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Testing extreme dependence in financial time series☆

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ABSTRACT

Financial interdependence indicates a process through which transmission of shock originating in the financial market of one economy spreads to others. This paper provides a new idea of Residual and Recurrence Times of high or low values for bivariate time series to detect extreme dependence or contagion. In presence of financial extreme dependence, the distributions of residual and recurrence times are not the same. We examine the equality of two distributions using the permutation test. In comparison to other methods in multivariate extreme value theory, our proposed method does not need the i.i.d. assumption. Our method can handle the situation where the extremes for different components do not occur at the same time. We justify our methods in two ways: first using thorough simulation studies and then applying the proposed method to real data on weekly stock indices from sixteen markets.

1. Introduction

In financial market research, interdependence mostly quoted as contagion is a widely researched term. Financial interdependence can be at both levels: at the domestic level, for example, the crash of Lehman Brothers and subsequent depressed United States financial markets, and, at the international level, for example, the Mexican crisis in 1994, the Asian crisis in 1997 or the most recent global, and Eurozone crisis. King and Wadhwani (1990) demonstrate that the correlations between the United States, the United Kingdom, and other developed markets increased significantly following the 1987 stock market crash whereas Lee and Kim (1993) extend this analysis to more countries including emerging markets to show presence of increased correlations during the 1987 crash. In financial markets, contagion refers to the transmission of a financial shock in one market to other interdependent markets. In this paper, we are proposing a test for extreme dependence, which is of interest as it indicates contagion.

Despite the wide use of the term contagion, several definitions exist in the literature (see Pericoli and Sbracia (2003)). Contagion could refer to i) significant rise in the probability of a crisis conditional on a crisis in another country, ii) spill overs of volatility from the crisis country to the financial markets of other countries, iii) significant increase in co-movements across different markets following a crisis in one or group of markets, iv) disproportionate co-movements following a shock in one country and v) co-movements across markets that can not be explained by fundamentals. Therefore three characteristics are important: the presence of a crisis, the dynamics of the interdependencies and the way of measuring these interdependencies.

According to Forbes and Rigobon (2001), there have been four methods to test and measure contagion effects. The first and most straightforward one is based on cross-markets correlation coefficient in asset returns and examines whether inter-related financial markets exhibit anomalous patterns of correlation in returns during two different periods: stable period and the period following a shock. If the correlation coefficient increases significantly after the shock, this implies the presence of contagion. Forbes and Rigobon (2002) distinguish between interdependence and contagion.[1] Bekaert et al. (2005) have defined contagion as excess correlation on top of the correlation in economic

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[1] Shift contagion refers to a situation where the propagation of shocks during crisis periods increases systematically from that observed during normal times. A broader definition refers to contagion as the transmission of shocks through any channels that cause markets to co-vary. We acknowledge that our proposed test cannot distinguish between interdependence and (shift) contagion, given that there is no control for common shocks. We use the term contagion and interdependence interchangeably throughout the paper.

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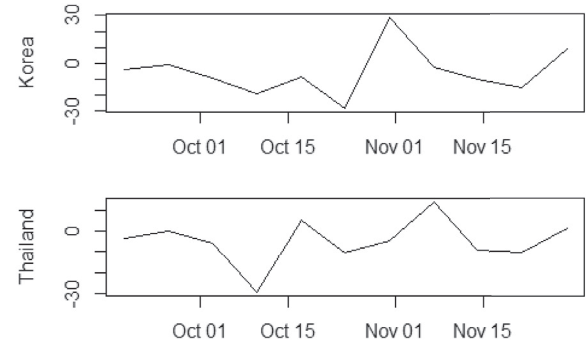

Fig. 1. Percentage return series of Korea and Thailand in Oct–Nov 2008.

fundamentals. In this framework, test for contagion is being conducted by examining the correlation in the residuals obtained from employing a multi-factor model. In a recent paper, Blatt et al. (2015) detect changes in correlation matrix, hence extending the approach of the aforementioned papers to multiple dimensions. But correlation is a moment based statistic and therefore is affected by extreme values. However, correlation may be high even without extreme events moving together.

The second approach as in Hamao et al. (1990), the ARCH or GARCH models are used to test for the presence of significant volatility spillover from one market to another during or after the crisis. Leung et al. (2017) employed GARCH model to examine the volatility spillover between the exchange rates markets and the equity markets during the global financial crisis and the euro debt crisis and test whether the increased spillover is the resultant of fundamental contagion (see Dornbusch et al. (2000)) or pure contagion (see Lin et al. (1994)). Shen et al. (2015) have used the Kalman filter to estimate the time-varying correlation coefficients of the stock market indices between the Eurozone and China to tests for pure contagion and interdependence. See also Ahmad et al. (2013), and Hemche et al. (2016) for dynamic conditional correlation using GARCH model for an application.

