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Contagion or Interdependence in the recent Global Financial Crisis? An application to the stock markets using unconditional cross-market correlations.

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Contagion or Interdependence in the recent Global Financial Crisis? An application to the stock markets using unconditional cross-market correlations.*

Jilber Urbina†

May 13, 2013

Abstract

We consider stock market contagion as a significant increase in cross-market linkages after a shock to one country or group of countries. Under this definition we study if contagion occurred from the U.S. Financial Crisis to the rest of the major stock markets in the world by using the adjusted (*unconditional*) correlation coefficient approach (Forbes and Rigobon, 2002) which consists of testing if average cross-market correlations increase significantly during the relevant period of turmoil. We would not reject the null hypothesis of interdependence in favour of contagion if the increase in correlation only suggests a continuation of high linkages in all state of the world. Moreover, if contagion occurs, this would justify the intervention of the IMF and the suddenly portfolio restructuring during the period under study.

1 Introduction

During the last two decades, a growing literature has emerged in an attempt to study the importance of the existence of financial contagion between countries. It has been made clear that the existence of contagion has important economic implications in terms of international policies taken and carried out by International Monetary Fund (IMF) jointly with the affected country or group of countries. Moreover, investors need to understand the nature of changes in correlations of stock markets in order to evaluate the potential benefits of international portfolio diversification as well as the assessment of risks.

We define contagion, following King and Wadhwani (1990) and Forbes and Rigobon (2002), as a significant increase in cross-market linkages after a shock to one country (or group of countries). According to this definition, contagion does not occur if two markets show a high degree of co-movement during both stability and crisis periods. The term interdependence is used instead if strong linkages between the two economies exist in all states of the world. In the empirical analysis we follow Forbes and Rigobon (2002) using the correlation approach corrected for heteroscedasticity bias. Forbes and Rigobon (2002) call this approach *unconditional correlation procedure.*

The empirical strategy adopted in this paper is using a vector autoregressive (VAR) framework for estimating the dynamic relationship among markets and then performing the contagion test over the residual of the VAR previously estimated. After adjusting for heteroskedastity bias in the correlations as suggested by Forbes and Rigobon (2002), we failed in rejecting the null hypothesis of interdependence between US and the *i-th* country embedded in the sample. The empirical findings drawn from the analysed sample strongly suggest not contagion, only interdependence, this means that shocks, whether of a global or local nature, can be transmitted across countries because of their real and financial linkages (Masson, 1998; Dornbusch et al., 2000; Pristker, 2000; Forbes and Rigobon, 2002).

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In this paper we study empirically the recent 2008 - 2009 US Financial Crisis using a straightforward approach based on cross-market correlation coefficients. Our results indicate that there is no empirical evidence of contagion; instead, we find evidence of interdependence in which the financial markets remain highly correlated over time. This has two major implications: first, the IMF's intervention through the use of bailout funds to avoid crisis in the affected country will be less effective, and second, given the high level of financial market integration and interdependence among them, portfolio diversification will be only effective in periods of relative stability.

The remainder of the paper is arranged as follows. section 2 discusses the Conceptual Framework, going from several definitions of contagion to the importance of measuring it for policy and investment purposes. section 3 discusses the traditional technique of measuring stock market contagion showing that the conditional correlation coefficient is biased, so unconditional correlation coefficient[1] is used to perform the hypothesis test. section 4 presents the model and data used to test for contagion while section 5 discusses the results and an extensive set of robustness analysis is done in section 6. Conclusions are summarized in section 7.

2 Conceptual Framework

There is a vast set of empirical research that addresses the contagion issue. The widespread disagreement of what contagion is, represents the first important issue being covered in these empirical papers, but before we go any further, it is necessary to define contagion.

Forbes and Rigobon (2002) define it as a significant increase in cross-market linkages after a shock to one country (or group of countries). According to this definition, if two markets show a high degree of co-movement during periods of stability, even if the markets continue to be highly correlated after a shock to one market, this may not constitute contagion. According to this definition, it is only contagion if cross-market co-movement increases significantly after the shock. If the co-movement does not increase significantly, then any continued high-level of market correlation suggests strong linkages between the two economies that exist in all states of the world. Forbes and Rigobon (2002) use the term interdependence to refer to this situation. Interdependence, as opposed to contagion, occurs if cross-market co-movements is not significantly bigger after a shock to one country or group of countries.

According to The World Bank, this definition of contagion is *very restrictive*;[2] but even being very restrictive, it has two important advantages: First, it provides a straightforward framework for testing if contagion occurs. Simply compare linkages between two markets (such as cross-market correlation coefficients) during a relatively stable period with linkages directly after a shock or crisis. And as a second benefit, it provides a straightforward method of distinguishing between alternative explanations of how crises are transmitted across markets.Being quite short with the definition of contagion, Corsetti et al. (2001) specify that contagion occurs when country-specific shock becomes "regional" or "global".

Dungey and Tambakis (2003) argue that use of the word 'contagion' to describe the international transmission of financial crises has become fraught with controversy. In their paper it is suggested that the World Bank's 'restrictive' definition of contagion is a useful benchmark and has been used by Eichengreen et al. (1995) and Eichengreen et al. (1996). The World Bank defines contagion in its 'restrictive' definition as transmission of shocks to other countries beyond any fundamental link among countries and beyond common shocks. Usually this kind of contagion is it said to be explained by herding behaviour.[3] Herd behaviour is a characteristic feature of contagion (Dungey and Tambakis, 2003) and often stands out as the cause of the transmission mechanism of shocks is discontinuous (Corsetti et al., 2001).

Even with agreement on this definition, there are formidable difficulties in reaching the appropriate set of fundamentals to use as control variables, suggesting that such models based on the 'restrictive' definition may not be effectively operational. On the counter side, recent empirical research proposes two alternative means:

[1]Definition of unconditional correlation can be find in section 3.

[2]See World Bank web site in order to read in further details about its officials definitions of contagion. http://econ.worldbank.org

[3] This is an asymmetric information problem. Information is costly so investors remain uninformed about the countries in which they invest. Therefore, investors try to infer future price changes based on how the rest of the market is reacting. The relatively uninformed investors follow the supposedly informed investors.

Dungey et al. (2003) propose the use of latent factor models, which do not require the exact specification of the fundamental relationships, while Pesaran and Pick (2004) suggest controlling for fundamental-based market interdependencies using trade flow data and examining contagion as transmissions above that. This 'restrictive' definition of contagion does not need any type of link among countries, its nature only implies that contagion it is said to be explained by causes beyond any fundamental links, namely, herd behaviour, financial panics, or switches of expectations across instantaneous equilibria (see Corsetti et al., 2001). We do not consider this definition to test for contagion in this paper, we only use the 'very restrictive' definition.

