FINANCIAL CRISIS AND STOCK MARKET LINKAGES

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Abstract: *This paper investigates interdependencies and linkages between international stock markets in the short-run. Thus, twelve European and non-European markets were selected, and the period from 4 October 1999 to 30 June 2011 was chosen, which includes the Dot-Com crisis and the recent Global Financial Crisis. To investigate interdependence and dynamic linkages between stock markets, a vector autoregressive model, the concept of Granger causality and impulse-response functions were considered. We concluded that the global financial crisis contributes to the intensification of the interdependence between stock markets.*

Keywords: *Global Financial Crisis, Stock Markets, Co-Movements, Vector Autoregressive model, Granger Causality, Impulse-Response.*

1. INTRODUCTION

The linkage between international stock markets has been studied extensively. The seminal work of Grubel (1968) has contributed to increase the importance of studying this subject. However, the findings of the first studies about this subject were not always coincident. Ripley (1973) detected a certain degree of interdependence between open markets for foreign investment and capital. Bertoneche (1979) studied the interrelationships between seven stock markets, including Germany, Belgium, the USA, France, Italy, the Netherlands and the United Kingdom, in the period from 1969 to 1976, concluding that these markets were highly segmented, which provided good opportunities for international diversification. Granger and Morgenstern (1970), Agmon (1972) and Branch (1974) found no significant lead-lag relationship between international stock markets. In turn, Roll (1988) found that co-movements between international stock markets were tenuous.

More recent studies have come to different conclusions from those obtained in early studies. In some of these there is a common denominator, which connects the 1987 crash to the strengthening of linkages between markets and to the occurrence of simultaneous falls between them. Shim and Eun (1989) have detected a substantial multilateral interaction between nine major stock markets. Jeon and Von Furstenberg-(1990) have shown that the degree of international stock market co-movement increased significantly after the 1987 crash. Using daily information for the 1986-1989 period, Lau and McInish (1996) have deepened approaches applied in earlier works, in particular through the study of changes in lead-lag structures of international stock market co-movements, considering the pre- and post- 1987 crash of sub-samples to conclude that the occurrence of the crash has caused changes on stock market co-movements. Similarly, Arshanapalli, Dukas and Lang (1995) suggest that the responses of the world's stock markets were more similar and connected, after the 1987crash. The occurrence of lead-lag effects between stock markets, as identified

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in these studies, can be seen as a violation of the efficient market hypothesis, according to which asset prices are not predictable, behaving as a random walk (Fama, 1970).

Hassan and Naka (1996) have investigated the dynamic linkages between the US, Japan, the UK and Germany stock markets, using daily data for the 1984-1991period, detecting short-term and long-term significant relationships between those markets. The study concluded that the US stock market has influenced other markets, both in the short and long term, before and after the crash of October 1987. A co-integration relationship was also detected in the long run between the four markets, limiting possibilities of international diversification over long periods. For its part, using daily returns, Peiro et al. (1998) have studied the New York, Tokyo and Frankfurt stock markets, from 1990 to 1993. They concluded that the first is the most influential stock market. The Japanese market is more sensitive to international shocks. Similarly, Ozdemir and Cakan (2007) have studied the US, Japan, France and the United Kingdom stock markets, for the 1990-2006 period, applying bivariate Granger causality tests, to conclude that the US stock market leads the other stock markets.

The works of Koch and Koch (1991) and Longin and Solnik (1995) have identified an increase in the correlation between international stock markets during the periods they studied. Koch and Koch (1991) have examined the dynamic relation between returns of eight major national indices. To this end, they resorted to dynamic simultaneous equations to describe contemporary and lead-lag relationships between different national markets in three different years (1972, 1980, and 1987). They have concluded that there was an increase in market interdependencies within the same geographical region over time. In turn, Longin and Solnik (1995) have studied the correlation between monthly returns of seven major markets for the 1960-1990 period. This study concluded that the covariance and correlation matrices are unstable over time and the conditional correlations between these markets increased over the period, especially in high volatility periods.

Goetzmann, Li and Rouwenhorst (2005) have concluded that the correlation structure of the global stock markets varied considerably over the last 150 years, and was strong in periods of economic integration. Bekaert et al. (2007) have concluded that the integration of stock markets in a global context is strong in countries where there were processes of liberalization, in capital markets, stock markets and banking systems. Using Granger causality tests and impulse response functions, Tudor (2011) has concluded that linkages between Central and Eastern Europe stock markets and the US stock market increased with the emergence of the recent global financial crisis. Similarly, Mandigma (2014) found that dynamic linkages between Southeast Asian countries and the US market became closer.

The global financial markets experienced their worst crisis since 1929. The global financial crisis had its beginnings in 2007, when the subprime credit crisis was triggered in the United States, spreading rapidly to other financial markets around the world. As the crisis worsened, stock markets around the world observed substantial declines in asset prices and entered in a highly volatile environment.

Based on the recent financial crisis, we believe that this is a good opportunity to study interdependencies between international stock markets. In order to carry out this study, we estimated a vector autoregressive (VAR) model, from which causality tests and impulse-response functions are estimated, in order to check short-term linkages and interdependencies between international stock markets.

In terms of structure, this research continues in Section 2 with the description of data and methodology, in Section 3 with the presentation of the empirical results and in Section 4 with the presentation of the summary and the main conclusions.

2. DATA AND METHODOLOGY

2.1 DATA

To analyze stock market linkages, indices representing international stock markets were selected (particularly European and non-European indices as well as developed and emerging indices), taking in account the Morgan Stanley Capital International criteria. The developed market set included European and non-European markets. From the European continent, we considered the following stock markets: Germany (DAX 30), France (CAC 40), UK (FTSE 100), Spain (IBEX 35), Ireland (ISEQ Overall), Greece (ATG) and Portugal (PSI 20). Developed markets set outside Europe include: the U.S. (Dow Jones), Japan (Nikkei 225) and Hong-Kong (Hang-Seng). Finally, two emerging markets were considered, namely Brazil (Bovespa) and India (Sensex).

The data used in this study was collected from *Econostats* and covers the period from 4 October 1999 to 30 June 2011, which in turn was subdivided into three sub-periods, taking into account the behavior of the series in levels, but also the option followed in other studies, forming sample sub-periods with the same number of observations. To analyze the Dot-Com crisis, the period from 04/10/1999 to 31/03/2003 was considered.

