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# Stock market contagion during the global financial crisis: A multiscale approach

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ABSTRACT

We propose a multiscale correlation contagion statistic to test for stock market contagion during the global financial crisis (GFC) from the US to the other six G7 and BRIC countries. We find that cross-market correlations between the US and selected countries are conditional on the time scale. Stock market contagion during the GFC is dependent on both the recipient country and the time scale, e.g., contagion from the US to Japan, China, and Brazil occurs when the time scale is longer than 50 days or more. Our findings are important to international investors when they make decisions about global portfolio diversification.



## 1. Introduction

The global financial crisis (GFC) of 2007–2009 is generally considered the worst financial crisis and the largest economic downturn since the Great Depression of 1929–1939. It has focused the attention of academics and policy-makers who want to better understand financial market contagion. One question is whether the apparent market transmission of the GFC from the US to other countries is actually contagion. Although much effort has been devoted to this topic (see, e.g., Fry-McKibbin et al., 2014; Mollah et al., 2016; Tabak et al., 2016), little attention has been paid to the multiscale (or multi-horizon) effect[1] on financial market contagion. This is an important concern because the trading and investment strategies of market participants vary across the different time scales associated with different trading and investment horizons (Wang et al., 2016).

Here we propose a multiscale correlation contagion test for quantifying stock market contagion during the GFC at different time scales. Our work combines the correlation contagion test proposed by Forbes and Rigobon (2002) (FR) and further refined by Fry et al. (2010) with the multiscale correlation coefficient (MCC) developed by Zebende (2011),[2] where

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[1] The multiscale (or multi-horizon) effect is widely found in finance literature (see, e.g., Gençay et al., 2003; In and Kim, 2006; Kim and In, 2006; Masih et al., 2010; Dewandaru et al., 2016).

[2] The MCC is also known as the detrended cross-correlation coefficient because it is based on the detrended fluctuation analysis (DFA) proposed by Peng et al. (1994) and the detrended cross-correlation analysis (DCCA) developed by Podobnik and Stanley (2008), which are used to detect auto-correlation in a time series and cross-correlation between two time series, respectively.

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the former is based on adjusted correlation coefficients by taking account of the heteroskedasticity bias due to the changing volatility and the latter can quantify the level of correlation between two time series at different time scales. Forbes and Rigobon (2002) define contagion as "a significant increase in cross-market linkages after a shock to one country (or group of countries)." They also point out that there is no contagion and only interdependence if two markets exhibit a high level of co-movements during both the pre-crisis and crisis periods. Based on the work of Forbes and Rigobon (2002), Fry et al. (2010) propose the *FR* statistic to test for contagion from the source country to the recipient country by comparing the adjusted correlation in the crisis period with the correlation in the pre-crisis period. By introducing multiscale correlation analysis, we extend their research and develop a multiscale *FR* statistic to investigate whether stock market contagion during the GFC changes across various time scales. We empirically examine stock market contagion during the GFC from the US to the other six G7 and BRIC countries at different time scales.

Our study contributes to the literature on multiscale correlation measurements for contagion. Gallegati (2012) proposes a wavelet-based multiscale correlation method to test for stock market contagion during the US subprime crisis. Ranta (2013) uses this approach to analyze contagion among world stock markets during different crisis episodes. Reboredo et al. (2014) introduce the MCC to study contagion between oil prices and exchange rates of USD. da Silva et al. (2016) investigate the contagion effect of the 2008 financial crisis between the G7 countries (in terms of GDP) using the MCC. However this literature focuses only on correlation changes between the pre-crisis and crisis periods at different time scales and ignores the heteroskedasticity bias noted by Forbes and Rigobon (2002) because cross-market correlation coefficients are conditional on market volatility. By considering the heteroskedasticity bias, our proposed multiscale correlation contagion test differs from the above research and contributes to the contagion literature from a multiscale point of view.

The rest of this paper is organized as follows. In Section 2 we introduce the proposed multiscale correlation contagion test. In Section 3 we present the data and empirical results. We draw our conclusions in Section 4.