According to our definition of contagion; there should be a shock as a cause of contagion and this is represented by a crisis. Thus, Corsetti et al. (2001) claims that crises are characterized by an increase of variance and covariance of return across-markets, but not necessarily by an increase in correlation and also identify some features of contagion patterns and call them empirical regularities:

1. Sharp falls in stock markets tend to concentrate in periods of international financial turmoil.
2. Volatility of stock prices increases during crisis periods.
3. Covariance between stock market returns increases during crisis periods.
4. Correlation between stock market returns is not necessarily larger during crisis periods than during tranquil periods.

It is important to note that the economies are linked through financial, real, and political links. Financial links exist when two economies are connected through the international financial system; while the real ones are the fundamental economic relationship among economies which have been usually associated with international trade. Political links represent political relationships among countries, much less stressed in the literature.

These linkages mentioned above are often called *Fundamentals* and could be considered as the transmission mechanism through contagion spreads.

2.1 Causes of Contagion

According to Masson (1998); Dornbusch et al. (2000); Pristker (2000), and Forbes and Rigobon (2001) the causes of contagion can be divided conceptually into two categories: The first category emphasizes spillovers that result from the normal interdependence among market economies. This interdependence means that shocks, whether of a global or local nature, can be transmitted across countries because of their real and financial linkages. Reinhart and Calvo (1996) term this type of crisis propagation "*fundamentals-based contagion*". These forms of co-movements would not normally constitute contagion.

The second category involves a financial crisis that is not linked to observed changes in macroeconomics or other fundamentals but is solely the result of the behaviour of investors or other financial agents. Under this definition, contagion arises when a co-movement occurs, even when there are no global shocks and interdependence and fundamentals are not factors. A crisis in one country may, for example, lead investors to withdraw their investments from many markets without taking account of differences in economics fundamentals. This type of contagion is often said to be caused by "irrational" phenomena, such a financial panics, herd behaviour, loss of confidence, and increased risk aversion. Among fundamental causes of contagion one can enumerate the followings[4] in Table 1.

Despite all the disagreement about the definition of contagion, it seems to be that there is a common point of view about the circumstance that allows it spreads, which is a necessary condition for the propagation, namely, the spread of a crisis depends on the degree of financial market integration. But, does it mean that there are reasons to believe that a country or group of countries must not worry about contagion if they are

[4] For a detailed explanation see Dornbusch et al. (2000), page 180.

Table 1: Fundamental causes of contagion

Macroeconomics causes	Investor's behavior as cause of contagion
1. Common shocks	1. Liquidity and incentive problems
2. Trade links and competitive devaluations	2. Information asymmetries and coordination problems
3. Financial links	3. Multiple equilibriums
	4. Changes in the rules of the game

not financially integrated? or will a country be immune to contagion if it faces lack of access to international financing? The answer is yes, countries that are not financially integrated, because of capital controls or lack of access to international financing are by definition immune to contagion. This is true in our definition of contagion, but it might not be true under other definitions.

It is also said by Forbes and Rigobon (2001) that the theoretical literature of contagion could be split into two groups: *crisis-contingent* and *non-crisis-contingent* theories. Crisis-contingent theories as its name suggests are those that explain why transmission mechanisms change during a crisis and therefore why a shock leads to increase the cross-market linkages. On the other hand, Non-crisis-contingent theories assume that transmission mechanisms are same during a crisis as during more stable periods, and therefore cross-market linkages do not change (increase) after a shock. These theories belonging to the second group may be interpreted as pure interdependence not as contagion.

Contagion may be explained by
- Crisis-Contingent Theories
  - Multiple equilibria
  - Endogenous liquidity
  - Political economy
- Crisis-Contingent Theories
  - Trade
  - Policy coordination
  - Country reevalution
  - Random aggregate shocks

2.2 Why is important measure contagion?

Evaluating if contagion occurs is important for several reasons. First, a critical tenet of investment strategy is that most economic disturbances are country specific, so stock markets in different countries should display relatively low correlations. International diversification would therefore substantially reduce portfolio risk and increase expected returns. If contagion occurs after a negative shock, however, market correlations would increase in bad states, which would undermine much of the rational for international diversification, because ignoring the contagion can lead to poor portfolio diversification and an underestimation of risk. Second, many models of investor behaviour are based on the assumption that investors react differently after a large negative shock. Knowing if contagion occurs is key to understand how individual behaviour changes in good and bad states. Third, many international institutions and policy makers worry that a negative shock to one country can have a negative impact on financial flows to another country—even if the fundamentals of the second economy are strong and there is little real connection between the two countries. Even if this effect is temporary, it could lead to a financial crisis in the second country—a crisis completely unwarranted by the country's fundamentals and policies. If this sort of contagion exists, it could justify IMF intervention and the dedication of massive amounts of money to stabilization funds. A short-term loan could prevent the second economy from experiencing a financial crisis. On the other hand, if the crisis is due to interdependence instead of contagion, a bailout fund might reduce the initial negative impact, but it does not avoid the crisis by itself. It only gives more time to make necessary adjustments.

For all of these reasons, it is important to evaluate under what circumstances contagion might be occur.

2.3 How contagion is testing?

Cross-market linkages can be measured by a number of different statistics, such as the correlation in asset returns, the probability of speculative attack, or the transmission of shocks or volatility. Reason why there are four types of general approaches to achieve the test for contagion: 1) analysis of cross-market correlation coefficients, 2) probit models, 3) GARCH frameworks, and 4) cointegration models. Note that the tests are associated with the measures, but not with the definitions of contagion.

Tests based on cross-market correlation coefficients are the most straightforward and have two advantages previously mentioned in section 2. These tests compare the correlation in returns between two markets during stable periods and turmoil periods and, if cross-country correlation coefficients increase significantly after a shock, then there is evidence enough to believe that contagion occurs. The first major paper that utilized this approach was King and Wadhwani (1990), they test for an increase in cross-market correlations between the US, UK and Japan and found that correlations increased significantly after the US crash. Then Lee and Kim (1993) extended the analysis using up to 12 major markets and they find evidence of contagion. Reinhart and Calvo (1996) use this approach to test for contagion after 1994 Mexican Peso crisis and also find contagion from Mexico to Asian and Latin American emerging markets. The most thorough analysis using this framework was built by Goldfajn and Baig (1999) testing for contagion in stock indices, currency prices, interest rates, and sovereign spreads in emerging markets during the 1997-1998 East Asian crisis, they reached the same conclusion: contagion occurred.

The second approach to test for contagion is constituted by probability models such as probit models. An extensive list of papers has included tests for contagion using this approach, mainly because it is simple and uses simplifying assumptions and exogenous events to identify a model and directly measure changes in the propagation mechanism. Such list of papers covers Eichengreen et al. (1996), Goldfajn and Baig (1999), Kaminsky and Reinhart (1998), and Forbes and Rigobon (2001). One important conclusion from these papers is that trade is the most important transmission mechanism through contagion spreads.