For the latest crisis episode, which began in the U.S., with the subprime credit crisis, and that would have a new epilogue with the sovereign debt crisis, we chose to follow the same assumption of other studies, indicating the emergence of the crisis for the summer months of 2007, as in Tudor (2011). For many authors, including Horta *et al.* (2008), Toussaint (2008), and *Naoui et al.* (2010), 1 August 2007 was the date of the crisis emergence, when the financial markets were surprised by the subprime crisis, with the rising rates of Credit Default Swaps. In addition to the sub-periods of crisis, a third sub-period was also considered (called quiet sub-period), on the delay of 01/04/2003 to 31/07/2007, which corresponds to a general increase in global stock indices.

The original closing prices were transformed in return series, r_t, through the application of the expression $\ln(P_t/P_{t-1})$, where P_t and P_{t-1} represent the closing values of a particular index in days t and $t-1$, respectively.

In order to investigate the stationarity of the series, we applied the traditional ADF tests. The null hypothesis (H_0) of these tests stipulates that the series must have a unit root, i.e., that it is an integrated series of order n. 1, I(1), versus the alternative hypothesis (H_a), which states that the series must not have a unit root or it is I(0). In all sub-periods, the return series is stationary, at a significance level of 1%.

2.2 METHODOLOGY

2.2.1 CORRELATION COEFFICIENT AND LIKELIHOOD RATIO

To analyze linkages between international stock markets we considered two statistical measures.

The first measure is the correlation coefficient, which provides a measure of association between each pair of indices.

The correlation coefficient is given by the standard measure

$$r = \left(\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) \right) / \left[\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2 \right]^{0,5} \qquad (1)$$

To test the statistical significance of the correlation coefficient, the statistic $t = \left(r \cdot \sqrt{n-2}\right) / \sqrt{1-r^2}$ is applied, which follows the Student t distribution, with $n-2$ degrees of freedom, where r is the correlation coefficient between each pair of indices and n is the number of observations in the sample.

The second measure is provided by the likelihood ratio, according to the suggestion of Rotenberg and Pindyck (1990), to test if the correlation coefficient matrix is generally different from the identity matrix, providing an indication about the significance of the joint correlation matrix. The null hypothesis of this test assumes that there is no correlation between stock markets. The test statistic is given by $t = -N \cdot \log|R|$, which follow the chi-square distribution, with $0{,}5p(p-1)$ degrees of freedom, where $|R|$ is the determinant of the correlation matrix, N is the number of observations in the common sample and p is the number of series in the test.

In order to understand if the linear correlations have increased with statistical significance, we considered the t test in two samples, also called the test for heteroskedasticity, according to the proposal of Forbes and Rigobon (2002). This test corresponds to the null hypothesis, in which the correlation level during the Global Financial Crisis sub-period is equal or greater than the correlation in the two previous sub-periods, against the alternative hypothesis that the correlation during the last sub-period is lower than the correlation in the two previous sub-periods.

$$H_0 = r_{i,j}^1 \geq r_{i,j}^0 \qquad (2)$$

$$H_1 = r_{i,j}^1 < r_{i,j}^0 \qquad (3)$$

Where $r_{i,j}^t$ is the correlation coefficient between markets *i* and *j* in period t.

In previous cases, the Global Financial Crisis sub-period matched the value "1" while the previous sub-periods corresponded to "0".

Using Fisher's *Z*-transformation, we obtained an approximately asymptotic normal distribution, with mean μ_t and variance σ_t^2, defined as follows:

$$\mu_t = \frac{1}{2} ln\left[\left(1 + r_{i,j}^t\right) / \left(1 - r_{i,j}^t\right)\right] \qquad (4)$$

$$\sigma_t^2 = 1 / \left(n_t - 3\right) \qquad (5)$$

The test statistic is calculated from the formula:

$$U = \left(\bar{\mu}_1 - \bar{\mu}_0\right) / \left(\sigma_0^2 + \sigma_1^2\right)^{\frac{1}{2}} \qquad (6)$$

Where μ_t and σ_t^2 are the mean and the transformed sample variance, respectively. The test statistic approximates the normal distribution with mean 0 and variance 1.

2.2.2 VECTOR AUTORREGRESIVE MODEL

To understand the interdependence and the dynamics of daily market returns, it is important to choose a model that clearly shows how returns are transmitted from one market to another and to study simultaneity interactions between stock markets. The Vector Autoregressive (VAR) model, developed by Sims (1980), is one of the most appropriate models, allowing us to estimate a system of simultaneous dynamic equations without establishing prior restraints in the structure of relationships between variables.

The present study expresses the VAR model as follows:

$$Y_t = C + \sum_{s=1}^{m} A_s Y_{t-s} + \varepsilon_t \qquad (7)$$

Where $\varepsilon_t \sim N(0,\Omega)$, Y_t is a column vector (12×1), with twelve stationary dependent variables, C is a column vector (12×1), for the deterministic component, A_s is the matrix of autoregressive parameters (12×12), m is the lag number, which is calculated by Akaike´s information criteria, s is the number of markets, with $s = 1$ - ATG, $s = 2$ - BOV, $s = 3$ - CAC, $s = 4$ - DAX, $s = 5$ - DJ, $s = 6$ - FTSE, $s = 7$ - HANG, $s = 8$ - IBEX, $s = 9$ - ISEQ, $s = 10$ - NIKKEI, $s = 11$ - PSI20 and $s = 12$ - SENSEX, ε_t (12×1) is the vector of disturbances or unexpected components, associated with the respective dependent variables, called innovations, shocks or impulses in VAR terminology, which are independent and identically distributed with a normal distribution with zero mean and variance-covariance Ω. The disturbances from each equation in the VAR model may be simultaneously correlated. Covariances are brought into the off-diagonal matrix elements $E(\varepsilon_t \varepsilon'_t) = \Omega$.

2.2.3 CAUSALITY TESTS

In order to study the short-term linkages between the selected stock markets and the direction of influence between them, we used the Granger causality concept, introduced by Granger (1969), and later popularized by Sims (1972), based on the assumption that X_t causes Y_t if the prediction of the Y_t variable is improved with the lagged information of X_t, that is, if the prediction of Y_t is more accurate when using the combined lagged information of X_t and Y_t, than considering only the information of Y_t. The Granger causality test will be obtained from the VAR model estimates, in order to know if the lags of the excluded variable affect the endogenous variable. This test is called VAR Granger Causality/Block Exogenety Wald Tests, assuming the null hypothesis, in which, in the Granger sense, the lagged endogenous variables do not cause the dependent variable.

