



Testing for financial contagion based on a nonparametric measure of the cross-market correlation[☆]



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ABSTRACT

When contagion is defined as a significant increase in market comovement after a shock to one country, we propose a test for financial contagion based on a nonparametric measure of the cross-market correlation. Monte Carlo simulation studies show that our test has reasonable size and good power to detect financial contagion, and that Forbes and Rigobon's test (2002) is relatively conservative, indicating that their test tends not to find evidence of contagion when it does exist. Applying our test to investigate contagion from the 1997 East Asian crisis and the 2007 Subprime crisis, we find that there existed international financial contagion from the two financial crises.

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1. Introduction

Since 1987, international financial markets have experienced a series of financial crises such as the U.S. stock market crash in 1987, the Mexican peso crisis in 1994, the East Asian crisis in 1997, the Russian crisis in 1998, and the 2007 subprime crisis. A common characteristic of these financial crises is that dramatic movements in the financial market of a crisis country, such as large drops in asset prices and increases in market volatility, can quickly spread to other markets with different sizes and structures across the world. This leads many economists to raise the question of whether the high cross market comovements provide empirical evidence of contagion.

To answer this question, we need define contagion first. In this paper, we adopt the definition of contagion introduced by Forbes and Rigobon (2002), who define contagion as a significant increase in the cross-market linkages after a shock to one country or group of countries.¹ According to this definition, contagion occurs only if cross-market linkage

increases significantly after the shock. Given the definition of contagion above, the most common strategy of testing for contagion is to use cross-market Pearson correlation coefficient as the measure of cross-market linkage.² If there exists a significant increase in the correlation coefficient after a shock, this suggests that the transmission mechanism between the two markets increases after the shock and contagion occurs.

However, using a linear framework, Forbes and Rigobon (2002) show that an increase in cross-market correlation coefficients around crises may not necessarily indicate contagion due to econometric problems associated with heteroskedasticity, which can cause cross-market correlations to increase after a crisis, even if there is no increase in the underlying correlations. Consequently, Forbes and Rigobon (2002) suggest one method of correcting for this heteroskedasticity by adjusting cross-market correlation coefficients. When the adjusted correlation coefficient is used to test for contagion, they find no contagion during the 1997 East Asian crisis. Instead, a high level of cross-market correlation coefficient after a crisis only reflects a continuation of strong cross-market linkages. Their conclusion is that there is no contagion, only interdependence.

Obviously, this adjustment is based on the assumptions that there are no omitted variables and endogeneity, and the analysis of correlation is limited to the case of bivariate normal distribution between the two markets. However, an increase in asset price correlations could occur due to changes in omitted variables, such as economic fundamentals, risk perceptions, and preference, even if contagion is not present. Even though the correlation coefficient can indicate the strength of a linear relationship between two variables, it may not be sufficient to evaluate this relationship, especially in the case where the assumption of

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¹ It is important to mention that there are different methods to identify contagion in the literature. For example, contagion may be viewed as the opening of new channels of transmission during crisis (Dungey & Martin, 2007). Other authors (e.g., Bae, Karolyi, & Stulz, 2005; Billio & Caporin, 2005) use threshold models to separate stable and crisis periods. More recently, Markwat, Kole, and van Dijk (2009) view contagion as a domino effect of crises, and Dungey, Milunovich, and Thorp (2010) propose an identified structural GARCH model to disentangle the hypersensitivity of a domestic market and the contagion imported to a tranquil domestic market from foreign crisis.

² Pearson correlation coefficient between two random variables x and y with expected values μ_x and μ_y and standard deviations σ_x and σ_y is defined as $\rho_{xy} = \frac{E[(x-\mu_x)(y-\mu_y)]}{\sigma_x\sigma_y}$.

normality is incorrect.³ As a result, the measure based on the correlation coefficient misses a potentially important dimension of the contagion phenomenon such as nonlinear dependence. Consequently, the Forbes and Rigobon's correlation-adjusted test (2002, hereafter, FR's test) is still inaccurate and should be used cautiously.

Going beyond the linear approach, Rodriguez (2007) uses Kendall's tau, a nonparametric measure of correlation, as the main measure of dependence to analyze comovements, but he does not construct a test statistic to detect if there is a significant increase during the crisis time. Busetti and Harvey (2011) propose stationarity tests to detect changes in the dependent structure between two variables. Their tests can detect a wide range of changes in the dependent structure between two variable, but their tests cannot reveal the possible sources of the changes. For example, when their tests reject the null hypothesis of stationarity, their tests cannot detect whether the rejection comes from the change in the variance or the correlation coefficient. As Forbes and Rigobon (2002) point out, the increase in the variance (heteroscedasticity) is not evidence of a significance increase in cross-market linkages.

In this paper, we use Kendall's tau as a measure of cross-market comovements to build a test of financial contagion. Unlike FR's test, our test does not rely on the assumption that the data are drawn from a given probability distribution (e.g., a bivariate normal distribution), so that it allows for maximal flexibility in fitting into the data. Moreover, our test avoids the problem of omitted variables associated with FR's test, because Kendall's tau does not impose the restriction that there exists a regression relationship between two variables. Since Kendall's tau used in our test is based on the measure of the concordance between two variables, which reflects the direction of their comovements and is not related to their variances, our test does not suffer from the heteroskedasticity associated with the Pearson correlation coefficient.⁴ Compared to the tests of Busetti and Harvey (2011), our test cannot test whether the dependent structure (copula function) between two variables changes, but it is able to directly test whether Kendall tau changes significantly.