ARCH and GARCH framework constitute the third approach to test for contagion; this implies the estimation of the variance-covariance matrix of the transmission mechanism across countries. This framework has been used to analyze the 1987 US stock market crash. Hamao et al. (1990) and Chou et al. (1994) find evidence of significant spillovers across markets but contagion did not occur.

The fourth and last series of tests for contagion focuses on changes in the log-run relationship between markets, instead of on any short-run changes after a shock. These papers use the same basic procedures as above (GARCH), except for test in changes in the co-integrating vector between stock markets instead of in the variance-covariance matrix. One example of this methodology used to test for contagion is the paper of Longin and Solnik (1995), they consider seven OECD countries from 1960 to 1990 and report that average correlations in stock market returns between the US and other countries rose by about 0.36 over this period. However, Forbes and Rigobon (2001) consider that this approach is not an accurate test for contagion, since it assumes that real linkages between markets remain constant over the entire period.

Summarizing this section, four general approaches have been used to test if contagion occurred during several crisis. It is explained that the transmission shocks has been measured by: simple cross-market correlation coefficients, probit models, GARCH models, and cointegration techniques. It is important to have in mind that cointegration approach is not an accurate test for contagion due to the long time under consideration. In this paper will be used the cross-market correlation coefficient approach, because its resutls are very similar to GARCH models and probit models; and for being the simpler procedure we have chosen it. Furthermore, this framework is the one that best fits our definition of contagion.

3 Conditional and Unconditional Correlations

This section is set up to demonstrate the bias of the conditional correlation[5] due to the presence of heteroskedasticity.

[5]Conditional Correlation is the term used by Forbes and Rigobon (2002) to refer to the correlation coefficient biased due to heteroscedasticity. This analysis and demonstration is done in Forbes and Rigobon (2002).

Heteroscedasticity biases the cross-market correlation making the hypothesis tests for contagion an inaccurate tool for identifying whether contagion exists or not. For simplicity, the following discussion focuses on the two-market case. Consider two stochastic variables, x and y both related through the following equation:[6]

$$y_t = \alpha + \beta x_t + \epsilon_t \tag{1}$$

Considering the standard and classical assumptions for this Ordinary Least Squares (OLS) regression we have:

$$E(\epsilon_t) = 0, \tag{2}$$

$$E(\epsilon_t^2) = c < \infty \tag{3}$$

Where c is a constant

$$E(x_t, \epsilon_t) = 0 \tag{4}$$

Equation 2 to Equation 4 ensure OLS estimation of Equation 1 to be consistent without omitted variables and with no endogeneity for both groups and $\beta^h = \beta^l$, only these assumptions are required to make the proof and it is not required to make further assumptions about the distribution of the residuals.

Splitting the sample into two groups: one group with high variance (h) and the other one, with the lower variance (l), recall that in terms of our definition of contagion, the lower variance group corresponds to the period of relative market stability and the high variance group is the period of turmoil, namely the period after and including the crisis. By construction we know that $\sigma_{xx}^h > \sigma_{xx}^l$, which when combine with the standard definition of β :

$$\beta^h = \frac{\sigma_{xy}^h}{\sigma_{xx}^h} = \frac{\sigma_{xy}^l}{\sigma_{xx}^l} = \beta^l \tag{5}$$

implies that $\sigma_{xx}^h > \sigma_{xx}^l$. As it is explained before and given $\sigma_{xx}^h > \sigma_{xx}^l$, it is clear that the covariance of each group is very different and it must be greater in the high volatility group than the lower one, this is because if the $\beta's$ are equal in the two groups and by construction we have stated $\sigma_{xx}^h > \sigma_{xx}^l$, so $\sigma_{xy}^h > \sigma_{xy}^l$ must be met. Another important thing that one has to note is this increase in the cross-market covariance from that in the first group is directly proportional to the increase in the variance of x which is congruent with the empirical regularities in Corsetti et al. (2001).

From Equation 1 we can define the variance of y as follows:

$$\sigma_{yy} = \beta^2 \sigma_{xx} + \sigma_{ee} \tag{6}$$

From Equation 6 we can observe that since the variance of the residuals is assumed to remain constant over the entire sample, this implies that the increase in the variance of y across groups is less than proportional to the increase in the variance of x. Therefore:

$$\left(\frac{\sigma_{xx}}{\sigma_{yy}}\right)^h > \left(\frac{\sigma_{xx}}{\sigma_{yy}}\right)^l \tag{7}$$

Finally, using the standard definition of the correlation coefficient we have:

$$\rho^h = \rho^l \sqrt{\frac{(1+\delta)}{(1+\delta\left[\rho^l\right]^2)}} \tag{8}$$

Where ρ^h is the conditional correlation coefficient, ρ^l is the unconditional correlation coefficient and δ is the relative increase in the variance of x:

[6]See Forbes and Rigobon (2002) for a formal proof.

$$\delta \equiv \frac{\sigma_{xx}^{h}}{\sigma_{xx}^{l}} - 1 \tag{9}$$

Equation 8 [7] clearly shows that the estimated correlation coefficient is increasing in δ. Therefore, during periods of high volatility in market x, the estimated correlation (the conditional correlation) will be greater than the unconditional correlation, even if the unconditional correlation coefficient remains constant over the entire period, the conditional correlation coefficient will be biased upward and still being greater than the unconditional correlation and this has direct implications for test for contagion based on cross-market correlation coefficients.

This result implies that performing a test for contagion based on correlation leads to accept wrongly the null hypothesis about contagion and conclude that contagion occurs when this is false. It is clear to see how heteroscedasticity affects the conditional correlation and, therefore, the test provides a misleading conclusion.

Without adjusting for the bias, however, it is impossible to deduce if this increase in the conditional correlation represents an increase in the unconditional correlation or simply an increase in market volatility. According to our definition of contagion, only an increase in the unconditional correlation coefficient would constitute contagion.

The adjustment for this bias is a straightforward procedure under the assumptions discussed earlier and it only requires a simple manipulation of equation Equation 8, solving for the unconditional correlation coefficient $\left(\rho^{l}\right)$, yields

$$\rho^{l} = \frac{\rho^{h}}{\sqrt{1 + \delta\left[1 - \left(\rho^{h}\right)^{2}\right]}} \tag{10}$$

The main finding of Forbes and Rigobon (2002) shows that the absolute magnitude of the correlation, conditional on a change greater than or equal to a given absolute size in one of the variables, is monotonically increasing in the magnitude of that absolute change. All this framework is straightforward and it only implies simple algebra for demonstrating the bias and correct for it, but one has to have in mind the potential problems that carries this procedure. According to Forbes and Rigobon (2002), one potential problem with this adjustment for heteroskedasticity is that is assumed there are no omitted variables or endogeneity between markets (written as Equation 2 and Equation 4).