2.2.4 IMPULSE RESPONSE FUNCTIONS

To analyze the short-term linkages between international stock markets, impulse response functions should also be considered. In considering all the variables entered into the system, this approach provides a dynamic analysis, generated from the VAR model, allowing us to analyze the causal relationships, even when they were not previously detected by the Granger causality relationships between variables (Lutkepohl, 1999).

The impulse response functions show how a particular variable responds to shocks to other variables in the system. In other words, an innovation in a given variable triggers a chain reaction over time in the remaining variables. The impulse response functions allow us to assess these chain reactions.

According to Lutkepohl and Saikkonen (1997) and Aziakpono (2006), if the process is white noise, then the estimated VAR can be converted into a moving average representation, whose coefficients are forecast error impulse responses. The moving average is given by:

$$Y_t = C + \sum_{s=0}^{k} B_s \varepsilon_{t-s} \quad (8)$$

Where Y_t denotes a linear combination, of current and past one-step-ahead forecast error innovations, the coefficient β_s expresses the response of one stock market returns to a one standard error shock of any of the markets under study s periods ago.

In this study, we selected generalized impulse response functions, which were introduced by Koop, Pesaran and Potter (1996) and Pesaran and Shin (1998), and applied the Monte Carlo simulation procedure, repeated 1000 times. This approach differs from the traditional orthogonalized impulse-response analysis, because it does not vary with the ordering of variables in the VAR model.

3. EMPIRICAL RESULTS

In order to study the behavior of stock markets in the three sub-periods, firstly we have calculated the contemporary correlation coefficients between each pair of markets and analyzed their intensity level, according to the suggestion of Pestana and Gageiro (2000).

During the Dot-Com sub-period, all correlation coefficients showed positive values and were statistically significant at the significance level of 1%. However, fifteen pairs showed very weak correlations $\left(0 \leq |R| < 0{,}20\right)$, many of them involving non-European markets, especially the Sensex index. Nearly half correlation coefficients have a weak intensity level $\left(0{,}20 \leq |R| < 0{,}40\right)$, particularly pairs involving ATG, HANG and NIKKEI markets. Fourteen pairs exhibited moderate intensity $\left(0{,}40 \leq |R| < 0{,}70\right)$, highlighting the DJ index, in five pairs. Six market pairs have strong correlations $\left(0{,}70 \leq |R| < 0{,}90\right)$, involving only European pairs, namely CAC-DAX, CAC-FTSE, CAC-IBEX, DAX-FTSE, DAX-IBEX and FTSE-IBEX pairs. The first three pairs have correlations higher than 0.8. Finally, during this sub-period, there was no strong correlation $\left(0{,}90 \leq |R| \leq 1{,}00\right)$.

In the Quiet sub-period all pairs exhibited positive correlation values and proved to be statistically significant at the significance level of 1%. In this sub-period, only four pairs showed very weak correlations. Thirty-five pairs have exhibited a weak correlation, evidencing nine cases with the BOV index. Twenty-one market pairs showed moderate correlations, especially the ISEQ index, with six pairs. Five pairs showed strong correlations (above 0.8), in all cases involving European indices. Only the CAC-DAX pair showed a very strong correlation level (0.91).

During the Global Financial Crisis sub-period, as in previous sub-periods, all correlation pairs showed positive linear relationships and were significant at the significance level of 1%. Only the DJ-NIKKEI pair showed a very weak correlation; ten pairs showed weak correlation, especially those involving the NIKKEI index; forty-two pairs showed moderate correlation, highlighting ATG and HANG indices, with nine pairs each one; ten pairs showed strong correlation, in nine cases between European markets, while three pairs have very strong correlations, namely CAC-DAX (0.92), CAC-FTSE (0.93) and CAC-IBEX (0.91) pairs. These results therefore confirm a clear superiority of the correlation values in this sub-period, as compared to the previous sub-periods. The correlation coefficients for the Global Financial Crisis sub-period were, in all cases, higher than during the Dot-Com sub-period. Given the Quiet sub-period, only the DAX-IBEX pair did not increase in the most recent sub-period, although the difference was very slight.

While correlation coefficients allow us to understand the linear association between stock market pairs, the likelihood ratios facilitate a joint analysis. The values of these ratios proved to be significant at a level of 1%, all above the critical value of 95.63, and showed an increasing trend, with 5315, 8202 and 11000, in the Dot-Com, Quiet and Global Financial Crisis sub-periods, respectively, conveying the idea that the stock market movements tended to be closer.

In order to show if the correlation coefficients increase was statistically significant, the *t* test in two samples was applied, according the proposal of Forbes and Rigobon (2002). The test results are shown in Table 1, which compares the global financial crisis sub-period with the previous two.

During the Global Financial Crisis sub-period, in comparison with the Dot-Com sub-period, the linear dependence level across stock markets has changed substantially. All 66 correlation pairs have registered an increased value. 61 of them were statistically significant at the significance level of 5%, exceeding the critical value of 1.96. Only DAX-DJ, DJ-NIKKEI, HANG-IBEX, HANG-ISEQ and ISEQ-NIKKEI pairs did not show a correlation increase with statistical significance. Comparing with the Quiet sub-period, in general the correlation coefficients have registered an increased value in the Global Financial Crisis sub-period. 65 of them have recorded an increase, wherein 56 have a statistically significant, at the significance level of 5%, exceeding the critical value of 1.96. FTSE, PSI and SENSEX indices revealed a statistically significant increase with all their pairs.