The third test, implemented by Longin and Solnik (1995), examines whether there is significant change in the cross-market correlations over time. The fourth procedure applies probit model to ascertain the probability of a crisis occurring in one economy conditional on a crisis that has already occurred in another economy (Eichengreen et al. (1996) and Kaminsky and Reinhart (2000)).

We propose a new method based on test of dependence between point processes using Residual and Recurrence Times (RRT). Our proposed method is closest to the fourth procedure that applies probit model to ascertain the probability of a crisis occurring in one economy conditional on a crisis that has already occurred in another economy. However our method is nonparametric in nature. All the other procedures relying on correlation, volatility etc. concentrates on the center of the data and not on the extremes. We do not treat the periods between the events and the contagion period as independent. However, they could be still uncorrelated. Tests based on correlation would not pick up the dependence but our proposed RRT test can not only detect dependence effect between the two components but also can tell the direction of the effect. This is our first contribution in the existing literature.

Interdependence or contagion is observed when one or more entities are going through extreme high or low economic phases. Such phases are economically the most interesting and high-impact periods. Standard methods of multivariate time series analysis are not suitable in this setting, since they concentrate on the joint behavior during stable and stationary periods. Another approach is through tail dependence in multivariate extreme value theory. Silvapulle et al. (2016) have used a robust copula method to model tail dependence and test for contagion effects. See Sen and Tan (2012) and references therein for a survey. The second contribution of our method to the existing literature by overcoming the limitation of standard multivariate extreme value theory that extreme events in different series occur concurrently. Given the presence of finite time lag in propagation of financial shocks originated in one market to be transmitted from one market to another, the extremes do not necessarily occur in both series at the same point of time. The same assumption is made in other works on contagion like Bae et al. (2003). Although block maxima methods address this to some extent, the length of the block is ad hoc in nature.

To illustrate our point, we present the returns of stock indices of Korea and Thailand in October–November 2008 in Fig. 1.

The small return of Thailand in early October is followed by small value of Korea in late October. The high value of Korea in early November is followed by high value of Thailand. Thus, contagion effect is present. We observe that in Fig. 1, the extreme events in the two series do not necessarily occur at the same time point. Thus, here bivariate extreme value theory may not be a good tool. Furthermore, we find that extremogram, see Davis and Mikosch (2009), for this kind of series is very small and hence, extremogram may not be appropriate to detect the extremal dependence largely due to an implicit assumption of fixed time lag between extreme events. Our proposed RRT method does not suffer from fixed time lag problem and removes the assumption of i.i.d. observations. Related studies in actuarial risk theory exist with renewal times. For instance Doss (1989) derives the asymptotic distribution of relevant estimators as the sample size goes to infinity. Our test is nonparametric and distribution-free and hence valid for any sample size. This is our third contribution in the existing literature.

We carry out a thorough simulation study to better emphasize that the test proposed outperforms various standard methods in the literature in terms of size and power. The comparison with the Longin and Solnik (1995) test is incomplete, since the latter has problems with computational feasibility. We consider independent iid series and GARCH type series to compute the size of the proposed test and that of the competing candidates. We consider correlated bivariate normal or bivariate dynamic conditional correlation GARCH DGP's to assess the power of the proposed test and compare it with that of the other competing tests. We also consider the case of a DGP characterized by extreme dependent bivariate series. We believe that this is our final contribution in the existing literature.

Our results using simulation studies show that the size and the power of the proposed test outperforms the other tests in general. We demonstrate that many small-sized countries (defined in terms of their market capitalization) have contagion effects between each other, whereas larger economies like USA, and China cannot be easily affected. Our results remain valid irrespective of whether we use return or volatility.

The rest of the paper is organized as follows: We introduce our proposed test and testing procedure in Section 2. The method validation for the RRT method under different scenarios is presented in Section 3. Section 4 provides the simulation study and Section 5 the results from our proposed test to real data from financial markets. Section 6 contains concluding comments. Proofs and details about related procedures are presented in the Appendix.

2. Testing procedure

In this section, we describe the testing procedure for the RRT approach. In Section 2.1, we introduce the used notations and definitions whereas Section 2.2 outlines the procedure for testing contagion.

2.1. Some notations and definitions

Let X and Y be two time series, for example, return on assets, volatility, volume, etc.

Definition 2.1. Extreme Event: An extreme event for series X (Y) is an event defined as being beyond a chosen threshold, say an upper or