To examine our test's finite sample performance, we design Monte Carlo simulation studies to capture both linear and nonlinear transmission mechanism of financial contagion. The results show that our test has reasonable size and good power to detect financial contagion, and the FR's test is relatively conservative, suggesting that FR's test tends not to find evidence of contagion when it does exist.

Our test is applied to reexamine whether there exist international financial contagion effects from the 1997 East Asian crisis and the 2007 Subprime crisis. When the FR's test is used to test for contagion, we find no contagion during the 1997 East Asian crisis (except for Italy) and the 2007 Subprime crisis. However, the empirical findings based on our test suggest that the 1997 East Asian crisis induced contagion in Asian countries, and it quickly spread to Latin American and the G7 countries. Compared with the 1997 East Asian financial crisis, there is much less evidence of contagion from the 2007 Subprime crisis in Asian countries, while the cross-market linkages between the U.S. stock market and G7 countries with the exception of France increased significantly during the 2007 Subprime crisis, suggesting that there was financial contagion in these countries from the 2007 Subprime crisis.

³ It is well known that the validity of the Pearson correlation coefficient crucially depends on the assumption that the two variables are jointly normally distributed. If the joint distribution of two random variables is not normal, then Pearson correlation coefficient may be unable to provide useful information or clear indication about the relationship between two random variables (Embrechts, McNeil, & Straumann, 1999). For example, let x_t be standard normally distributed, and $y_t = -x_t$ if $|x_t| < 1.54$, and $y_t = x_t$ if $|x_t| > 1.54$, then it can be shown that the joint distribution of x_t and y_t is not normal and the correlation coefficient between them is zero. However, obviously there is a relationship between x_t and y_t because of $|y_t| = |x_t|$.

⁴ This proposes that our test has the advantage not to suffer from the marginal distribution features like volatility bias put forward by Forbes and Rigobon (2002).

The remainder of the article is organized as follows. Section 2 provides a statistical test for financial contagion and Monte Carlo simulations are designed to investigate the finite sample performance of the test statistic. In Section 3, the test is applied to investigate financial contagion of the 1997 East Asian and the 2007 Subprime crises. Section 4 concludes the article.

2. The test statistic and its finite sample performance

2.1. The test statistic

Two points (x_1, y_1) , (x_2, y_2) in R^2 are said to be concordant if $x_1 > x_2$ whenever $y_1 > y_2$ and $x_1 < x_2$ whenever $y_1 < y_2$, and to be discordant in the opposite case. In a similar way, two-random vectors (x_1, y_1) and (x_2, y_2) are said to be concordant if $P[(x_1 - x_2)(y_1 - y_2) > 0] - P[(x_1 - x_2)(y_1 - y_2) < 0] > 0$ and discordant if $P[(x_1 - x_2)(y_1 - y_2) > 0] - P[(x_1 - x_2)(y_1 - y_2) < 0] < 0$.

Kendall's tau is defined as the difference between the probabilities $P[(x_1 - x_2)(y_1 - y_2) > 0]$ and $P[(x_1 - x_2)(y_1 - y_2) < 0]$,

$$\tau \equiv P[(x_1 - x_2)(y_1 - y_2) > 0] - P[(x_1 - x_2)(y_1 - y_2) < 0]. \quad (1)$$

Kendall tau is a non-parametric statistic used to measure the degree of concordance between two variables and assess the significance of this concordance. It satisfies axioms (i) to (vii) of a concordance measure in Cherubini, Luciano, and Vecchiato (2004).

If $\tau > 0$, then the concordance is higher than the discordance, indicating that x_1 and y_1 have more opportunities to move up or down together.⁵ A high value of Kendall tau means that most pairs are concordant. We use Kendall's tau to construct a test statistic to detect if there is a significant increase in Kendall's tau during the crisis period.

We use $\{x_t, y_t\}_{t=1}^n$ and $\{x_t, y_t\}_{t=n+1}^{n+m}$ to denote, respectively, the observations of two asset returns during a noncrisis period and a crisis period. Suppose that (x_t, y_t) , $t = 1, \dots, n$, is a stationary process with the distribution function $F(x, y)$.

If we use τ to express Kendall's tau during the noncrisis period and τ^h during the crisis period, the null and alternative hypotheses are respectively,

$$H_0 : \tau \geq \tau^h, \quad (2)$$

and

$$H_1 : \tau < \tau^h, \quad (3)$$

where the null hypothesis indicates that there does not exist a financial contagion, while the alternative hypothesis suggests that we are in favor of the existence of contagion. A nonparametric estimator of Kendall's tau τ (Hollander & Wolfe, 1973) is,

$$\hat{\tau}_n = \frac{2 \sum_{i=1}^{n-1} \sum_{j=i+1}^n Q((x_i, y_i), (x_j, y_j))}{n(n-1)}, \quad (4)$$

where,

$$Q((x_i, y_i), (x_j, y_j)) \equiv \begin{cases} 1 & \text{if } (y_j - y_i)(x_j - x_i) > 0 \\ -1 & \text{if } (y_j - y_i)(x_j - x_i) < 0. \end{cases}$$

⁵ Kendall's tau can also be expressed by the copula function $C(\cdot, \cdot)$ between x_1 and y_1 . Let U_1 and U_2 be the standard uniform variables and have the joint distribution $C(\cdot, \cdot)$, then we have:

$$\tau = 4E[C(U_1, U_2)] - 1$$

$$= 4 \int_0^1 \int_0^1 C(u_1, u_2) dC(u_1, u_2) - 1.$$

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