## 2. Multiscale correlation contagion test

The object of the multiscale correlation contagion test is to study financial market contagion during a financial crisis from a source country to a recipient country at different time scales. Our proposed test is based on the MCC introduced by Zebende (2011) and the correlation contagion test framework developed by Forbes and Rigobon (2002) and Fry et al. (2010). In what follows, we first introduce the MCC method for calculating cross-market correlation coefficients at different time scales, and then develop the multiscale *FR* statistic to test for contagion.

Consider two stock market returns $\{r_X(t)\}$ and $\{r_Y(t)\}$ of countries $X$ and $Y$ with the same length $N$. We integrate the two returns into two profiles, $R_X(k)=\sum_{t=1}^{k} r_X(t)$ and $R_Y(k)=\sum_{t=1}^{k} r_Y(t)$, where $k=1, 2,\dots, N$. Both profiles are split into $N-n$ overlapping boxes with an equal length $n+1$. In each box from $i$ to $i+n$ we define the local trends as $\tilde{R}_X^i(k)$ and $\tilde{R}_Y^i(k)$ $(i \le k \le i+n)$, which are estimated by the linear least-squares fitting of $R_X(k)$ and $R_Y(k)$. The "detrended walk" (or residual) is defined as the difference between the original walk (i.e., $R_X(k)$ or $R_Y(k)$) and the local trend (i.e., $\tilde{R}_X^i(k)$ or $\tilde{R}_Y^i(k)$). The covariance of the residuals in each box is defined as $\mathrm{Cov}_{XY}(n,i)=1/(n-1)\sum_{k=1}^{i+n}(R_X(k)-\tilde{R}_X^i(k))(R_Y(k)-\tilde{R}_Y^i(k))$. By averaging over all $N-n$ boxes of size (scale) $n$, we obtain the scale-dependent covariance

$$\mathrm{Cov}_{XY}(n)=(N-n)^{-1}\sum_{i=1}^{N-n}\mathrm{Cov}_{XY}(n,i). \tag{1}$$

When the two returns are identical, the scale-dependent covariance reduces to the scale-dependent variance

$$\mathrm{Var}_Z(n)=(N-n)^{-1}\sum_{i=1}^{N-n}\mathrm{Var}_Z(n,i),\ \ Z\in\{X,Y\}, \tag{2}$$

where $\mathrm{Var}_Z(n,i)=1/(n-1)\sum_{k=1}^{i+n}(R_Z(k)-\tilde{R}_Z^i(k))^2$.

Based on the scale-dependent covariance and variance, the multiscale correlation coefficient between two returns is defined

$$\rho_{XY}(n)=\frac{\mathrm{Cov}_{XY}(n)}{\sqrt{\mathrm{Var}_X(n)\mathrm{Var}_Y(n)}}, \tag{3}$$

where $\rho_{XY}(n)$ ranges from $-1$ and 1 at each time scale $n$.

The multiscale correlation contagion test developed here follows the framework proposed by Forbes and Rigobon (2002) and further extended by Fry et al. (2010). To test for contagion during the crisis from a source country $X$ to a recipient country $Y$, we divide the sample of stock market returns into a pre-crisis period and a crisis period, where the sample sizes of the two sub-periods are $N_{\mathrm{pre}}$ and $N_{\mathrm{c}}$, respectively. Given a time scale $n$, correlations between two stock market returns of countries $X$ and $Y$ during the pre-crisis and crisis periods are denoted as $\rho_{\mathrm{pre}}(n)$ and $\rho_{\mathrm{c}}(n)$. To remove the heteroskedasticity bias caused by increasing volatility in stock market returns of the source country during the crisis period, we follow Forbes and Rigobon (2002) and introduce the adjusted correlation coefficient at time scale $n$, i.e.,

$$\nu_c(n)=\frac{\rho_c(n)}{\sqrt{1+\delta(n)(1-\rho_c^2(n))}}, \tag{4}$$