Table 1: Test for the Equality of Correlations

Global Financial Crisis versus Dot-Com Crisis											
	BOV	CAC	DAX	DJ	FTSE	HANG	IBEX	ISEQ	NIKKEI	PSI	SENSEX
ATG	5.89	8.53	8.13	4.13	7.66	3.03	9.50	6.48	2.72	9.57	6.28
BOV		8,40	6,77	9,47	8,52	5,27	6,66	6,08	2,26	5,35	6,99
CAC			7,67	3,52	10,16	2,34	5,88	6,66	3,84	8,35	7,72
DAX				1,74	8,71	3,51	4,08	5,51	4,52	5,83	8,19
DJ					3,86	4,09	4,09	4,48	1,31	3,63	6,12
FTSE						2,89	5,55	4,96	3,58	8,75	7,36
HANG							1,93	1,48	5,30	3,05	9,25
IBEX								6,52	3,52	8,19	6,42
ISEQ									0,99	7,85	6,37
NIKKEI										4,35	4,80
PSI											6,57
Global Financial Crisis versus Quiet sub-period											
	BOV	CAC	DAX	DJ	FTSE	HANG	IBEX	ISEQ	NIKKEI	PSI	SENSEX
ATG	4.99	3.54	4.12	3.77	3.35	1.83	4.86	3.01	2.10	7.46	2.92
BOV		7,91	7,89	6,82	7,32	4,80	6,19	6,21	1,48	7,63	4,63
CAC			1,35	4,00	8,42	2,04	4,20	4,75	1,91	10,95	3,62
DAX				4,09	6,03	2,79	-0,29	3,39	2,20	8,27	5,03
DJ					3,88	3,58	3,22	4,49	1,34	4,72	5,20
FTSE						2,70	2,62	3,25	2,28	9,74	4,00
HANG							1,78	0,17	4,39	3,52	5,65
IBEX								3,74	1,80	12,72	3,33
ISEQ									0,48	7,43	2,76
NIKKEI										2,60	1,99
PSI											3,30

Considering all European stock markets, only the CAC-DAX pair did not show higher correlation with statistical significance. The higher contemporary correlations show a first indication of the short-term co-movements in stock markets. This is the first reason to believe that the stock markets, considered in the present analysis, described relations that were not explained by the usual movements based on economic basics. The Global Financial Crisis lead to a possible contagion phenomenon between markets, rather than simple common shock reactions, triggered in some of these stock markets.

In order to deepen the study about linkages between stock markets, we turned to the vector autoregressive model, to analyze the causal relationships and to estimate the impulse response functions. Before the model estimation, we checked the stationirity of all return series, through the ADF test, since the VAR model requires stationarity of all variables (Brooks, 2002; Alexander, 2008).

To check the statistical significance of causal relationships between the twelve indices, during the three sub-periods, the VAR Granger Causality procedure/Block Exogeneity Wald Tests was applied. The null hypothesis of this test states that there is no causal relationship. This procedure assesses the significance of each joint lagged endogenous variable in each VAR equation, through the statistical values χ^2, and simultaneously the significance of the joint contribution of all lagged endogenous variables in the equation, using F-statistic. For each equation of the VAR system, the Wald test statistics are shown, about the joint significance of each other's endogenous variables, based on the selected lag length, obtained according to the Akaike and Schwarz information criterion, which have selected 1, 1 and 3 lags, for the three sample sub-periods, respectively. The test results are shown in tables 2, 3 and 4, respectively.

The analysis with regard to the first sub-period (Table 2) shows that the HANG index was the most endogenous, according to the Granger theory, being caused by six of its pairs. For its part, BOV and DJ indices were the less endogenous, because, according to the Granger theory, they were not caused by any index. The most exogenous was the DJ index, which clearly stood out, containing information about the movements of nine of the remaining indices. Conversely, ATG, HANG, IBEX and PSI indices did not show any significant causal relationship with their pairs.

Table 2: Granger Causality Tests/Block Exogeneity Wald Tests during the Dot-Com Sub-Period

		Dependent Variables											
		ATG	BOV	CAC	DAX	DJ	FTSE	HANG	IBEX	ISEQ	NIKK	PSI	SENSE
Excluded Variables	ATG		1,33 (0,25	0,59 (0,44	0,01 (0,93	0,14 (0,71	0,03 (0,86	1,45 (0,23	0,19 (0,67	0,15 (0,70	0,50 (0,48)	0,16 (0,69	0,20 (0,65)
	BOV	2,71 (0,10		0,48 (0,49	0,02 (0,90	0,43 (0,51	0,06 (0,80	6,83 (0,01	3,94 (0,05	1,30 (0,25	0,74 (0,39)	13,7 (0,00	10,50 (0,00)
	CAC	0,13 (0,72	2,16 (0,14		0,52 (0,47	0,01 (0,93	0,53 (0,47	7,53 (0,01	4,78 (0,03	0,85 (0,36	0,00 (0,99)	1,06 (0,30	0,12 (0,73)
	DAX	0,17 (0,68	3,39 (0,07	4,55 (0,03		2,63 (0,10	0,87 (0,35	2,94 (0,09	2,01 (0,16	3,89 (0,05	7,86 (0,01)	2,60 (0,11	1,86 (0,17)
	DJ	25,2 (0,00	0,29 (0,59	44,0 (0,00	30,0 (0,00		70,77 (0,00	52,37 (0,00	30,8 (0,00	64,52 (0,00	22,15 (0,00)	5,57 (0,02	0,02 (0,88)
	FTSE	0,12 (0,73	0,49 (0,48	0,86 (0,35	0,85 (0,36	0,03 (0,86		6,85 (0,01	0,39 (0,53	0,30 (0,58	0,03 (0,85)	1,07 (0,30	0,01 (0,93)
	HANG	0,44 (0,51	0,25 (0,61	(0,97	0,75 (0,39	0,13 (0,72	0,18 (0,67		0,04 (0,84	1,27 (0,26	0,68 (0,41)	1,64 (0,20	0,20 (0,66)
	IBEX	0,49 (0,49	0,48 (0,49	2,90 (0,09	0,32 (0,57	0,18 (0,67	1,22 (0,27	1,32 (0,25		0,49 (0,48	1,07 (0,30)	0,11 (0,74	0,24 (0,63)
	ISEQ	0,01 (0,94	0,02 (0,90	7,57 (0,01	1,95 (0,16	1,59 (0,21	3,82 (0,05	4,60 (0,03	1,88 (0,17		0,48 (0,49)	4,42 (0,04	0,82 (0,37)
	NIKKE I	1,54 (0,21	0,21 (0,64	0,04 (0,85	0,29 (0,59	0,07 (0,79	0,31 (0,58	3,11 (0,08	0,81 (0,37	0,58 (0,45		0,66 (0,42	0,97 (0,32)
	PSI	0,85 (0,36	0,22 (0,64	1,45 (0,23	0,70 (0,40	0,84 (0,36	0,01 (0,92	15,12 (0,00	0,96 (0,33	0,25 (0,62	0,24 (0,63)		6,65 (0,01)
	SENSE X	0,12 (0,73	3,07 (0,08	0,22 (0,64	0,16 (0,69	1,23 (0,27	1,19 (0,28	0,02 (0,88	0,09 (0,76	0,65 (0,42	2,05 (0,15)	1,37 (0,24	
	All	53,9 (0,00	9,78 (0,55	94,1 (0,00	38,7 (0,00	7,12 (0,79	109,3 (0,00	237,6 (0,00	71,5 (0,00	125,2 (0,00	151,7 (0,00)	55,8 (0,00	49,33 (0,00)

Note: Values between parentheses show probability values.

