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# Volatility co-movements: A time-scale decomposition analysis

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A B S T R A C T

In this paper, we are interested in detecting contagion from US to European stock market volatilities in the period immediately after the Lehman Brothers collapse. The analysis is based on a factor decomposition of the covariance matrix, in the time and frequency domain, using wavelets. The analysis aims to disentangle two components of volatility contagion (anticipated and unanticipated by the market). Once we focus on standardized factor loadings, the results show no evidence of contagion (from the US) in market expectations (coming from implied volatility) and evidence of unanticipated contagion (coming from the volatility risk premium) for almost any European country. Finally, the estimation of a three-factor model specification shows that a European common shock plays an important role in determining volatility co-movements mainly in the tranquil period, while in the period of financial turmoil, the US common shock is the main driver of volatility co-movements.



## 1. Introduction

The aim of this paper is to analyze whether, during the period immediately after the Lehman Brothers collapse (from mid-September 2008 until the end of 2008), there was evidence of contagion between the volatilities in the US stock market and the stock markets of the UK, Germany, France, the Netherlands, and Switzerland.

The definition of contagion adopted is an increase in the propagation of a country-specific shock (the US in our study) to other markets in the transition from a period of non-crisis to a period of financial turmoil. For this purpose, we analyze co-movements by conditioning on the information set not only in the time domain (see Forbes and Rigobon, 2002, based on a comparison of the correlation of financial returns during crisis and non-crisis periods), but also in the frequency domain. The focus on frequency bands, and, in particular, those associated with short-term horizons, is helpful for the analysis of contagion as a temporary phenomenon. As a result, our main concern is the analysis of spillovers over the crisis window extending from mid-September 2008 to the end of December 2008, for frequency bands associated with a time horizon between 2–4, 4–8 and 8–16 days.

Contagion in financial markets has been investigated in the frequency domain by Bodard and Candelon (2009), who employ Granger causality tests (applied to a pre- and post-crisis sub-sample period). Contagion has been also investigated in the time and frequency domain, through wavelet analysis, by Rua and Nunes (2009) and Gallegati (2012), who employ the Continuous Wavelet Transform and the Maximal Overlapping Transform, MODWT, respectively (see also Ranta, 2013, along these lines).

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Our approach improves the understanding of contagion compared to previous studies in at least three respects. First, we control for heteroscedasticity bias, arising if an increase in the correlation between two variables from normal to crisis times can be ascribed entirely to the outcome of an increase in volatility (and not associated with any increase in the propagation mechanism). In a Monte Carlo simulation experiment, we show that, in the presence of series exhibiting long memory, heteroscedasticity bias arises even if we move from high to low frequency bands for a given regime. In our study, we employ a structural form modeling approach, based on a factor model specification along the lines of Dungey et al. (2005) and Dungey and Martin (2007) who focus on financial returns.[1] The factor model makes it possible to disentangle the role played by volatility and propagation (captured by standardized factor loadings) from the US to European markets for different regimes and different frequency bands. As a result, we are able to control for both sources of heteroscedasticity bias.

Second, unlike the previous wavelet-based studies of contagion (focusing on stock market returns), we investigate contagion affecting a) realized volatilities, defined over the next month; b) "market fear" indices proxied by implied volatility, which is the risk-neutral expectation of next-month volatility conditional on the information set available today; c) a forecast error, defined as the difference between a) and b), interpreted as the volatility risk premium (see Buraschi et al., 2014). We argue that decomposing contagion into different components of realized volatilities can shed light on contagion anticipated by the market (coming from implied volatility) and contagion not anticipated by the market (coming from a volatility risk premium).

Our final contribution to previous wavelet-based studies is to account for an omitted variable bias by investigating the role played not only by a US common shock but also by a European shock in shaping volatility co-movements during crisis and non-crisis periods and across different frequency bands.

