Expert Systems with Applications xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

# A spatial contagion measure for financial time series

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ARTICLE INFO

*Keywords:*
Contagion
Copula
Cluster analysis
Financial time series
Risk management

ABSTRACT

A novel spatial contagion measure is proposed that is based on the calculation of suitable conditional Spearman's correlations extracted from the financial time series of interest. Algorithms for the numerical estimation of this measure are illustrated, together with a simulation study showing its features in relations with popular families of copulas. Finally, two applications are presented about the use of spatial contagion measure for determining (asymmetric) linkages in the financial systems, and creating clusters of financial time series. In particular, contrarily to previous approaches in the literature, such clusters identify which time series increase their (positive) associative when the market is under distress. The presented methodology is also expected to be useful to select a diversified portfolio of asset returns.





## 1. Introduction

Measuring co-movements among financial time series is a widely debated issue since the seminal work of Grubel (1968) underlined the benefits from international portfolio diversification. In fact, it has been recognized that investors can reduce the risk of their portfolios through allocating their investments in various classes of financial instruments, industries and other categories of assets that would move in different ways in response to the same event. In other words, diversification benefits can be achieved when the comovements among the assets are taken into account.

Therefore, the portfolio diversification issue naturally poses the question of investigating the relationship between financial time series and checking whether they can be grouped together in a way that may be helpful to portfolio selection. As such, there has been a growing interest in exploring clustering methods to financial time series. A class of such methods is based on the pairwise dependence among assets. For instance, a popular methodology is grounded on the use of the Pearson correlation; e.g., see Mantegna (1999), Bonanno et al. (2004) and the references therein. Most recently, instead, several investigations have focused on the extreme linkages among financial markets, measured for instance by the tail dependence coefficient, as done by De Luca and Zuccolotto (2011) and Durante, Pappadà, and Torelli (2013a), or by conditional correlation coefficients, like Spearman's correlation, as suggested by Durante, Pappadà, and Torelli (2013b). Other methods include, for instance, the works by Basalto et al. (2007), Corduas and Piccolo (2008), Otranto (2008), Brida and Adrián-Risso (2010), Bastos and Caiado (2013), D'Urso, Cappelli, Lallo, and Massari (2013) and Aghabozorgi and Teh (2014).

However, especially during the last global financial crisis (i.e., 1997 Asian crisis, the so-called 2008 Subprime Mortgage, and 2011 Sovereign Debt crisis) a clear need arises among academic and financial engineering communities: namely, how to distinguish between markets interdependence, i.e. the presence of comovements among the markets, and contagion, i.e. the presence of a mechanism that allows the propagation of financial difficulties from one economy to the others (see, e.g., Kolb (2011) and the references therein). In fact, although these two aspects are closely related, they underline two different features of the market behavior. In particular, recognizing and managing the presence of contagion provides useful benefits when dealing with financial risks. For instance, diversification strategies for building portfolios may fail under contagion, i.e. when there is a shift in the dependence among assets in crisis period. In particular, Forbes and Rigobon (2002) reported recommendations in using suitable (econometric) tools aiming at catching evidence of contagion regardless of any other effect due to interdependence or market volatility. Although it could be considered "very restrictive" (see, e.g., Billio & Caporin, 2010), the latter approach is able to shed light on the international diversification issue. Following these ideas, Bradley and Taqqu (2004) suggested to focus on the probability distribution functions of target financial time series and, in particular, at the discrepancies between tail and central sets of these distributions. This method, which is somehow based on the geometry of the underlying distribution, was hence called *spatial contagion*. By adopting this

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0957-4174/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.eswa.2013.12.020

distributional-based approach, Durante and Jaworski (2010) suggested to define (and detect) the presence of contagion between markets $X$ and $Y$ in terms of copulas, which are the objects that may describe a variety of non-linear dependencies between two random variables (Cherubini, Mulinacci, Gobbi, & Romagnoli, 2012; Jaworski, 2010; Jaworski et al., 2013).

The aim of the present work is to analyze spatial financial contagion by providing a new measure that goes beyond the use of linear correlation and does not require, in addition, the a priori specification of crisis/non-crisis periods via suitable thresholds (as done for instance in Durante & Jaworski (2010)). The new measure is completely data-driven and can be calculated via non-parametric methods. As such, it avoids possible misspecification in the dependence structure. Spatial contagion measure can be calculated empirically via simple procedures and could be also used to identify sub-groups of assets that have similar behavior in crisis periods. In fact, compared with related approaches in the literature, the spatial contagion measure detects the changes in the dependence structure among financial markets and not the presence of a persistent extreme dependence, which is due to interdependence, but not to contagion (for such viewpoint, compare with the discussion in Forbes & Rigobon (2002)). Moreover, the measure of symmetric spatial contagion could be used to implement clustering procedures for financial time series, aiming at finding subgroups of assets that have similar behavior in periods of market distress.

The paper is structured as follows. Section 2 reviews methods aiming at detecting financial contagion. In Sections 3 and 4 a novel contagion measure is introduced and a detailed description on how to compute it is given. Section 5 reports a simulation study where contagion is detected according to different conditions of (extreme) dependence. Section 6 illustrates the methodology in practice. Finally, Section 7 concludes.

