Asian Academy *of* Management Journal *of* Accounting *and* Finance

AAMJAF Vol. 18, No. 2, 109–138, 2022

STOCK MARKET INTERDEPENDENCE, CONTAGION, THE FINANCIAL SUBPRIME CRISIS AND THE EUROPEAN SOVEREIGN DEBT CRISIS: EVIDENCE FROM THE CHINESE'S STOCK MARKET

Selma Jayech[1], Lamia Jaidane Mazigh[2] and Emna Abdennadher[3]*

[1]Faculty of Economics and Management, Sfax University, Street of Airport, km 4, LP 1088, Sfax 3018, Tunisia
[2] Faculty of Economics and Management, Monastir University, Sidi Messaoud - 5111 Hiboun - Mahdia, Tunisia
[3] Higher Institute of Management of Sousse, University of Sousse, Abedelaziz El Bahi Street, B.P. 763, 4000 Sousse, Tunisia

*Corresponding author: abdennadheremna@hotmail.com

ABSTRACT

This study analyses the contagion effects of the American, the British and the Greek stock markets on the Chinese stock market in the context of the 2007–2010 American and European financial crises. Two contagion tests have been performed using the Archimedean copula functions. The results of the first test suggest that the financial contagion existed between UK/China in the 2007 subprime financial crisis period and between U.S./China and U.K./China in the 2010 European sovereign debt crisis period. Finally, the second test shows that the contagion effects of the 2010 European sovereign debt crisis were clearly more intense than those caused by the 2007 subprime financial crisis just for the U.S./China pair. Investors' sentiment and behavior indirectly have impact on financial risk contagion in Chinese stock markets.

Keywords: 2007–2010 financial crises, financial contagion, Archimedean copula functions

Publication date: 30 December 2022

To cite this article: Jayech, S., Mazigh, L. J., & Abdennadher, E. (2022). Stock market interdependence, contagion, the financial subprime crisis and the European sovereign debt crisis: Evidence from the Chinese's stock market. *Asian Academy of Management Journal of Accounting and Finance, 18*(2), 109–138. https://doi.org/10.21315/aamjaf2022.18.2.6

To link to this article: https://doi.org/10.21315/aamjaf2022.18.2.6

INTRODUCTION

During the last two decades, the periods of severe turmoil has shaken the international financial system. The global financial crises have shown that the financial shocks in a country can quickly affect other countries and have bad impacts on a lot of other financial markets. This was particularly shown during the subprime crisis in the summer of 2007, when the financial markets of the developed, emerging and developing countries were highly affected. This crisis started by the subprime mortgage sector in the U.S. from July 2007, triggering the financial crisis of 2008, and continued by the debt crisis in the Euro area in 2010 (Jayech, 2016).

Thus, the financial crises between 2007 and 2010 were spread all over the world, including some Asian countries (Abdennadher & Hellara, 2018; Cheung et al., 2010; Chudik & Fratzscher, 2011; Dornbusch et al., 2000a; Glick & Hutchison, 2013; Kenourgios, 2014; Lee & Lee, 2021; Pomfret, 2014; Wang et al., 2014; Yamamoto, 2014). On the one hand, during the subprime crisis, some works were concerned about the study of the financial contagion effect on the Asian stock markets (Aloui et al., 2011; Jin & An, 2016; Morales & Andreosso-O'Callaghan, 2012; Ye et al., 2012). Some studies examined the transmission mechanism of this crisis from one country to another. They tried also to explain the contagion effect through the trade connections between countries or through financial links. On the other hand, during the sovereign debt crisis, various papers tested this serious phenomenon on sovereign debt markets, interest rates, government bonds, Credit Default Swap (CDS) spreads and banking stocks (Abdennadher & Helara, 2021; Arghyrou & Kontonikas, 2012; Beirne & Fratzscher, 2013; Claeys & Vašíček, 2014; Elkhaldi et al., 2014; Elkhaldi & Abelfatteh, 2014; Elkhaldi & Daadaa, 2015; Gorea & Radev, 2014; Kim et al., 2014; Metiu, 2012; Pais & Stork, 2011). However, the studies on the stock markets during the period of the Greek crisis are still few (Ahmad et al., 2013).

In general, the contagion phenomenon in the financial markets is very important because of the global economy's consequences in terms of international diversification, monetary and budgetary policy, optimal asset allocation, risk measure, shareholders' equity and optimal-assets valuation. Nevertheless, little attention was paid to evaluate the effect of both American and European financial crises between 2007 and 2010 on the main Asian economic power, China. On the one hand, the latter is presented as the second largest economy in the world, the most dynamic country, and the most important Asian economy during the financial subprime crisis. Certainly, this country played a major role in rescuing the Western financial institutions, hence participating in returning a market-related stability.