In other words, the proof of this bias and the adjustment is only valid if there are no exogenous global shocks and no feedback from stock market y to x.

One similar conclusion was achieved by Ronn et al. (2009), they consider the impact and implications of "large" changes in asset prices on the intra-market correlations in the domestic and international markets. In Ronn et al. (2009), it is shown the bias in the conditional correlation coefficient in both theoretical and empirical terms. One of the theoretical procedures involves not only the analysis, but the same conclusion achieved by Forbes and Rigobon (2002) in Equation 8. They clearly demonstrate that correlation, conditional on the magnitude of asset price changes, differ from unconditional correlations.

4 Base Model and Data

Following Forbes and Rigobon (2002), we use a Vector Autoregresive (VAR) framework to estimate cross-market correlations since we try to adjust for the fact that stock market are open during different hours and any exogenous global shock. For this, they propose:

$$X_t = \phi(L)X_t + \Phi(L)I_t + \eta_t \tag{11}$$

[7] You can also find this same equation in Ronn et al. (2009), these authors called this equation as Stambaugh Theorem which comes from a bivariate normality. They also observe that the conditional correlation increases or decreases depending the sign of the unconditional correlation is positive or negative, respectively.

$$X_t = \left\{x_t^C, x_t^j\right\}' \tag{12}$$

$$I = \left\{i_t^C, i_t^j\right\}' \tag{13}$$

Where x_t^C is the stock market return in the crisis country; x_t^j is the stock market return in another market j; X_t is a transposed vector of returns in the same two stock markets; $\phi(L)$ and $\Phi(L)$ are vectors of lags; i_t^C and i_t^j are short-term interest rates for the crisis country and the country j, respectively; and η_t is a vector of reduced-form disturbances. For each series of test, we first estimate the VAR model from Equation 11. Once the VAR is estimated, we proceed to estimate the variance-covariance matrices for each pair of countries during the full period, stable period and turmoil period. Afterwards, from the information given by the variance-covariance matrices we calculate the cross-market correlation coefficients for each set of countries and periods. Then, we apply the Fisher Transformation to each correlation coefficients in order to obtain a normal distribution of each of them.

Stock market returns are calculated as rolling- average, two days returns based on each country's aggregate stock market index. We also utilize average two days returns to control for the fact that the markets in different countries are not open during the same hours. We calculate returns based on US dollars as well as local currency, but focus on US dollars returns since these were most frequently used in past work on contagion, also US dollars have the additional advantage of controlling for inflation (under non-fixed exchange rate regimes). We utilize five lags[8] for $\phi(L)$ and $\Phi(L)$ in order to control for serial correlation and mainly for any within-week variation in trading patterns. Interest rates have been included in order to control for any aggregate shock and/or monetary policy coordination.[9] All of the data is from Datastream. An extensive set of sensitivity tests show that changing the model specification has no significant impact on results.

We use six aggregate stock market indices which cover twelve countries. We compare the correlation coefficients between US stock index and each stock index of each single country. Countries and stock indices are summarized in Table 2.

Table 2: Stock Market Indices and Countries

Stock Market Index	Country	Stock Market Index	Country
S&P 500	US		France
FTSE 100	UK		Finland
BOVESPA	Brazil		Spain
NIKKEI	Japan	EURO STOXX50	Germany
S&P/ASX200	Australia		Italy
			Netherlands
			Luxemburg

4.1 Hypothesis test

Using the specification of equation Equation 11, we perform the test for stock market contagion. The hypothesis test consists of determining if there is a significant increase in cross-market correlation coefficients after a shock, according to our definition of contagion we establish the following hypothesis:

$$H_0 : \rho_l^* \geq \rho_h^*$$
$$H_1 : \rho_l^* < \rho_h^*$$

[8] A VAR Lag Order Selection Criteria was applied to select the best length of lag for the VAR estimation, the result of this was 5 lags as the best order.

[9] As Forbes and Rigobon (2002) remark, interest rates are an imperfect measure of aggregate shocks, they are a good proxy for global shifts in real economic variables and/or policies that affect stock market performance.

Where ρ_l^* is the correlation during the full period and ρ_h^* is the correlation during the turmoil period. Moreover, H_0 represents the interdependence hypothesis and H_1 is contagion. The t-statistic has the following form:

$$t = \frac{\frac{1}{2}\ln\left[\frac{1+\hat{\rho}_h^*}{1+\hat{\rho}_h^*}\right] - \frac{1}{2}\ln\left[\frac{1+\hat{\rho}_l^*}{1+\hat{\rho}_l^*}\right]}{\sqrt{\left(\frac{1}{n_h-3}\right)+\left(\frac{1}{n_l-3}\right)}} \tag{14}$$

Test statistics and results are reported in the next section.

5 Results

Using the US. Financial Crisis as the event to drive contagion, we define our period of turmoil from August 5th, 2008 to September 16th, 2009. We define the period of relative stability as lasting from June 16th, 2003 to the start of the period of turmoil. The choice of the dates was made as a result from an analysis of the S&P500 behavior which is graphed in Figure 1 and this selection of dates also coincide with the World Bank's Crisis Timeline; but the extensive robustness tests performed below will show that period definition does not affect the central results.

The VAR models estimated in order to obtain the cross-market correlation coefficients are stable and none of the variables considered for these estimations have unit root, the VAR model satisfies the stability condition; hence the hypothesis test performed for testing whether contagion occurred or not is valid and it is only affected by the presence of heteroscedasticity.[10]

Table 3: CONDITIONAL CORRELATION COEFFICIENTS. This table reports conditional (unadjusted) cross-market correlation coefficients for US and each country in the sample. The stable period is defined as June 16th, 2003 through August 4th, 2008. The turmoil period is defined as August 5th, 2008 through September 16th, 2009. The full period is the stable period plus the turmoil period.

	Correlation Coefficients			Full vs. Turmoil		Stable vs.Turmoil	
	Full	Stable	Turmoil	t-stat	Contagion?	t-stat	Contagion?
UK	0.52	0.31	0.65	2.29	C	5.13	C
Australia	0.26	0.07	0.41	2.03	C	4.22	C
Brazil	0.56	0.35	0.73	3.58	C	6.54	C
Europe	0.53	0.32	0.66	2.41	C	5.32	C
Japan	0.14	0.08	0.20	0.80	N	1.43	N

The estimated conditional correlation coefficients for stable, turmoil, and full period are shown in Table 3. The critical value for the t-test at the 5% level is 1.65, so any test statistic greater than this critical value indicates contagion (C), while any statistic less than or equal to this value indicates no contagion (N). Since Fisher transformation ensures normality, we use the normal critical value at 95%.

Table 3 shows that cross-market correlation (conditional or unadjusted) coefficients between US and most of the countries in the sample increased during the turmoil period, this is a prerequisite for contagion to occur; but this is a misleading conclusion.