Our analysis is divided into two stages. First, following Percival and Walden (2000), we use Maximal Overlapping Discrete Wavelet Transform, MODWT, to obtain the time series of wavelet coefficients of the realized volatilities (and of its components: implied volatility and volatility risk premium) for different frequency bands. In the second stage, we explore the contribution of common and idiosyncratic shocks to the variability of each volatility series for different frequency bands by fitting a factor model to the wavelet coefficients retrieved in the first stage. The factor decomposition is obtained by maximum likelihood. Moreover, since the highest frequency range considered by the wavelet decomposition is between 2 and 4 days, we are also able to overcome the problem of asynchronous data, without losing any observations.[2]

The structure of the paper is as follows: Section 2 describes the empirical methodology, Section 3 presents the empirical evidence, and Section 4 concludes.

## 2. Multivariate analysis of realized volatility series and its components

A number of recent studies on volatility co-movements take into account long memory in implied and realized volatility series.[3] In order to account for long memory, the seminal work by Andersen et al. (2001) fits a VAR model to the differences of order $d$ (e.g., the fractional integration parameter) of the log of the currency markets realized volatilities. Bollerslev et al. (2013) adopt a co-fractional VAR to investigate the relationship between implied volatility, realized volatility, and stock market return for the US. More recently, Jung and Maderitsch (2014) suggest dealing with the strong persistence in log realized volatilities of the European, US, and Hong Kong stock markets, using the Heterogeneous Autoregressive Model of Realized Volatility (HAR-RV) proposed by Corsi (2009). To the best of our knowledge, the only studies analyzing implied volatility spillovers (distinguishing tranquil and turmoil periods) are the one by Jiang et al. (2012), employing a VAR model and the one by Kenourgios (2014), employing a dynamic conditional correlation model.

All the studies cited above are based on fully parametric multivariate models specified within the time domain and they rely on the choice of the lag length and/or the estimation of the fractional integration parameters. Unlike these studies, by using wavelet analysis, we are able to circumvent the lag length specification and the estimation of the fractional integration parameter.[4] Wavelet analysis is particularly useful for decomposing fractional integrated series, given that the estimation results on co-movements based on wavelet analysis are robust to the presence of long memory, as shown by Percival and Walden (2000).

In this study, focusing mainly on volatility co-movements and contagion, we intend to exploit an information set both in the time and the frequency domain. Wavelet analysis is particularly suitable to exploring the evolution of co-movements over different time periods and across different frequency bands (see the contagion study by Gallegati, 2012). Frequency domain approaches provide an insightful representation of econometric data by means of decomposition into sinusoidal components at various frequencies, with intensities varying across the frequency spectrum. The main shortcoming of Fourier analysis is related to the assumption of intensities as constant over time. This makes Fourier methods ineffective in analyzing signals containing local irregularities, such as spikes or discontinuities, that are a feature of financial time series. Wavelets can be a particularly useful tool when the signal is localized in time as well as frequency.

[1] Other studies of contagion within a structural form modelling framework are those based on structural VAR model identified through zero-exclusion restrictions on lagged endogenous variables (as in Favero and Giavazzi, 2002); through zero-exclusion restrictions based on the use of country-specific regressors (see Pesaran and Pick, 2007), through switches in second moments across time (see Caporale et al, 2005 and Dungey et al., 2010, where structural form country-specific shocks are modeled as GARCH innovations).

[2] Forbes and Rigobon (2002) use a moving average across two consecutive days to circumvent the problem of asynchronous data, halving the number of available observations.

[3] Baillie et al. (1996); Andersen and Bollerslev (1997); Comte and Renault (1998) provide evidence of long-run dependencies, described by a fractionally integrated process, in GARCH, realized volatilities, and stochastic volatility models, respectively. More recently, empirical studies show that the volatility implied from option prices exhibits properties well described by a fractionally integrated process (see, inter alia, Bandi and Perron, 2006).

[4] The volatility series under investigation are fractionally integrated. Results are available upon request.