For instance, China highlighted the key role of its sovereign funds to save the American economy. On the other hand, its role was weakened especially during the sovereign-debt crisis of 2010 since most of its financial markets were affected, particularly the Shanghai Stock Exchange,[1] which is the most representative index of the Chinese stock market. For a country with an annual GDP growth of 7%–8% per year for four years, how is it possible that its stock market declines for four years consecutively?

According to Shen et al. (2015), the Euro area has become the largest export market of China and its important foreign investment's source. Besides, the confidence and expectations of investors, mainly the Chinese, may have been affected by the Euro area market during the crisis.

The weakening of China would be bad news for the whole world. Given the strong connections between China and the Euro area, researchers and policy makers have to be concerned about the possible channels through which contagion is transmitted as well as the crisis' negative effects. Therefore, our goal is to understand how the subprime crisis was transmitted unexpectedly to the Chinese stock market and to identify the countries responsible for the spread of these financial stresses. In this article we try to compare the effect of the major Western financial crises on the Chinese stock market. Our issue is to answer the main question: Was the Chinese financial market affected in the same way by the different crises?

As far as we know, this is the first paper which applies the copula method in order to investigate the financial contagion between the American, British, Greek and Chinese stock markets throughout the two crises. We contribute methodologically to the literature by proposing to use copula rank correlation coefficients to measure the financial contagion's degree, such as Kendall's .We have used last new tests, suggested by Horta (2013) to study the financial contagion between the stock indices during the American financial crisis of 2007 and the European sovereign debt crisis of 2010. Our contribution is to improve a little bit the last test to compare between the two crises in terms of contagion intensity. Consequently, among the values of our serious work is to develop the new tests in finance and ameliorate a little the new methods used to study the transmission of crises. In addition, our major concern is to identify the countries responsible for the transmission of the international financial crisis on the Chinese stock market.

In this article, we use daily data considering its advantages, it may yield a more efficient Beta estimate compared with monthly data as suggested in some recent studies (Phuoc et al., 2018; Serra & Martelanc, 2013). This is also confirmed by Pham (2020) who found that daily data is more reliable and efficient, it has

higher forecasting power, and fits better with the assumption of market efficiency compared with monthly data. Many authors used daily data in their investigations (Dimitriou et al., 2013; Kenourgios et al., 2013; Kenourgios & Dimitriou, 2015).

LITERATURE REVIEW

The literature on financial contagion remained embryonic until the recent financial crisis of 2007–2010. Since then, many economists have theoretically and empirically studied this phenomenon. However, they have failed to agree on the concept of contagion: "paradoxically …there is no accordance on what contagion means" (Rigobon, 1999) or even: "… there is no consensus on exactly what constitutes contagion or how it should be defined" (Forbes & Rigobon, 2000). We initially have an overview of contagion definitions as presented in the literature by paying a special attention to the definition of Forbes and Rigobon (2002). Then, we present the crisis transmission theories where the distinction between the contingent and non-contingent theories to crises is drawn.

De ining Financial Contagion

Despite the multiplicity of theoretical and empirical work on this topic, contagion has not yet got a single definition that the authors would agree upon. The World Bank summarises three layers within contagion definitions (Dungey & Gajurel, 2014). [2] In a broad sense, "contagion is the cross-country transmission of shocks or general cross-country spillover effects". Contagion can take place both during "good" and "bad" times. Then, contagion does not need to be related to crises. However, contagion has been emphasized during crisis times. In a restrictive sense, "contagion is the transmission of shocks to other countries, or cross-country correlation, beyond any fundamental link among the countries and beyond common shocks". In a very restrictive sense, "contagion occurs when cross-country correlation increases during crisis times relative to during tranquil times".

Although most of the empirical studies are based on a very restrictive definition of contagion, the various concepts presented in the literature vary depending on the specific nature of each study. For example, Eichengreen et al. (1996) referred to contagion as "a significant increase in the probability of a crisis in one country, conditional on a crisis occurring in another country". This definition has been used by many researchers, such as (Dornbusch et al., 2000b; Glick & Rose, 1999; Hamao et al., 1990; Kaminsky & Reinhart, 1999). Hamao et al. (1990) defined contagion as "a volatility spillover from the crisis country to other countries". Jeanne (1997) referred to contagion as "cross-country co-movements of asset prices that cannot be explained by economic fundamentals".

Taking into account the last three definitions, Forbes and Rigobon (2002) formulated their definition in which "contagion is a significant increase in cross-market linkages after a shock to one country (or a group of countries)". According to this definition, there is not necessarily contagion if two markets are highly correlated after a shock, but contagion will occur if the correlation between markets dramatically increases. In other words, contagion arises as the transmission channel intensifies or changes after a shock to a country.