We can observe that the average correlation coefficient increased from 0.23 in the stable period to 0.53 in the turmoil period, it even has an increase from 0.40 in the full period to the 0.53 in the high volatility period. But, as discussed previously, these tests for contagion may be inaccurate due to the bias in the correlation coefficient resulting from heteroskedasticity. The estimated increases in the conditional correlation

[10]No omitted variables is an assumption considered in this test.

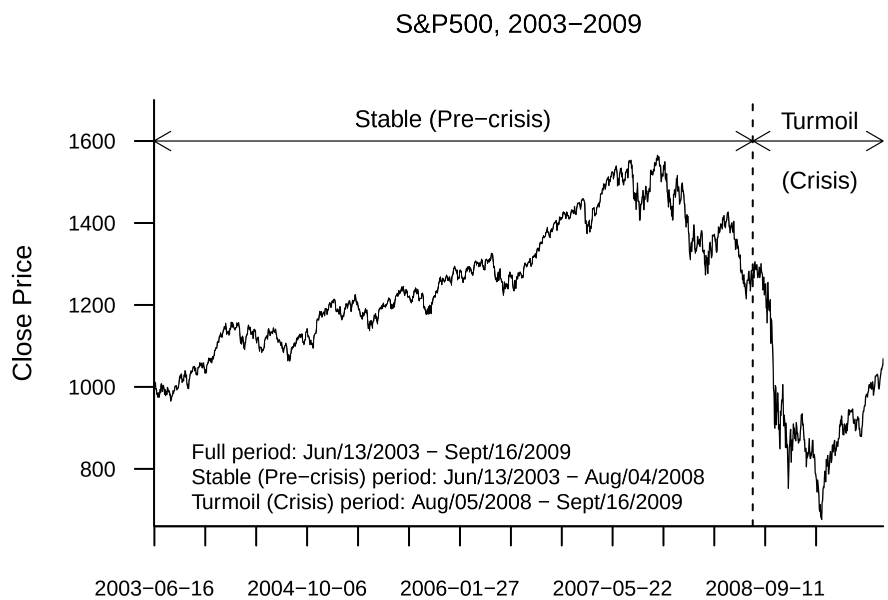

Figure 1: This picture depicts the daily Close Price of S&P500 since Jun/13/2003 until Sept/16/2009.

coefficient could reflect either an increase in cross-market linkages and/or increased market volatility (Forbes and Rigobon, 2002). But before making the adjustment for heteroscedasticity, it is first necessary to test whether the residuals are heteroscedastic or not and indeed they are, so we proceed to apply the correction provided in Equation 10.

Adjusting for heteroskedasticity has an immediately and significant effect on estimated cross-market correlation coefficients and therefore on the conclusion of the test. One particular pattern highlighted by Forbes and Rigobon (2002) and Dungey and Zhumabekova (2001), is that in each country, the unconditional correlation is substantially smaller (in absolute value) than the conditional correlation during the turmoil period and is slightly greater in the stable period, as you can see comparing Table 3 and Table 4 or see Figure 3 and Figure 4. During the turmoil period, the average conditional correlation coefficient for the entire sample is 0.53, while the average unconditional correlation is 0.33. During the stable period, the average conditional correlation is 0.23, while the average unconditional correlation is 0.33.

Based on Table 4, and according to this testing methodology, there is no evidence of contagion from US to the countries of the sample; but due to heteroskedasticity Table Table 3 reports contagion for the all countries in the sample, except for Japan.

Table 4 clearly shows that our results are highly stable, while Table 3 also provides a view of the results using the conditional correlation coefficients. Both kind of correlations, conditional and unconditional, seems to be robust, but as we move forward with the robustness analysis in section 6 will be shown that conditional correlation is not stable, whereas unconditional is.

There is no contagion because these countries are highly interdependent in all states of the world and cross-country linkages do not change significantly during periods of crisis.

These economies are closely connected in all states of the world, and therefore it is not surprising that a large negative shock in US stock market such this which is under discussion is quickly passed on those countries. If this transmission of a large shock from the US to the rest of countries (UK, Australia, Europe, Brazil and Japan) is a continuation of the same cross-market linkages that exist during more tranquil periods,

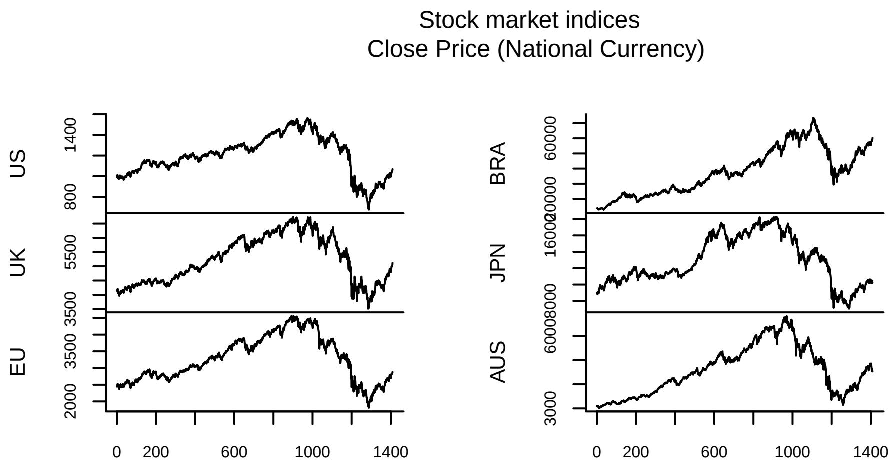

Figure 2: Stock market indices for each country in national currency. Period: Jun/13/2003 - Sept/16/2009.

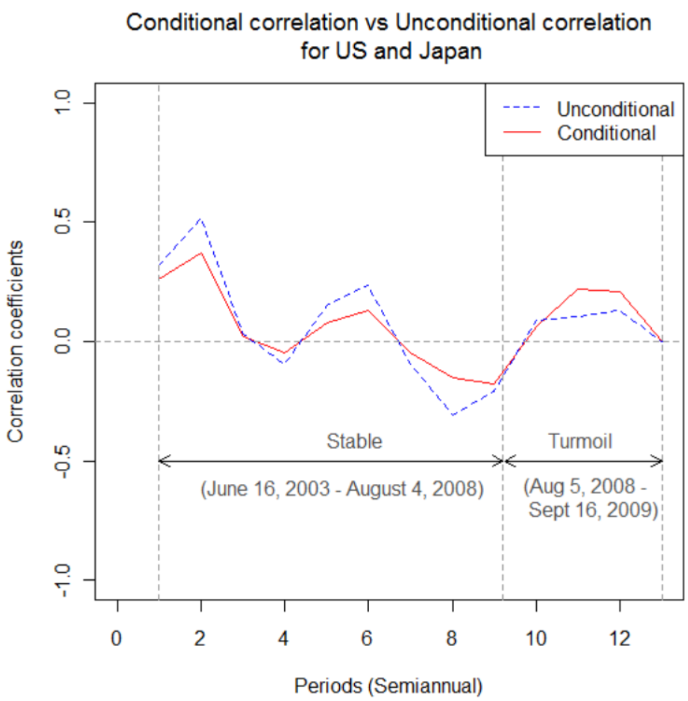

Figure 3: Cross-market correlation coefficients between US and Japan during the entire period

Table 4: UNCONDITIONAL CORRELATION COEFFICIENTS This table reports unconditional (adjusted) cross-market correlation coefficients for US and each country in the sample. The stable period is defined as June 13th, 2003 through August 4th, 2008. The turmoil period is defined as August 5th, 2008 through September 16th, 2009. The full period is the stable period plus the turmoil period.

