0.016269	0.7104
$af_{1,3}$	-0.067824	0.1805	$af_{2,3}$	-0.098674	0.2868	$a_{3,3}$	-0.075986	0.4799
$av_{1,2}$	0.053775	0.1167	$av_{2,1}$	0.215425	0.0281	$av_{3,1}$	0.038726	0.7210
$av_{1,3}$	0.019231	0.7022	$av_{2,3}$	-0.028493	0.7496	$av_{3,2}$	-0.033242	0.5361
$daf_{1,2}$	-0.130311	0.3606	$daf_{2,1}$	0.810393	0.0092	$daf_{3,1}$	0.496039	0.1513
$daf_{1,3}$	0.158855	0.3391	$daf_{2,3}$	0.087810	0.7117	$daf_{3,2}$	-0.124850	0.5320
$dav_{1,2}$	0.107365	0.4245	$dav_{2,1}$	-0.381383	0.1011	$dav_{3,1}$	-0.165932	0.4646
$dav_{1,3}$	0.207283	0.0645	$dav_{2,3}$	0.407953	0.0500	$dav_{3,2}$	0.357516	0.0242
γ_1	-0.160466	0.0016	γ_2	-0.158999	0.0112	γ_3	-0.153255	0.0133
δ_1	0.927778	0.0000	δ_2	0.826893	0.0000	δ_3	0.732662	0.0000

Source: Own elaboration

The interdependencies in terms of the second moment (volatility interactions) are estimated by the coefficient $a_{i,j}$. According to Table 6, the conditional variance of the

U.S. market is affected by past innovations. The conditional variances of Brazilian and Mexican stock markets are not affected by their past information, but are influenced by the innovations originated in the U.S. market.

The degree of persistence in volatility (measured by the coefficient γ_i) is quite similar among the three indices, equal to -0.1604 for the DJIA, -0.1589 for IBOVESPA and -0.1532 for INMEX. These results demonstrate that there is a persistence of volatility significantly different from zero, that is, the past volatility affects the current volatility in the three stock markets.

The asymmetry effect, estimated by the parameter δ_i, is highly significant for all markets. In all cases, the asymmetry effect is very high and close to the unit value. This result suggests that there is a significant asymmetric effect within their own markets, but also between the U.S. market and the others markets.

Table 7. Correlation matrix of the standardized innovations - VAR-EGARCH model (April 2, 2001 to July 12, 2002)

	DJIA	IBOV	INMEX
DJIA	1.000000	0.429649	0.424157
IBOV		1.000000	0.314725
INMEX			1.000000

Source: Own elaboration

The correlation coefficients of the standardized residuals using VAR-EGARCH model shown in Table 7, indicate that the highest correlation is observed between DJIA and IBOVESPA (0.43) followed by DJIA and INMEX (0.42) and IBOVESPA and INMEX (0.31). From these results, it is evident that the market for U.S. assets was strongly correlated with other markets during the attacks of September 11, 2001.

Table 8. Diagnosis of VAR-EGARCH model based on the residuals

(April 2, 2001 to July 12, 2002)

Statistic	DJIA	IBOVESPA	INMEX
Mean	0.006993	0.009433	0.013915
Variance	0.983461	1.002815	1.087570
Asymmetry	0.113140	-0.299605	0.261969
Kurtosis	3.104541	3.642726	4.388401
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	(0.470)	(0.897)	(0.614)
LB(10) to Z_t^2	1.8058	6.0783	2.2968
	(0.998)	(0.809)	(0.994)

Note: LB(n) is the Ljung-Box statistic for up to n lags, distributed as χ^2 with n degrees of freedom; the values in brackets represent the p-value.

Source: Own elaboration

Comparing tables 3 and 6, we find that the degree of persistence in volatility, γ_i, the restricted model is greater than that found in the unrestricted model, except for the coefficient γ_2. The reason is that the restricted model does not consider the interactions between market volatility. Comparing the correlation structure of the restricted model and the full model, it was observed that all correlation coefficients of the restricted model are higher than those found in the unrestricted model, that is, provided that interactions between markets are not considered, the correlations calculated by the restricted model are oversized.

5. Conclusion

This article, analyzed the dynamic interdependence and volatility transmission between three of the major American and Latin American stock markets during the terrorist attacks of September 11, 2001. Dynamic interdependencies were researched in terms of first and second moments of asset markets in the United States, Brazil and Mexico using a multivariate VAR-EGARCH, enabling to examine the dynamic interdependence between selected assets in the three markets, as well as verify potential asymmetries that may exist in the volatility transmission mechanism.

The multivariate VAR-EGARCH captures market interactions, i.e., lead-lag relationships and volatility interactions among the three markets. In terms of lead-lag relationships, the research identified that the current IBOVESPA returns are correlated with past returns of the DJIA, and returns of the INMEX are influenced only by their own past returns. Moreover, the returns of the DJIA are not influenced by its own past returns, or past returns of IBOVESPA and INMEX. The relationship between the returns of the Brazilian and the U.S. markets is unidirectional. This suggests that the DJIA, at least in the studied period, has little relevance as a provider of information to other markets when analyzed variable is the return.

The conditional variance of the U.S. market is affected by its past 'innovations', the opposite occurs in the Brazilian and Mexican stock markets. In addition, the variance in these two markets is influenced by innovations originated in the U.S. market, which has an important role in the transmission of volatility for other markets. These results suggest that the markets have become more integrated during the terrorist attacks of September 11, 2001, in the sense that each one reacts not only to local news but also to news originated in other markets, especially when the news is adverse.

The persistence of volatility is quite similar among the three indices and significantly different from zero, showing that past volatility influences the current volatility in the three stock markets.

The informational asymmetry is highly significant for all markets and close to unit value. This result suggests that there is a significant asymmetric effect within the markets themselves, so that when a j market declines – negative return rates – this implies in a lower volatility that would occur in case market rises – positive returns rates. This does not contradict the initial perception that volatility should be greater at the onset of bad news. It means, however that bad news is valued more "rationally" by market participants and is reflected in asset prices in a less abrupt way. On the other hand, when return rates are positive, there seems to be increased market stress, reflecting sharp changes in asset prices.

Finally, it was found that the degree of persistence in the volatility of the restricted model is greater than that found in the unrestricted model, consistent with the foundation that the restricted model does not consider the interactions between market volatility. Comparing the models' correlation structure, it was observed that all correlation coefficients of the restricted model are higher than those found in the full model. That is, provided that interactions between markets are not considered, the correlations calculated by the restricted model are oversized.

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