The causality test results for the second sub-period are shown in Table 3. These results support the conclusion that the ISEQ index was the one with the highest expression in terms of endogeneity, according to the Granger theory, being caused by five of their pairs, while the DJ index had lower expression in terms of exogeneity, and it wasn't caused by any of the remaining indices. For its part, the DJ index was the most exogenous, improving the estimate of 10 of its pairs, while the IBEX index did not help to improve the forecasting of any of the remaining indices.

Table 3: Granger Causality Tests/Block Exogeneity Wald Tests During the Quiet Sub-Period

		Dependent Variables											
		ATG	BOV	CAC	DAX	DJ	FTSE	HAN	IBEX	ISEQ	NIKK	PSI	SENSE
Excluded Variables	ATG		0,97 (0,32	0,97 (0,32	0,37 (0,54	0,49 (0,48	0,72 (0,40	1,70 (0,19	0,37 (0,54	8,49 (0,00	0,07 (0,80)	0,79 (0,37	0,17 (0,68)
	BOV	5,00 (0,03		4,76 (0,03	5,27 (0,02	2,16 (0,14	9,16 (0,00	32,00 (0,00	6,62 (0,01	10,85 (0,00	11,71 (0,00)	2,15 (0,14	11,50 (0,00)
	CAC	17,27 (0,00	0,02 (0,90		2,01 (0,16	0,06 (0,80	3,20 (0,07	1,08 (0,30	7,29 (0,01	4,26 (0,04	3,08 (0,08)	1,64 (0,20	3,45 (0,06)
	DAX	9,28 (0,00	0,21 (0,65	0,12 (0,73		0,01 (0,92	0,02 (0,90	0,59 (0,44	0,56 (0,45	3,21 (0,07	0,00 (0,95)	0,00 (0,98	1,18 (0,28)
	DJ	52,92 (0,00	2,54 (0,11	73,48 (0,00	44,1 (0,00		65,60 (0,00	43,85 (0,00	54,14 (0,00	63,66 (0,00	49,09 (0,00)	34,9 (0,00	17,56 (0,00)
	FTSE	0,02 (0,90	3,55 (0,06	0,18 (0,67	3,32 (0,07	0,70 (0,40		1,31 (0,25	1,32 (0,25	3,34 (0,07	0,22 (0,64)	1,06 (0,30	0,90 (0,34)
	HANG	3,16 (0,08	7,93 (0,00	3,57 (0,06	0,89 (0,35	0,63 (0,43	3,91 (0,05		0,67 (0,41	9,37 (0,00	0,05 (0,82)	4,53 (0,03	5,21 (0,02)
	IBEX	0,02 (0,89	1,59 (0,21	0,02 (0,89	0,96 (0,33	1,79 (0,18	0,02 (0,90	3,45 (0,06		0,21 (0,65	0,00 (0,97)	0,47 (0,49	3,28 (0,07)
	ISEQ	0,77 (0,38	3,83 (0,05	0,33 (0,57	0,06 (0,81	0,03 (0,87	0,90 (0,34	0,39 (0,53	0,08 (0,78		0,45 (0,50)	0,14 (0,71	7,03 (0,01)
	NIKKEI	0,14 (0,71	0,21 (0,65	0,29 (0,59	0,41 (0,52	0,29 (0,59	0,11 (0,74	12,27 (0,00	0,00 (1,00	0,29 (0,59		1,69 (0,19	0,62 (0,43)
	PSI	0,74 (0,39	0,91 (0,34	0,64 (0,42	0,97 (0,32	0,51 (0,48	0,18 (0,67	3,78 (0,05	0,02 (0,89	0,11 (0,74	4,75 (0,03)		0,68 (0,41)
	SENSEX	0,16 (0,69	0,00 (0,97	1,60 (0,21	1,61 (0,20	0,09 (0,77	2,40 (0,12	4,20 (0,04	3,16 (0,08	0,01 (0,93	2,23 (0,14)	6,52 (0,01	
	All	127,1 (0,00	20,1 (0,04	137,0 (0,00	90,5 (0,00	6,64 (0,83	137,8 (0,00	222,4 (0,00	118,6 (0,00	158,3 (0,00	244,3 (0,00)	71,4 (0,00	91,44 (0,00)

Note: Values between parentheses show probability values.

Table 4 presents the results of causality tests for the Global Financial Crisis sub-period. In this sub-period, HANG and NIKKEI indices were the most endogenous, caused in the Granger sense by 9 and 8 of their pairs, respectively, contrasting with the CAC index, only caused by ATG and DJ indices. With respect to exogeneity, the highlights go to CAC and DJ indices, for helping to predict the daily return movements of all their pairs. Conversely, FTSE and ISEQ indices help to explain a single index. In the last sub-period, in the Granger sense, each index individually was caused by the combined effect of lagged returns of other indices, contrary to what happened in the previous two sub-periods. In the Dot-Com sub-period, BOV and DJ indices were not caused in the Granger sense by the combined lagged effect of other indices. The same happens in the Quiet sub-period with the DJ index. The performed analysis allowed us to detect several cases of unidirectional causality. Specifically, 24, 33 and 53 unidirectional causality relations were detected, with statistical significance, at the significance level of 5%, for the Dot-Com, Quiet and Global Financial Crisis sub-periods, respectively, which corresponds to 18%, 25% and 40% of linkages between market pairs with statistical significance, in each of the three sub-periods. On the other hand, in the first sub-period we didn't find any mutual causality relationship with statistical significance, at the significance level of 5%. In the second sub-period two cases of bidirectional causal relationship were recorded (level of 5%), namely BOV-HANG and HANG-SENSEX pairs. In the last sub-period, the number cases increased to twelve, highlighting the DJ index, with seven cases, particularly with ATG, BOV, CAC, DAX, ISEQ, NIKKEI and PSI indices.