	Correlation Coefficients			Full vs. Turmoil		Stable-Turmoil	
	Full	Stable	Turmoil	t-stat	Contagion?	t-stat	Contagion?
UK	0.52	0.45	0.40	-1.76	N	-0.68	N
Australia	0.26	0.10	0.23	-0.38	N	1.47	N
Brazil	0.56	0.50	0.49	-1.16	N	-0.19	N
Europe	0.53	0.46	0.42	-1.78	N	-0.71	N
Japan	0.14	0.12	0.11	-0.35	N	-0.17	N

then this should not be considered contagion, therefore according to Table 4 there is only a continuation of interdependence. The "contagion" evidence from the conditional correlation (given in Table Table 3) could be classified as *Spurious Contagion* (Dungey et al., 2005). Figure 3 and Figure 4 graph the interdependence in terms of the unconditional correlation coefficients, these correlations are compute based on equation Equation 10 and are compared with the conditional correlation, in those figures are reported the correlations between US and Japan stock market through the S&P500 and NIKKEI and between US and UK through the S&P500 and FTSE100. Each graph reports semiannual correlations in order to show the pattern of each of them, note that unconditional correlation is above the conditional correlation in the period of relative stability and it is below in turmoil period as mentioned above.

The average conditional cross-market correlation coefficient between US and Japan in the stable period, measured as semiannual frequency reported in Figure 3, is 0.05 and it jumps up to 0.12 during the turmoil period, this could be contagion, but it is not, because the average unconditional (adjusted for heteroscedasticity) cross-market correlation coefficient during stable period is 0.06 and only changes and reaches the value of 0.08 during the turmoil period, this is a clear evidence of interdependence instead of contagion between US and Japan.

The same situation happens between US and UK, as shown in Figure 4, the unconditional correlation coefficient gives signs of interdependence instead of contagion. The average conditional correlation coefficient between US and UK during the stable period is 0.28 and during the turmoil period is 0.55, but after the adjustment, the view changes significantly and the unconditional correlation coefficient during the stable period is 0.40 and during the crisis period is 0.45, you can observe this change is only evidence of continuation of the cross-market linkages.

6 Robustness Analysis

In this section we test for the impact of modifying the interest controls, the currency denomination and the period definitions. In each case the central results do not change. Tests based on conditional correlation coefficients find some evidence of contagion, while tests based on the unconditional coefficients find no evidence of contagion.

6.1 Using no Interest Rate Controls

As a first set of robustness, we eliminate the interest rate controls. As discussed in section 4, we utilize interest rate to control for any aggregate shocks and/or monetary policy coordination which simultaneously affect different stock markets. Table 6 summarizes the results.

Note that both correlation coefficients and statistical significance in Table 3 and Table 5 are very similar, this is because the variable Interest Rate is not statistically significant in the model. Previously is explained that including interest rates is an imperfect measure in order to control for the effects of aggregate shocks, therefore, the results remain almost the same. It is also expected that the results of Table 3 and Table 6 are

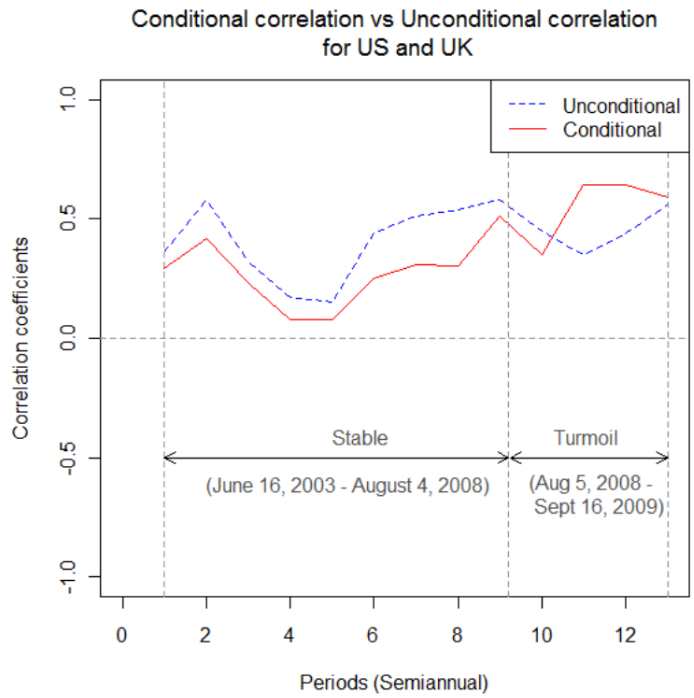

Figure 4: Cross-market correlation coefficients between US and UK during the entire period

virtually unchanged and that the conclusion of interdependence achieved in the previous section continue to be the same.

Table 5: CONDITIONAL CORRELATION COEFFICIENTS. Robustness to eliminating the interest rate controls.

	Correlation Coefficients			Full vs.Turmoil		Stable-Turmoil	
	Full	Stable	Turmoil	t-stat	Contagion?	t-stat	Contagion?
UK	0.52	0.30	0.64	2.24	C	5.18	C
Australia	0.26	0.05	0.42	2.07	C	4.52	C
Brazil	0.56	0.35	0.74	3.61	C	6.64	C
Europe	0.53	0.31	0.66	2.37	C	5.42	C
Japan	0.14	0.08	0.21	0.80	N	1.48	N

6.2 Utilizing Local Currency

As another way to test the validity of the results we modify the currency denomination. Table 7 and Table 8 show the results in local currency of each country.

Table 6: UNCONDITIONAL CORRELATION COEFFICIENTS. Robustness to eliminating the interest rate controls.