## 2. Literature review

There is no agreement in the literature on the notion of contagion for financial markets. Loosely speaking, financial contagion is refereed to diffusion of financial distress from one market/economy to another one. In a recent survey, for instance, Pericoli and Sbracia (2003) discussed various definitions of contagion that reflect the wide variety of meanings ascribed to this term.

Here, we follow on one of these definition that refers to contagion as "a significant increase in comovements of prices and quantities across markets, conditional on a crisis occurring in one market or group of markets". In the literature, several theoretical and empirical works have been devoted to the search for the change in the correlation/dependence structure of the underlying distribution governing the behavior of historical financial time series as an indicator of the presence of contagion.

In early papers (see e.g., the discussion in Corsetti, Pericoli, & Sbracia (2011)), cross-market (Pearson) correlation coefficients were used to test for contagion. Specifically, if there is a significant increase in the correlation coefficient in financial returns between two markets after a shock, with respect to their correlation during a stable period, then it can be argued that the transmission mechanism between the two markets strengthened after the shock and contagion occurred. In fact, as noticed for instance by Kaminsky, Reinhart, and Vég (2003), correlation-based contagion appears "only if there is excess comovement in financial and economic variables across countries in response to a common shock". It follows that, if two markets are strongly correlated at any time (but the link is not changing), they exhibit no contagion.

However, tests for contagion based on correlation coefficients may be problematic. In fact, changes in market volatility can bias the estimate of correlation coefficients and, hence, the related detection of contagion. In the later years, a series of papers began to investigate how the bias affects cross-market correlations. In particular, Forbes and Rigobon (2002) proposed a heteroscedasticity corrected version of correlation test. Specifically, they were able to distinguish two different phenomena: the interdependence and the contagion among financial markets. One problem of Forbes–Rigobon's strategy, as pointed by Bradley and Taqqu (2004) (see also Bradley & Taqqu, 2005b, 2005a), is that the power of this test is very low due to the short crisis period. Thus, they proposed a different approach to attempt the detection of contagion by using a local correlation coefficient (Bjerve & Doksum, 1993). Among various advantages of their approach, Bradley and Taqqu (2004) recognized that contagion is a "spatial" notion, in the sense that is based on the different behavior of the joint distribution function between two markets $X$ and $Y$ in the central and in the tail regions of its domain. Following their idea, there is contagion from market $X$ to market $Y$ if there is more dependence between $X$ and $Y$ when $X$ is doing badly than when $X$ exhibits typical performance, that is, if there is more dependence at the loss distribution of $X$ than at its center.

In the same spirit of Bradley and Taqqu (2004) and Durante and Jaworski (2010) investigated a related notion of *spatial contagion* between two financial markets $X$ and $Y$, by describing their dependence not by means of the local correlation coefficient, but by using the information contained in the copula of $(X, Y)$. Notice that copulas have been already used for checking financial contagion: see, for instance, Rodríguez (2007), Kenourgios, Samitas, and Paltalidis (2011), Peng and Ng (2012) and Ye, Liu, and Miao (2012). However, most of these approaches require the specification of a parametric (copula-based) model for asset returns. Such models, that have several advantages as illustrated in Patton (2012), may suffer from the fact that most of statistical goodness-of-fit tests cannot identify the correct copula (see, e.g., Grundke & Polle, 2012).

Specifically, as discussed by Durante and Jaworski (2010) (see also Durante, Foscolo, & Sabo, 2013; Durante & Foscolo, 2013) a notion of spatial contagion can be introduced by comparing the Spearman's correlation among the time series when $X$ and $Y$ are experiencing severe losses (which depends on the related threshold copula) with the Spearman's correlation when $X$ and $Y$ are in an untroubled (i.e., tranquil) scenario. Such an idea is grounded on some previous investigations about exceedance correlations (Longin & Solnik, 2001). However, the Spearman's correlation is used instead of Pearson's correlation in order to detect also nonlinear (yet monotone) dependence among the data (see, e.g., McNeil, Frey, & Embrechts, 2005). The main aspects of this procedure together with the introduction of a novel related measure are discussed below.

## 3. The spatial contagion measure: theoretical aspects

We recall here some basic aspects of spatial contagion that will be useful in the following.

Let $X$ and $Y$ be two random variables on a suitable probability space representing the returns (or log-returns) of financial markets whose dependence is described by means of a copula $C$. Consider the following Borel sets of $\mathbb{R}^2$:

- the *tail set* $T_{\alpha_1,\alpha_2}$ given by
$$T_{\alpha_1,\alpha_2} = [-\infty, q_X(\alpha_1)] \times [-\infty, q_Y(\alpha_2)],$$
where $\alpha_1, \alpha_2 \in [0,1]$ and $q_X$ and $q_Y$ are the quantile functions associated with $X$ and $Y$, respectively.
- the *central set* (or *mediocre set*) $M_{\beta_1,\beta_2}$ given by
$$M_{\beta_1,\beta_2} = [q_X(\beta_1), q_X(1-\beta_1)] \times [q_Y(\beta_2), q_Y(1-\beta_2)]$$



Q1 Please cite this article in press as: Durante, F., et al. A spatial contagion measure for financial time series. *Expert Systems with Applications* (2014), http://dx.doi.org/10.1016/j.eswa.2013.12.020