Also, this definition presents some operational advantages, namely its usefulness for the financial investors engaged in strategic international diversification, or for the monetary authorities aiming to justify the bailing out interventions in the markets affected by these foreign crises but displaying strong fundamentals (Forbes & Rigobon, 2002; Horta et al., 2010). Several studies have used this definition (Billio & Pelizzon, 2003; Caramazza et al., 2004; Horta et al., 2010, 2014; Wen et al., 2012). In our paper, we define contagion by referring to the work of Forbes and Rigobon (2002).

Mechanisms of Crisis Transmission

Contagion is usually used to describe the propagation of disturbances in a market from one country to another. It is a process observed through the co-movements of the exchange rates, stock prices, sovereign debt and capital flows. It can occur for various reasons and can be conceptually classified into two categories (Forbes & Rigobon, 2000; Masson, 1998; Pritsker, 2001).

One group argues that the economic fundamentals of different countries are interconnected by their cross-border flows of goods, services, and capital. Kaminsky and Reinhart (1999) considered an interdependent process as the one that allowed the transmission of the crisis in the context of regional contagion. This interdependence can transmit local or global shocks through trade and financial links. In addition, common shocks, like the major economic shift in the industrial countries, the significant changes in the oil prices, the changes in American interest rates, and the changes in the exchange rates, might adversely have an impact on the economic fundamentals of various economies simultaneously, and potentially might cause a crisis (Eichengreen et al., 1996). Consequently, interdependence or fundamental contagion mechanisms, dealt with common macroeconomic shocks (Caramazza et al., 2004; Haile & Pozo, 2008) including their repercussions on the global scale and local shocks from one country to other neighboring one, transmitted through trade links (Dornbusch et al., 2000a; Gerlach & Smets, 1995; Van Rijckeghem & Weder, 2001) and financial links (Baig & Goldfajn, 1999; Forbes & Rigobon, 2000; Pritsker, 2001).

The second category focuses on pure contagion which is explained neither by interdependencies with the country at the origin of the crisis, nor by the fundamental problems of the contaminated countries. These theories indicate that a financial crisis is transmitted from a country to another because of market imperfections or due to the behaviour of international investors. Masson (1999) gave three explanations of pure contagion: The first was the one of the "wake-up-call" models which were an alternative to M. P. R. Masson (1998) model. A crisis in the world was an alarm signal that made financial markets reconsider the other countries' fundamental data (Goldstein & Pauzner, 2004; Van Rijckeghem & Weder, 2001). The second explanation analysed the role of the information asymmetry and investors' heterogeneity in front of a crisis in the rest of the world (Agénor & Aizenman, 1998; Banerjee, 1992; Calvo & Mendoza, 2000; Kim & Wei, 2002; Shiller, 1995). The third explanation was presented through the risk factor that plays an important role in the rebalancing of portfolios. This explanation showed the importance of the diversification in the realisation of contagion (Goldstein & Pauzner, 2004).

The first empirical literature concerning the financial crises and contagion focalised on some fundamentals-based mechanisms and it was directed to developing several early warning systems (Eichengreen et al., 1996; Kaminsky & Reinhart, 1999; Van Rijckeghem & Weder, 2001) whereas the later empirical works focalised on various investor behaviour-based mechanisms (Bekaert et al., 2011; Dungey et al., 2005).

The crises of 2007–2011 have been extensively studied in the recent years (Chudik & Fratzscher, 2011; Horta et al., 2014; Jung & Maderitsch, 2014; Samitas & Tsakalos, 2013; Yamamoto, 2014). The recent works have not only studied the transmission channels but have also sought to measure contagion and analyse its evolution over time. For example, Aloui et al. (2013), Baur (2013) and Samitas and Tsakalos (2013), studied the financial contagion during the 2007 financial crisis by using the copula theory. The results confirmed the benefits of using this theory to study this phenomenon during a crisis.

Kenourgios and Padhi (2012) examined financial contagion of three emerging market crises of the late 1990s, as well as the subprime crisis of 2007, focusing on financial markets of emerging economies, the U.S. and two global indices. The results show that there is a stronger transmission mechanism during the three contagious crises between the different stock markets.

Kenourgios et al. (2011) studied financial contagion of four emerging equity markets, namely Brazil, Russia, India, China (BRIC) and two developed markets (the U.S. and the U.K.), during five recent financial crises. The results

show the presence of contagion effect from the crisis country to all others, for each of the examined financial crises. They provided the evidence that emerging BRIC markets are more prone to financial contagion, while the industry-specific turmoil has a larger impact than country-specific crises.