Table 4: Granger Causality Tests/Block Exogeneity Wald Tests during the Global Financial Crisis Sub-Period

		Dependent Variables											
		ATG	BOV	CAC	DAX	DJ	FTSE	HAN	IBEX	ISEQ	NIKK	PSI	SENSE
Excluded Variables	ATG		15,2 (0,0	9,54 (0,02	17,47 (0,00	10,3 (0,0	6,09 (0,11	10,54 (0,01	8,38 (0,04	4,71 (0,19	2,52 (0,47)	7,42 (0,06	4,08 (0,25)
	BOV	8,42 (0,04		6,59 (0,09	5,35 (0,15	16,7 (0,0	4,27 (0,23	41,63 (0,00	6,37 (0,09	4,64 (0,20	12,64 (0,01)	13,42 (0,00	9,53 (0,02)
	CAC	15,60 (0,00	22,6 (0,0		24,96 (0,00	8,68 (0,0	28,84 (0,00	25,08 (0,00	41,89 (0,00	14,45 (0,00	13,28 (0,00)	29,42 (0,00	11,47 (0,01)
	DAX	5,16 (0,16	8,99 (0,0	1,47 (0,69		9,30 (0,0	0,98 (0,81	7,07 (0,07	2,30 (0,51	3,97 (0,26	13,72 (0,00)	3,03 (0,39	1,23 (0,74)
	DJ	29,34 (0,00	13,6 (0,0	97,74 (0,00	82,20 (0,00		114,3 (0,00	36,61 (0,00	66,47 (0,00	72,05 (0,00	100,1 (0,00)	55,08 (0,00	17,52 (0,00)
	FTSE	3,28 (0,35	2,33 (0,5	1,59 (0,66	0,72 (0,87	2,51 (0,4		10,09 (0,02	3,22 (0,36	0,83 (0,84	5,05 (0,17)	2,99 (0,39	2,62 (0,45)
	HANG	3,53 (0,32	3,13 (0,3	0,79 (0,85	3,47 (0,33	5,73 (0,1	0,42 (0,94		0,14 (0,99	1,10 (0,78	13,40 (0,00)	0,98 (0,81	8,53 (0,04)
	IBEX	3,28 (0,35	3,13 (0,3	1,50 (0,68	3,86 (0,28	3,42 (0,3	1,17 (0,76	16,02 (0,00		11,02 (0,01	8,64 (0,03)	4,70 (0,20	7,69 (0,05)
	ISEQ	1,26 (0,74	4,40 (0,2	5,63 (0,13	5,90 (0,12	8,40 (0,0	5,79 (0,12	1,29 (0,73	3,94 (0,27		5,53 (0,14)	2,19 (0,53	2,77 (0,43)
	NIKKE I	2,57 (0,46	5,42 (0,1	2,19 (0,53	4,71 (0,19	7,95 (0,0	3,08 (0,38	7,97 (0,05	1,73 (0,63	1,12 (0,77		2,35 (0,50	4,60 (0,20)
	PSI	1,09 (0,78	14,3 (0,0	5,07 (0,17	8,87 (0,03	14,9 (0,0	12,40 (0,01	9,63 (0,02	6,23 (0,10	4,11 (0,25	8,78 (0,03)		10,37 (0,02)
	SENSE X	12,37 (0,01	7,44 (0,0	6,17 (0,10	9,03 (0,03	3,61 (0,3	13,90 (0,00	20,03 (0,00	5,85 (0,12	4,06 (0,26	13,77 (0,00)	10,86 (0,01	
	All	116,4 (0,00	99,2 (0,0	259,9 (0,00	209,5 (0,00	89,2 (0,0	297,0 (0,00	426,7 (0,00	221,9 (0,00	180,1 (0,00	664,6 (0,00)	223,3 (0,00	133,0 (0,00)

Note: Values between parentheses show probability values.

The obtained results suggest a gradual increase in causal relationships between markets over the period analyzed, but also the influence of the US index, by helping to explain the behavior of the remaining markets, corroborating the results obtained by other authors, namely Koch and Koch (1991), Longin and Solnik (1995), Goetzmann, Rouwenhorst and Li (2005), and Cakan Ozdemir (2007) Bekaert et al. (2007), Tudor (2011) and Mandigma (2014). However, linkages between markets were clearly stronger than those resulting from previous global crisis studies, both unidirectional and bidirectional. The results show that the assumptions of the efficient market hypothesis are questionable, since the movements in a particular market, are, in part, preceded by past movements in other markets, showing a certain predictability in these movements.

Once the linkages between stock markets are very volatile, other estimates were made, considering sampling periods slightly different from those assumed in this work, in particular for the last sub-period. However, the results didn’t change relatively to the initial assumption, which reinforces its robustness.

The Granger causality test helps to understand linkages between stock markets, but doesn’t explain why a certain market produces a negative effect or a positive effect on their pairs, or whether some linkage is stronger than other. To this end, we use the generalized impulse response functions corresponding to a one standard error shock of any stock market under study, in order to obtain additional evidence about the short-term movements and the transmission mechanisms.

The results about the impulse response functions, in each sample sub-period, are summarized in Tables 5, 6 and 7, respectively.