	Correlation Coefficients			Full vs. Turmoil		Stable vs.Turmoil	
	Full	Stable	Turmoil	t-stat	Contagion?	t-stat	Contagion?
UK	0.52	0.44	0.40	-1.81	N	-0.68	N
Australia	0.26	0.08	0.23	-0.42	N	1.75	C
Brazil	0.56	0.51	0.49	-1.23	N	-0.31	N
Europe	0.53	0.46	0.41	-1.85	N	-0.72	N
Japan	0.14	0.12	0.11	-0.39	N	-0.19	N

Table 7: CONDITIONAL CORRELATION COEFFICIENTS. Robustness tests based on local currency returns

	Correlation Coefficients			Full vs. Turmoil		Stable vs. Turmoil	
	Full	Stable	Turmoil	t-stat	Contagion?	t-stat	Contagion?
UK	0.42	0.33	0.49	1.14	N	2.26	C
Australia	-0.01	-0.07	0.07	0.89	N	1.60	N
Brazil	0.28	0.11	0.47	2.64	C	4.54	C
Europe	0.49	0.38	0.59	1.58	N	3.06	C
Japan	0.25	0.14	0.34	1.25	N	2.48	C

Table 8: UNCONDITIONAL CORRELATION COEFFICIENTS. Robustness tests based on local currency returns

	Correlation Coefficients			Full vs. Turmoil		Stable vs. Turmoil	
	Full	Stable	Turmoil	t-stat	Contagion?	t-stat	Contagion?
UK	0.42	0.43	0.30	-1.53	N	-1.62	N
Australia	-0.01	-0.10	0.04	0.56	N	1.53	N
Brazil	0.28	0.14	0.30	0.30	N	1.91	C
Europe	0.49	0.49	0.37	-1.67	N	-1.59	N
Japan	0.25	0.21	0.19	-0.68	N	-0.18	N

Measuring returns based on local currency instead of US dollars clearly has minimal impact on our central results. Cross-market correlations of Table 7 and Table 8 are calculated taking into account the local currency denomination of each country; for example, the correlation between US and UK with interest rate controls has been computed using the S&P500 and FTSE100 in Pounds, as well as the correlation between US and Australia has been calculated using the stock indices S&P500 and S&P ASX200 in Australian dollars, and as the same way for the remaining countries.

One important thing that deserve to be highlighted is the result of the first part of Table 7 where everything indicates that contagion not occur, while the second part of the same table shows evidence of contagion, so as we said in the previous section, conditional correlation results are not stable, while unconditional correlations results are strongly stable.

6.3 Local Currency and No Interest Rates Controls

In this set of robustness tests, we find two potential countries receiving contagion from US financial crisis, these countries are Australia and Brazil, but as explained above, this could be spurious contagion due to the effect of inflation and lack of controlling aggregate shocks or monetary implications. Also Table 6 and Table 8 support this potencial contagion on Brazil and Australia.

Table 9: CONDITIONAL CORRELATION COEFFICIENTS. Robustness tests based on local currency returns and no interest rate controls.

	Correlation Coefficients			Full vs. Turmoil		Stable vs. Turmoil	
	Full	Stable	Turmoil	t-stat	Contagion?	t-stat	Contagion?
UK	0.42	0.33	0.49	1.12	N	2.31	C
Australia	0.00	-0.08	0.07	0.93	N	1.80	C
Brazil	0.30	0.11	0.50	2.89	C	5.14	C
Europe	0.49	0.38	0.57	1.46	N	2.97	C
Japan	0.25	0.14	0.34	1.25	N	2.48	C

Table 10: UNCONDITIONAL CORRELATION COEFFICIENTS. Robustness tests based on local currency returns and no interest rate controls.

	Correlation Coefficients			Full vs. Turmoil		Stable vs. Turmoil	
	Full	Stable	Turmoil	t-stat	Contagion?	t-stat	Contagion?
UK	0.42	0.43	0.30	-1.59	N	-1.74	N
Australia	0.00	-0.11	0.04	0.55	N	1.74	C
Brazil	0.30	0.14	0.32	0.26	N	2.20	C
Europe	0.49	0.50	0.36	-1.81	N	-1.89	N
Japan	0.25	0.21	0.19	-0.68	N	-0.18	N

After all there is still evidence of interdependence instead of contagion. Despite these results, we still support the interdependence, because results of Table 10 could be cause of policy coordination or aggregate shocks which we are not able to control due to a lack of an appropriate variable for this purpose.

6.4 Modifying Period Definitions

As a final of this sensitivity analysis, we modify definitions for the stable period and the turmoil period based on an analysis of recursive variances of S&P500. Figure 5 shows the new period definition. The recursive variances have been calculated with four different bandwidths, the first with a bandwidth of 1 day, the second with a bandwidth of 30 days, the third with 50 days as bandwidth, and the last one which is graphs in Figure 5, this has a bandwidth of 100 days. All of these recursive variances indicate the same conclusion to specify the new period definition.

The new period definition is as follows, stable period goes from November 24, 2006 to August 31, 2007; the crisis period lasts from September 3, 2007 up to September 16, 2009; Full period is stable period plus turmoil period. Daily returns are also adjusted for weekends and holidays as in the previous definition. Taking into account this new date specification, we compute the new set of cross-market correlation coefficients in US dollars with interest rate controls, also in US dollars with no interest rates, we besides calculated the correlations in local currency with interest rates and we repeat the routine without controlling for interest rates. Results are summarizing from Table 11 to Table 14.

As we can see from Table 11 and Table 12 the unconditional cross-market correlation coefficient is highly stable to changes in dates, and the lack of stability of the conditional correlation coefficient is evident, while the results of Table 3 and Table 5 based on conditional correlation suggest evidence of contagion, Table 11 suggests no evidence of contagion at all, this indicates that conditional correlation is sensitive to changes in period definitions. In contrast, we find that unconditional correlations remains almost without changes even if the period definitions are changed.

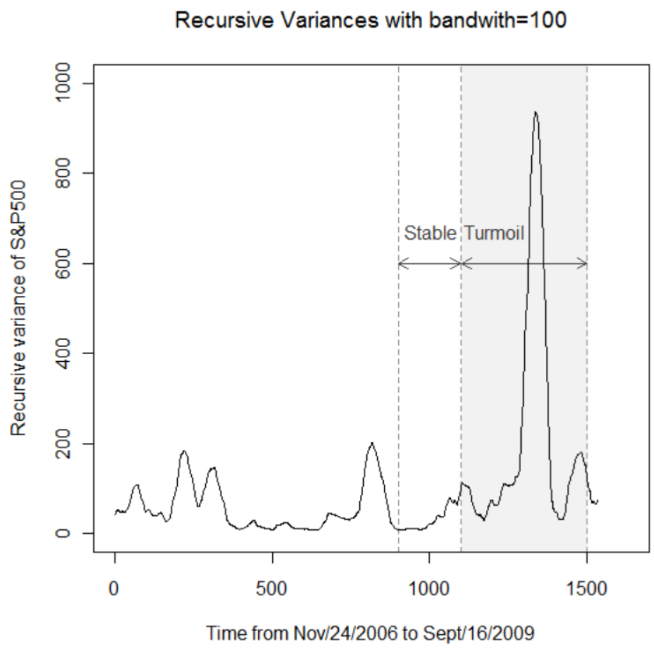

Figure 5: Recursive variance of S&P500 for specifying the new periods of turmoil and stability. Using a bandwidth = 100 days

Table 11: FULL VS. TURMOIL new period definitions, stable period goes from 11/24/2006 to 08/31/20007. Crisis period is from 09/03/2007 to 09/16/2009.