Chen et al. (2014) also studied the quantitative measurement of contagion effect between the U.S. and Chinese stock market during the financial crisis by combining multifractal volatility (MFV) with the copula method. Considering the asymmetric dependency structure and regime switching process, Changqing et al. (2015) constructed the dynamic Markov regime switching copula models to measure the financial risk contagion during the subprime mortgage crisis and the European debt crisis. They provided the evidence of financial risk contagion between Chinese stock market and international stock markets. This article possesses some limitations; the cause and the path of the financial risk contagion channel have not been fully investigated in this paper; our research could provide more detailed theoretical and empirical explanations about the financial risk contagion using copula theory.

COPULA THEORY

Generally, copula theory differs fundamentally from most of the methods used in the literature for dependency analysis between financial markets, which is also sometimes referred to as co-movement. A copula is a function that connects the marginal distributions to reestablish the joint distribution. The advantages of using copulas in the analysis of the concerned co-movements are numerous. First, copulas allow us to model marginal behaviour and dependency structure separately. This property gives us more options in specifying the model and estimating. Second, the copula function can give us not only the degree of dependence, but also its structure.

There are several families of copulas, the best known of which are the elliptical copulas and the Archimedean copulas. Elliptical copulas are symmetrical and exhibit relative symmetry to the lower and upper dependence dynamics of the tails of the distributions. The two most widely used classes of elliptical copulas are the Gaussian copula and the Student copula. Elliptical copulas are less suitable in finance because they apply to symmetrical distributions. Archimedean copulas have the great advantage of describing very diverse dependency structures, including the so-called asymmetric dependencies where the coefficients of lower tail (λ_L) and upper tail (λ_U). There are three types of Archimedean copula functions: Clayton, Gumbel and Frank.

Presentation of Archimedean Copula Functions

In this section, we present the Archimedean copula functions used to study the dependence structure between the stock market return, the estimation method and the goodness of fit test applied to select the best copula.

The Archimedean copulas are a prominent class of copulas with a common method of construction involving one-dimensional generator functions (Joe, 1997; Nelsen et al., 1999). They play an important role because they present several desirable properties such as associative symmetry and they are capable of capturing wide ranges of (Ghorbel & Trabelsi, 2009). The definition of the Archimedean copula is as follows (Ye et al., 2012):

> Let ϕ denote a set of functions ϕ:[0,1] $\rightarrow$[0,∞], which are continuous, strictly decreasing, convex, then $\varphi(0) = \infty$ and $\varphi(1) = 0$. Each $\varphi \in$ Ö has an inverse φ^{-1}: [0,1] $\rightarrow$ [0,∞], which has the same properties except that $\varphi^{-1}(\infty) = 0$ and $\varphi^{-1}(0) = 1$. Thus, $C(u, v) = \varphi^{-1}(\varphi(u) + \varphi(v))$is called 'Archimedean copula' generated from φ^{-1}, where $\varphi(.)$ is a generator of C.

The Archimedean copula functions can be grouped according to the generator $\varphi(t)$There are many different kinds of Archimedean copula functions, where each generator includes one γ parameter. For example, the generator of the Gumbel copula is as follows:

$$\varphi_{\gamma}(t) = (-lnt)^{\gamma} \tag{1}$$

Genest and MacKay (1986) showed the relation between the Kendall correlation coefficient ρ_{τ} and the generator of Archimedean copula functions, which could be used to determine the candidate copula family, which is as follows:

$$\rho_{\tau} = 1 + 4\int_0^1 \frac{\varphi(t)}{\varphi(t)} dt \tag{2}$$

An asymptotic measure of dependence, especially focusing on bivariate extreme values, is the tail dependence coefficient (Dias & Embrechts, 2004). Moreover, the tail dependence between X_1 and X_2, as one of the copula properties, is invariant under a strictly increasing transformation of X_1 and X_2. The lower (inferior) and upper (superior) tail dependence coefficients are defined as:

Formally, λ_U and λ_L are defined respectively as:

$$\lambda_U = \lim_{u \to 1} P\left(x_1 \geq F_1^{-1}(u) | x_2 \geq F_2^{-1}(u)\right) \tag{3}$$

$$\lambda_L = \lim_{u \to 0} P\left(x_1 \leq F_1^{-1}(u) | x_2 \leq F_2^{-1}(u)\right) \tag{4}$$

where $F_1^{-1}(u)$ and $F_2^{-1}(u)$ are the marginal quantile functions.

Archimedean Copula Families

In this paper, we consider three Archimedean families (Gumbel, Clayton and Frank). In addition, we use the survival copulas.