Table 5: Impulse Response Functions During the Dot-Com Sub-Period: Summary of Results

	ATG	BOV	CAC	DAX	DJ	FTSE	HANG	IBEX	ISEQ	NIKKEI	PSI	SENSEX
ATG		2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	1 1 +	2 1,2 +,+	2 1,2 +,+	1 1 +	2 1,2 +,+	1 1 +
BOV	1 1 +		1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +
CAC	1 1 +	2 1,2 +,+		2 1,2 +,+	2 1,2 +,+	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +
DAX	1 1 +	1 1 +	1 1 +		2 1,2 +,+	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +
DJ	1 1 +	1 1 +	1 1 +	1 1 +		1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +
FTSE	1 1 +	2 1,2 +,+	1 1 +	2 1,2 +,+	2 1,2 +,+		1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +
HANG	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	3 1,2,4 +,+,–	2 1,2 +,+		2 1,2 +,+	2 1,2 +,+	1 1 +	2 1,2 +,+	1 1 +
IBEX	1 1 +	3 1,2,3 +,+,–	1 1 +	2 1,2 +,+	3 1,2,3 +,+,–	1 1 +	1 1 +		1 1 +	1 1 +	1 1 +	1 1 +
ISEQ	1 1 +	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+		1 1 +	2 1,2 +,+	1 1 +
NIKKEI	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	1 1 +	2 1,2 +,+	2 1,2 +,+		2 1,2 +,+	2 1,2 +,+
PSI	2 1,2 +,+	2 1,2 +,+	2 1,3 +,–	3 1,2,3 +,+,–	3 1,2,3 +,+,–	2 1,3 +,–	1 1 +	3 1,2,3 +,+,–	2 1,3 +,–	1 1 +		1 1 +
SENSEX	2 1,2 +,+	3 1,2,3 +,+,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	3 1,2,3 +,+,+	

Notes: market responses in rows, impulses from markets in columns; each cell has three rows: the first row indicates the number of days during which each market response was statistically significant, according to the criterion of one standard deviation, the second row indicates the number of order of these days and the third row indicates the signal of the impulse response.

For the first sub-period, the impulse response functions obtained from the vector autoregressive model shows that in all cases the reactions to outside shocks were statistically significant (Table 5). The main shocks have produced statistically significant effects only for a single day before they faded. The overwhelming majority of responses are consistent with the expected direction, following the direction of the market variation where the shock is originated. In general, stock markets do not record correction reactions to the initial shock. Only three indices contradict this generalization, specifically the Hang-Seng index in response to DJ impulses, IBEX, in response to BOV and DJ indices, and in particular, the Portuguese index, which registered negative responses to CAC, DAX, DJ, FTSE, IBEX and ISEQ indices.

The impulse response functions show that during the Quiet sub-period, similar to what happened in the preceding sub-period, all market relations were statistically significant (Table 6). During the second sub-period, the shocks were statistically significant, mostly for a day only, then fading. Generally, the reactions were in agreement with the expected direction, following the signal market where the impulse was generated. Only nineteen reactions did not follow this direction, showing negative reactions with statistical significance, particularly involving NIKKEI responses.

Table 6: Impulse Response Functions during the Quiet Sub-Period: Summary of Results

	ATG	BOV	CAC	DAX	DJ	FTSE	HANG	IBEX	ISEQ	NIKKEI	PSI	SENSEX
ATG		2 1,2 +,+	1 1 +	2 1,2 +,+	3 1,2,3 +,+,–	1 1 +	1 1 +	2 1,2 +,+	1 1 +	1 1 +	1 1 +	1 1 +
BOV	1 1 +		1 1 +	1 1 +	1 1 +	1 1 +	2 1,2 +,–	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +
CAC	1 1 +	3 1,2,3 +,+,–		1 1 +	4 1,2,3,4 +,+,–,+	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +
DAX	1 1 +	2 1,2 +,+	1 1 +		3 1,2,3 +,+,–	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +
DJ	1 1 +	1 1 +	1 1 +	1 1 +		1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +
FTSE	1 1 +	3 1,2,3 +,+,–	1 1 +	1 1 +	4 1,2,3,4 +,+,–,+		1 1 +	1 1 +	2 1,2 +,–	1 1 +	1 1 +	1 1 +
HANG	2 1,2 +,+	2 1,2 +,+	3 1,2,3 +,+,–	2 1,2 +,+	2 1,2 +,+	3 1,2,3 +,+,–		2 1,2 +,+	2 1,2 +,+	1 1 +	2 1,2 +,+	2 1,2 +,+
IBEX	1 1 +	3 1,2,3 +,+,–	2 1,2 +,–	1 1 +	4 1,2,3,4 +,+,–,+	1 1 +	1 1 +		1 1 +	1 1 +	1 1 +	1 1 +
ISEQ	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	3 1,2,3 +,+,–	1 1 +	1 1 +	2 1,2 +,+		1 1 +	1 1 +	1 1 +
NIKKEI	2 1,2 +,+	3 1,2,4 +,+,–	3 1,2,3 +,+,–	2 1,2 +,+	3 1,2,4 +,+,–	3 1,2,3 +,+,–	3 1,2,3 +,+,–	2 1,2 +,+	2 1,2 +,+		2 1,2 +,+	2 1,2 +,+
PSI	1 1 +	2 1,2 +,+	1 1 +	1 1 +	2 1,2 +,+	1 1 +	1 1 +	1 1 +	1 1 +	1 1 +		2 1,2 +,+
SENSEX	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	1 1 +	2 1,2 +,+	2 1,2 +,+	1 1 +	2 1,2 +,+	

Notes: market responses in rows, impulses from markets in columns; each cell has three rows: the first row indicates the number of days during which each market response was statistically significant, according to the criterion of one standard deviation, the second row indicates the number of order of these days and the third row indicates the signal of the impulse response.

As in the first two sub-periods, during the Global Financial Crisis, in all cases, the relationships between markets showed statistical significance (Table 7).

Table 7: Impulse Response Functions During the Global Financial Crisis Sub-Period: Summary of Results