Full vs. Turmoil				
	In US dollars			
	Interest rates		No Interest rates	
	Conditional Contagion?	Unconditional Contagion?	Conditional Contagion?	Unconditional Contagion?
UK	N	N	N	N
Australia	N	N	N	N
Brazil	N	N	N	N
Europe	N	N	N	N
Japan	N	N	N	N

Our results in terms of the unconditional correlation coefficients are time invariant. The conclusion reached is the same as above: There is no evidence of contagion, it is only interdependence.

The following last pair of tables not only demonstrates the lack of evidence of contagion, but also highlight the evidence in favour to interdependence and besides highlight the robustness of the unconditional correlation coefficient.

Table 12: STABLE VS. TURMOIL new period definitions, stable period goes from 11/24/2006 to 08/31/20007. Crisis period is from 09/03/2007 to 09/16/2009.

Stable vs. Turmoil				
	In US dollars			
	Interest rates		No Interest rates	
	Conditional Contagion?	Unconditional Contagion?	Conditional Contagion?	Unconditional Contagion?
UK	C	N	C	N
Australia	C	N	C	N
Brazil	C	N	C	N
Europe	C	N	C	N
Japan	C	C	C	C

Table 13: FULL VS. TURMOIL new period definitions, stable period goes from 11/24/2006 to 08/31/20007. Crisis period is from 09/03/2007 to 09/16/2009. In Local Currency

Full vs. Turmoil				
	In Local Currency			
	Interest rates		No Interest rates	
	Conditional Contagion?	Unconditional Contagion?	Conditional Contagion?	Unconditional Contagion?
UK	N	N	N	N
Australia	N	N	N	N
Brazil	N	N	N	N
Europe	N	N	N	N
Japan	N	N	N	N

Table 14: STABLE VS. TURMOIL new period definitions, stable period goes from 11/24/2006 to 08/31/20007. Crisis period is from 09/03/2007 to 09/16/2009. In Local Currency

Stable vs. Turmoil				
	In Local Currency			
	Interest rates		No Interest rates	
	Conditional Contagion?	Unconditional Contagion?	Conditional Contagion?	Unconditional Contagion?
UK	N	N	N	N
Australia	C	C	C	C
Brazil	C	N	C	N
Europe	C	N	C	N
Japan	C	N	C	N

Table 13 and Table 14 show the variability in the conclusion about whether contagion occurred or not based on conditional correlation. In Table 13 it is clear that contagion not occurred, but in Table 14 is evident that contagion affected almost the entire sample, but unconditional correlation remains almost invariant and the null hypothesis written in subsection 4.1 is not rejected, and with a lot of empirical evidence and with large battery of robustness analysis we conclude that there was not contagion, only interdependence!

Even by a more dramatic change in the period definitions the conclusion remains invariant, interdependence prevails see Table 15. The another period definition is as sketched in Figure 6. Stable period is 11/24/2006 to 1/08/2008, turmoil period is 4/08/2008 to 03/16/2009, and full period as defined as 11/24/2006

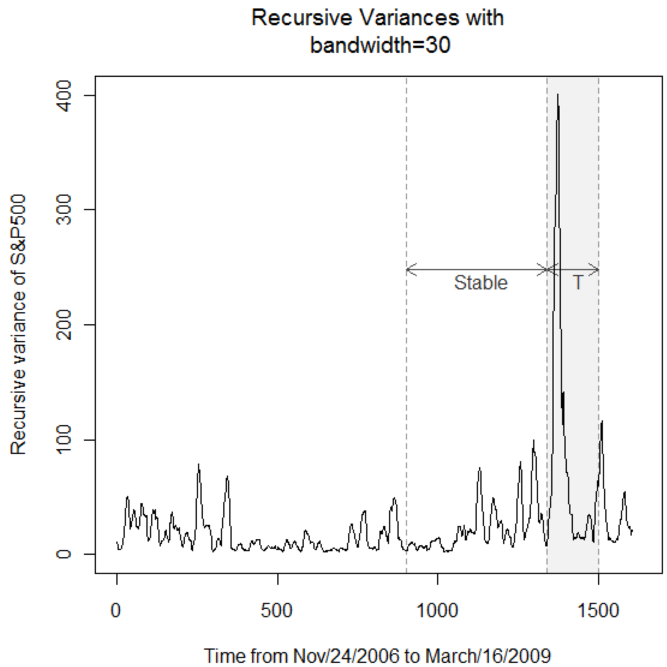

Figure 6: Recursive variance of S&P500 for specifying the new periods of turmoil and stability. Using a bandwidth = 30 days

to 03/16/2009.

Table 15: Stable period is 11/24/2006 to 1/08/2008, turmoil period is 4/08/2008 to 03/16/2009, and full period as defined as 11/24/2006 to 03/16/2009. Currency: US dollars

In US dollars				
	Full vs Turmoil		Stable v Turmoil	
	Conditional Contagion?	Unconditional Contagion?	Conditional Contagion?	Unconditional Contagion?
UK	N	N	C	N
Australia	N	N	C	N
Brazil	N	N	C	N
Europe	N	N	C	N
Japan	N	N	C	C

7 Conclusions

Hypothesis test using conditional correlations is a straightforward procedure, nevertheless it is biased by heteroskedasticity. Conditional correlation coefficient could be adjusted to perform more accurate hypothesis tests.

The majority of our results based on conditional correlation suggest contagion, but these results are biased though. Conditional correlation not only suggests contagion for all the countries in the sample, but also indicates no contagion (interdependence) at the same time; this is clearly a lack of robustness.

It is shown after performing the robustness analysis that conditional correlation is unstable and very sensitive to changes in period definitions. Nevertheless, unconditional correlation performs much better than the conditional correlation and the conclusions achieved with unconditional correlation-based tests are more stable than those reached by the correlation without adjustment.

The $2008 - 2009$ US Financial Crisis has a significant effects all over the world; however, in the countries under examination in this paper, these effects are a consequence of interdependence instead of contagion. Therefore that is why these effects have enormous consequences in all these economies, causing recession, unemployment and economic slowdown.

We find enough evidence that these economies are closely linked and therefore show a high level of market co-movement during all states of the world.

This paper supports and highlights the presence of interdependence instead of contagion between US and the set of countries belong to the sample.

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