Gumbel copula

The Gumbel copula is an extreme value copula as well as an Archimedean one, which can capture a different sense of risk occurring during stress periods. It has the following form:

$$C_{Gumbel}(u_1, u_2) = exp\left(-\left[\left(-ln(u_1)\right)^{\theta} + \left(-ln(u_2)\right)^{\theta}\right]^{\theta^{-1}}\right) \tag{5}$$

here $\theta \geq 1$ expresses the degree of dependence. If $\theta = 1$, X_1 and are independent, then $\theta \to \infty$, where the degree of dependence approaches the one of the perfect dependences.

Clayton copula

The Clayton copula (Clayton, 1978) is also an asymmetric Archimedean copula but it exhibits a greater dependence in the lower tail than in the upper one. This copula is given by:

$$C_{Clayton}(u_1, u_2) = max\left\{\left(u_1^{-\theta} + u_2^{-\theta} - 1\right)^{-\theta^{-1}}, 0\right\} \tag{6}$$

where $\theta \in [-1, +\infty[\setminus \{0\}$, the lower tail dependence is $\lambda_{L_{Clayton}} = 2^{-\theta^{-1}}$.

Frank copula

The Frank copula (Frank, 1979) is a symmetric Archimedean copula. This copula is given by:

$$C_{Frank}\left(u_1,u_2\right)=-\theta^{-1}ln\left(1+\frac{\left(exp\left(-\theta u_1\right)-1\right)\left(exp\left(-\theta u_2\right)-1\right)}{exp\left(-\theta\right)-1}\right) \quad (7)$$

where $\theta\in\left[-\infty,+\infty\right[\setminus\{0\}$, the lower tail dependence is $\lambda_{L_{Frank}}=0$, and the upper tail dependence is $\lambda_{L_{Frank}}=0$.

ECONOMETRIC METHODOLOGY

Empirically, the crisis spread is measured in terms of the correlation between financial markets. The basic assumption is to check whether this spread changed or did not before and after the crisis. According to the survey of Forbes and Rigobon (2002), the co-movements between two markets are measured by their correlation coefficient. Therefore, the contagion is evident when the correlation during the crisis period rises significantly. Indeed, this increase suggests that there is a strengthening of links or of transmission mechanisms between the two concerned markets. However, if the increase is not statistically significant, we are witnessing only a phenomenon of interdependence and not of contagion.

Our tests about the contagion existence are carried out through a three-step process like that of Horta (2013), Horta et al. (2010), Jayech (2016), and Jayech and Zina (2012) who used this methodology to check if there was contagion during the subprime crisis.

First, we start by using the AR (p)-GARCH (1, 1) models to remove the autoregressive series and the conditional heteroskedastic effects. The returns are assumed to be generated by a stochastic process with time-varying volatility in an GARCH model. Actually, the conditional distributions change over time in an autocorrelated way and the conditional variance is an autoregressive process.

Second, the samples of filtered returns are divided into three periods: the pre-crisis, the 2007 financial subprime crisis, and the 2010 European sovereign debt crisis periods. The Gaussian distribution is used to estimate the copulas by a maximum likelihood and the AIC is again used to select the most adequate copula. The Archimedean copulas are estimated. The former copulas are the

Clayton, Gumbel and Frank. The measures λ_L, λ_U, ρ and τ are computed using the estimated copulas.

Finally, the bootstrap technique, referred to by Trivedi and Zimmer (2005) is used to calculate the variance-covariance *V* matrix for the estimated parameters and for the other remaining indicators associated with the copulas. The bootstrap procedure may be summarised as follows (Horta, 2013):

1. The computation with the IFM method can help us estimate the vector of marginal distribution parameters $\left(\hat{\beta}_1 \text{ and } \hat{\beta}_2\right)$ and that of the copula $(\hat{\theta})$. The vector of global estimated parameters is defined as $\widehat{\Omega} = \left(\hat{\beta}_1, \hat{\beta}_2, \hat{\theta}\right)^T$.
2. The definition of a sample of "observations" is obtained from the original data with a random draw by reposition.
3. The use of this sample is to re-estimate $\beta_1, \beta_2 \, et \, \theta,$ using the IFM method.
4. The replication of steps (2) and (3) *R* time, is the *r*-th re-estimation identified by:
5. $\widehat{\Omega}(\mathrm{r}) = \left(\hat{\beta}_1(r), \hat{\beta}_2(r), \hat{\theta}(r)\right)^T$
6. The parameters' standard deviations are the square roots of the main diagonal elements in the matrix *V,* estimated as follows:

$$\widehat{V} = R^{-1} \sum_{r=1}^{R} [(\widehat{\Omega}(r) - \widehat{\Omega})\left(\widehat{\Omega}(r) - \widehat{\Omega}\right)^T]$$

The output of the bootstrap results is used in the assessment of the hypothesis of contagion. The test may be expressed as follows:

Test 1: If there is contagion, dependence or co-movement between the markets is greater during the period of the crisis.