	ATG	BOV	CAC	DAX	DJ	FTSE	HANG	IBEX	ISEQ	NIKKEI	PSI	SENSEX
ATG		2 1,2 +,+	3 1,3 +,+,–	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	1 1 +	3 1,2,3 +,+,–	2 1,2 +,+	1 1 +	3 1,2,3 +,+,–	3 1,2,4 +,+,–
BOV	1 1 +		3 1,3,5 +,+,–	2 1,5 +,+	1 1 +	3 1,3,5 +,+,–	1 1 +	3 1,3,5 +,+,–	1 1 +	2 1,3 +,–	3 1,3,5 +,+,–	1 1 +
CAC	2 1,5 +,+	3 1,2,3 +,+,–		3 1,3,5 +,–,+	4 1,2,3,5 +,+,–,+	4 1,3,4,5 +,–,–,+	3 1,2,3 +,+,–	3 1,3,5 +,–,+	1 1 +	2 1,5 +,+	3 1,3,5 +,–,+	2 1,2 +,+
DAX	3 1,3,5 +,–,+	2 1,2 +,+	3 1,3,5 +,–,+		4 1,2,3,5 +,+,–,+	3 1,3,5 +,–,+	1 1 +	3 1,3,5 +,–,+	1 1 +	2 1,3 +,–	3 1,3,5 +,–,+	2 1,2 +,+
DJ	2 1,3 +,–	2 1,2 +,–	4 1,2,3,4 +,–,–,+	3 1,3,4 +,–,+		3 1,3,4 +,–,+	2 1,2 +,–	3 1,2,3 +,–,–	1 1 +	3 1,3,4 +,–,+	4 1,2,3,4 +,–,–,+	1 1 +
FTSE	2 1,5 +,+	3 1,2,3 +,+,–	3 1,3,5 +,–,+	3 1,3,5 +,–,+	4 1,2,3,5 +,+,–,+		2 1,3 +,–	3 1,3,5 +,–,+	2 1,3 +,–	1 1 +	3 1,3,5 +,–,+	3 1,2,4 +,+,–
HANG	2 1,2 +,+	3 1,2,5 +,+,–	3 1,2,6 +,+,+	3 1,2,6 +,+,+	2 1,2 +,+	3 1,2,6 +,+,+		3 1,2,3 +,+,–	2 1,2 +,+	1 1 +	3 1,2,3 +,+,–	3 1,2,6 +,+,+
IBEX	2 1,5 +,+	2 1,2 +,+	3 1,3,5 +,–,+	3 1,3,5 +,–,+	4 1,2,3,5 +,+,–,+	3 1,3,5 +,–,+	3 1,2,3 +,+,–		2 1,3 +,–	1 1 +	3 1,3,5 +,–,+	2 1,2 +,+
ISEQ	1 1 +	2 1,2 +,+	3 1,3,5 +,–,+	3 1,3,5 +,–,+	3 1,2,3 +,+,–	3 1,3,5 +,–,+	3 1,2,3 +,+,–	3 1,3,5 +,–,+		1 1 +	3 1,3,5 +,–,+	2 1,2 +,+
NIKKEI	2 1,2 +,+	2 1,2 +,+	4 1,2,3,4 +,+,–,–	3 1,2,6 +,+,+	2 1,2 +,+	5 1,2,3,4,6 +,+,–,–,+	3 1,2,4 +,+,–	3 1,2,3 +,+,–	2 1,2 +,+		3 1,2,3 +,+,–	3 1,2,4 +,+,–
PSI	2 1,2 +,+	2 1,2 +,+	2 1,5 +,+	2 1,5 +,+	2 1,2 +,+	3 1,4,5 +,–,+	1 1 +	3 1,3,5 +,–,+	1 1 +	1 1 +		3 1,2,4 +,+,–
SENSEX	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	2 1,2 +,+	3 1,2,3 +,+,+	2 1,2 +,+	1 1 +	2 1,2 +,+	2 1,2 +,+	1 1 +	2 1,2 +,+	

Notes: market responses in rows, impulses from markets in columns; each cell has three rows: the first row indicates the number of days during which each market response was statistically significant, according to the criterion of one standard deviation, the second row indicates the number of order of these days and the third row indicates the signal of the impulse response.

Contrary to what happened in the first two sub-periods, during the Global Financial Crisis, in all stock markets, with the exception of the SENSEX index, there are some cases where, at a first moment, the reaction direction was according to the original shock, and then a contrary reaction occurred. The number of negative reactions were 9, 19 and 67, in Dot-Com, Quiet and Global Financial Crisis sub-periods, respectively. This market correction to a first exaggerated reaction to the initial shock, may be explained by the high market turbulence during the Global Financial Crisis.

With regard to the persistence of reactions, in general, the Nikkei index produced less lasting effects, in most cases for a single day. In the first sub-period, only the SENSEX index response had statistical significance for two days; during the Quiet sub-period any market revealed persistence for more than one day, while in the latter sub-period it happened with BOV, CAC, DAX and DJ indices.

With the emergence of the Global Financial Crisis, the profile of the impulse response functions changed significantly. During this sub-period, all stock markets have recorded the most persistent reactions. The number of significant reactions, for more than one day, was 64, 54 and 110 (in 132 possible reactions) in the Dot-Com, Quiet and Global Financial Crisis sub-periods, respectively. In some cases, the responses showed statistical significance for five or six days. A possible example is given by NIKKEI and Hang-Seng indices. In regard to the DJ index in the first two sub-periods, impulse reactions had significant effects over a single day, as opposed to those seen in the last sub-period, with several significant responses for four days.

This high persistence can be interpreted as evidence that market information was not instantly incorporated, contrary to the efficient market hypothesis. These situations reflect a greater interdependence between stock markets, reducing the possibilities for a diversification strategy among the twelve markets.

4. Summary and conclusions

The study of linkages and short-term interdependencies between stock markets has become a very popular topic of study in finance. The absence of linkages between markets represents an advantage for portfolio investment diversification in a global context. Previous studies reported a reduction of diversification opportunities, especially after the occurrence of extreme events, as is the case of the stock market crashes.

In the present study two crisis episodes were examined corresponding to a drop in the index prices, and another sub-period corresponding to a rising phase of stock prices, in order to ascertain the possible existence of short-term co-movements and to analyze interdependencies between stock markets.

Starting from the logarithmic returns of twelve international stock markets, correlation coefficients and likelihood ratios were calculated, autoregressive vectors were estimated, Granger causality tests were applied and impulse response functions were estimated, in order to check if the global financial crisis had produced changes in short-term linkages between stock markets. The contemporaneous correlation coefficients increased sharply in the Global Financial Crisis sub-period, in relation to the previous sub-periods. In addition, the likelihood ratios proved to be highly significant and showed an increasing trend, reinforcing the idea of a stronger linkage between stock markets, particularly after the emergence of the Global Financial Crisis.

The results of Granger causality tests suggested an increase in the short-term, both unidirectional or bi-directionally, over the period under examination. In each of the three sub-periods, the DJ appears as the most exogenous index. In the last sub-period DJ shares this position with the CAC index. In turn, the impulse response functions showed several positive and negative shocks, with statistical significance, with persistence of up to six days, and in some cases characterized by over-reactions, particularly during the global financial crisis. Given the results, we may conclude that the assumption of the efficient market hypothesis is questionable, since the behavior prediction of a given market can be improved by considering the lagged movements of other markets, generating possible arbitrage operations.

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