Using the Kendall's tau:

$$\begin{cases} H_0 : \Delta\tau = \tau_{Crisis}(x) - \tau_{pre-crisis}(x) \leq 0 \\ H_1 : \Delta\tau = \tau_{Crisis}(x) - \tau_{pre-crisis}(x) > 0 \end{cases} \quad (8)$$

Where x : China and $\tau_{crisis}(x)$ and $\tau_{pre-crisis}(x)$ respectively measure the correlation between the U.S. market index (or the Greek market index) and the index of market *x*, during the pre-crisis and the crisis periods.

Test 2: The second test evaluates whether the stock markets in the sample were mostly affected by the Subprime crisis or by the European sovereign debt crisis. Accordingly, if the stock markets data reflect the fact that the Subprime crisis was most contagious, the increase in dependence between the U.S. market (or the U.K. market) and each European market index should have been stronger than the increase in the dependence between the Greek market index and each European market index, from the calm to the respective crisis period.

Using the Kendall's tau:

$$\begin{cases} H_0 : \Delta\tau_{Supbrime,\,Debt}(x) = \left(\tau_{Crisis}^{Subprime}(x)\right) - \left(\tau_{Crisis}^{Debt}(x) - \tau_{Calm}^{Debt}(x)\right) \leq 0 \\ H_1 : \Delta\tau_{Supbrime,\,Debt}(x) = \left(\tau_{Crisis}^{Subprime}(x)\right) - \left(\tau_{Crisis}^{Debt}(x) - \tau_{Calm}^{Debt}(x)\right) \leq 0 \end{cases} \quad (15)$$

Where x : *China,* $\tau_{Crisis}^{Subprime}(x)$is the global dependence measure between the U.S. market index (or U.K. index) and the index of market x, for the Subprime crisis period, and $\tau_{Crisis}^{Debt}(x)$ refers to the global dependence measure between the Greek market index and the index of market x, for the European sovereign debt crisis period.

The superscripts "Subprime" and "Debt" refer to the Subprime crisis and the European sovereign debt crisis, respectively.

The results of the estimation process described in steps 1 to 4 and of the two contagion tests described above are presented in the next section.

DATA AND EMPIRICAL RESULTS

Data

In this paper, the equity index returns of the Standard & Poor's 500 (S&P 500) index, the FTSE 100, the Greece Stock Exchange Composite (GSEC) index and the Shanghai Stock Exchange Composite (SSEC) index during the 2007–2010 financial and debt crises are analyzed based on the methodology outlined above.

Daily logarithmic returns are calculated for equity markets of the U.S. (S&P 500 index), U.K. (FTSE 100), Greece (Greece Stock Exchange Composite Index) and China (Shanghai Composite Index) from 25 March 2005 to 16 April 2012 (representing a total of 1,842 observations for each index). For all indices, the returns are defined as the percentage logarithmic difference of the stock price,

i.e., $R_t = \left[Ln(I_t) - Ln(I_t)\right] * 100$ with I_t being the stock price at time *t*. All data come from Econstate.

We examine our data all over three sub-periods: the pre-crisis (from 25 March 2005 to 1 August 2007) comprising 614 observations for each index, the 2007 financial subprime crisis period (from 2 August 2007 to 8 December 2009) comprising 614 observations, and the 2010 European sovereign debt crisis (from 8 December 2009 to 16 April 2012) comprising 614 observations for each index.

The decomposition of the period (the stable period, the beginning of the subprime crisis period, and the sovereign debt crisis) is based on previous researchers. we have followed Horta (2013), Horta et al. (2010; 2014), and Jebran et al. (2017). In fact, Fry et al. (2010) claimed that "the bubble of the subprime crisis in the United States began in the mid-2007..." and Gallegati (2012) acknowledged that "... the bursting of the bubble of the American subprime crisis occurred in August, 2007..." (See also Longstaff [2010] to have a look at the chronological events in the 2006/2008 period). It is also noticeable that in August 2007, the BNP Paribas bank closed two common investment funds exposed to the subprime crisis, something that was considered by the markets as an important event.

Empirical Results

Results for marginal distribution models

First, we estimate the marginal models: models of type AR (p)-GARCH (1, 1) for each series of asset returns. The autoregressive parameter *p* is set at a maximum of 2. We set out the orders of a GARCH process of $p = 1$ and $q = 1$. The parameter estimates are reported in Table 1. As shown in Table 1, most of the coefficients in the equations of the variance means are statistically significant at a 5% level, which means that the ARCH has a very strong effect on all the countries.

Table 1
Parameter estimates for the marginal distribution models

	U.S. (std. error)	U.K. (std. error)	Greece (std. error)	China (std. error)
Panel A: Pre-crisis period (25 March 2005 to 1 August 2007; n = 614)				
	0.0002***	0.0003***	0.0007***	0.0024***
	(0.0003)	(0.0003)	(0.0004)	(0.0006)
AR (1)	–0.0351	–0.0235	0.1133**	–0.0173
	(0.0459)	(0.0428)	(0.0446)	(0.0384)
AR (2)	0.0132**	–0.0575	–0.0367	–0.0340
	(0.0417)	(0.0437)	(0.0413)	(0.0433)
	–0.8631	–0.6445	–0.5860	–0.0193
	(0.1734)	(0.1900)	(0.1707)	(0.0215)
	–0.0243	0.9352	0.1220**	0.0768**
	(0.0204)	(0.0190)	(0.0464)	(0.0183)
	0.9148**	0.1327	0.9374**	0.9968***
	(0.0173)	(0.0484)	(0.0181)	(0.0026)
L(1)	–0.2337	–0.1710	–0.1275	0.0377***
	(0.0276)	(0.0309)	(0.0273)	(0.0070)
Panel B: 2007 financial subprime crisis period (2 August 2007 to 8 December 2009; n = 614)				
	–0.0004	–0.0003	3.94e-005***	0.0004***
	(0.0006)	(0.0006)	(0.0006)	(0.0009)
AR (1)	–0.1431	–0.0917	0.0559**	0.0133**
	(0.0490)	(0.0473)	(0.0469)	(0.0427)
AR (2)	–0.0293	0.0051	0.0348**	–0.0022
	(0.0438)	(0.0420)	(0.0418)	(0.0442)
	–0.1409	–0.2272	–0.2858	–0.5508
	(0.0421)	(0.0568)	(0.1060)	(0.1237)
	0.1077**	0.9726	0.2319**	0.1079**
	(0.0254)	(0.0070)	(0.0450)	(0.0321)
	0.9829***	0.0860	0.9633**	0.9275**
	(0.0052)	(0.0275)	(0.0132)	(0.0162)
L(1)	–0.1256	–0.1343	–0.1068	–0.1227
	(0.0222)	(0.0202)	(0.0239)	(0.0229)
Panel C: 2010 European sovereign debt crisis period (9 December 2009 to 16 April 2012; n = 614)				
	0.0003***	–3.88e-005	–0.0016	–0.0005
	(0.0003)	(0.0004)	(0.0009)	(0.0005)
AR (1)	–0.0167	0.0232	–0.0098	–0.0173
	(0.0496)	(0.0471)	(0.0402)	(0.0417)
AR (2)	–0.0234	–0.0587	–0.0809	–0.0036
	(0.0427)	(0.0406)	(0.0437)	(0.0394)
	–0.4584	–0.3239	–0.3846	–2.5196
	(0.0693)	(0.0633)	(0.1889)	(1.2442)
	0.1284**	0.9644	0.1575**	–0.0115
	(0.0339)	(0.0072)	(0.0380)	(0.0480)
	0.9492***	0.0730	0.9492**	0.7130
	(0.0078)	(0.0368)	(0.0248)	(0.1417)
L(1)	–0.2180	–0.1974	–0.0419	–0.0875
	(0.0284)	(0.0251)	(0.0220)	(0.0402)

Note: *, **, *** mean significance at 10%, 5% and 1% level, respectively.

To stress the distinct markets' behaviour in the pre-crisis, the 2007 financial subprime crisis and 2010 European sovereign debt crisis periods, the series of conditional volatility for the U.S., U.K., Greek and Chinese indices are displayed in Figure 1. The trend of the conditional volatility of the filtered returns, for the three analysed periods, which has been obtained through the Hodrick-Prescott filter with a smoothing parameter 1,000,000, is shown in Figure 2. Using the tests of Ljung-Box-Pierce and Engle ARCH, we can confirm that the return series of the stock market indices show evidence of temporal dependence (Table 2).

Table 2
Ljung-Box test and ARCH of Engle's test for the return series

Series	Q(10)	Q(15)	Q(20)	Q^2(10)	Q^2(15)	Q^2(20)	LM(10)	LM(15)	LM(20)
US	50.520*	64.233*	91.058*	1568.8*	2215.4*	2750.3*	515.78*	596.97*	600.59*
UK	51.542*	54.737*	60.503*	1298.6*	1724.6*	2091.7*	453.86*	479.92*	517.86*
Greece	12.827*	29.584*	37.040*	542.45*	650.91*	743.58*	234.98*	238.52*	247.57*
China	14.276*	30.249*	41.165*	212.80*	280.71*	348.93*	118.10*	130.90*	140.92*

Notes: *Q*(.) are the Ljung-Box tests for returns and for squared returns. LM refers to the Engle (1982) Lagrange Multiplier test for the presence of ARCH effect. *The rejection of the null hypotheses of no autocorrelation, normality and homoscedasticity at the 5% levels of significance, respectively for statistical tests.

On average and in variance, the ARMA models are selected for the average return of each asset and then estimated by the maximum likelihood as well as by the GARCH models for the respective variances.

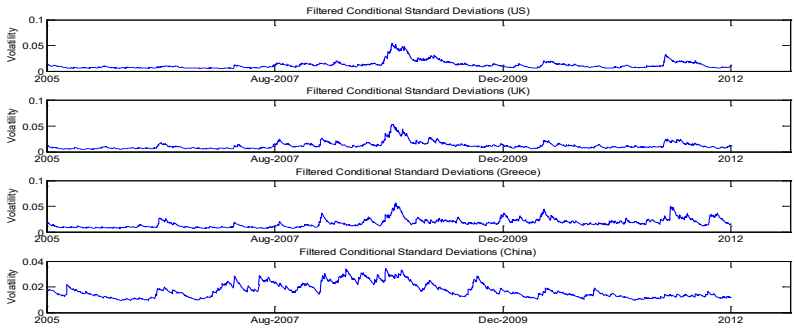

Figure 1. Filtered conditional standard deviations

Accordingly, the volatility rise of the filtered returns during the subprime crisis is obvious. Although the increase was initially progressive, there was a sudden rise in April 2008 when Fannie Mae and Freddie Mac were bailed out by the U.S. government. The peak of the stock market volatility was reached in November

2008, two months after the stock market peak, which coincided with the collapse of the Lehman Brothers on 15 September 2008. Finally, after applying the Hodrick Prescott, the conditional volatility series of the stock markets rose in the crisis period, which shows the turbulent environment in the international financial markets.

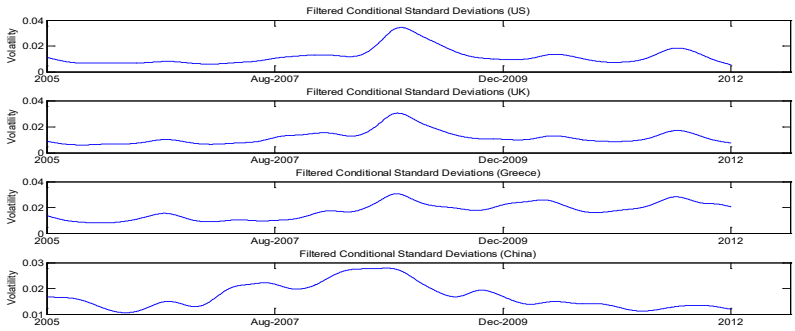

Figure 2. The trend of the conditional volatility of filtered returns

Based on these results, it is apparent that there is a strong impact of Euro zone crisis on the Chinese stock market. We shall further reconfirm this by examining the cross-market correlations and discuss it in the next subsection.

Copula estimates of dependence

Afterwards, we take into account the following market pairs, U.S./China, U.K./ China and U.K./China, and estimate the parameters of the copula model. For each pair, the estimated parameters of the best copula and the coefficient values of the high and low tail dependence are reported in Table 2.

Table 2 shows the results for the copula selected during the three periods of stability, subprime crisis and sovereign debt crisis, where the stock returns of two countries were associated with each period. We present the copula parameter (θ) and several measurements obtained from the estimated copula, that is Kendall's tau (τ) and the asymptotic tail dependence coefficients $\lambda_L$and λ_U (the standard deviations in brackets).

For the calm period, the best fit copula for the U.S./China pair is that of Frank, which suggests that the markets generally show symmetry of returns, whereas Clayton's copula is the best fit for the Greece/China pair. The main difference between these two models is that the Clayton's copula has an asymptotic dependence to the left which is not the case of Frank's copula.

During the subprime crisis, in Table 3, Gumbel's copula is the best fit for both the U.S./China and Greece/China pairs. Unlike Frank's copula, Gumbel's helps model the extreme dependencies. Actually, it captures the positive dependencies and has the characteristic to represent the risks whose dependence structure is more pronounced on the upper tail. Similar to the Clayton's copula, the Gumbel's does not permit a negative dependency, which means that it contradicts Clayton's since it includes a heavy tail dependence to the right and a relatively low tail dependence to the left ($\lambda_L = 0$).

Also, during the sovereign debt crisis, the Clayton and Gumbel's copula are the best fit for the U.S./China and Greece/China pairs, respectively. Clayton copula is also called the copula of Kimeldorf and Sampson (1989) or Cook and Johnson (1981). This copula has an asymptotic dependence to the left, which is not the case of the Frank's. For example, during the sovereign debt crisis, the tail dependencies to the left for the U.S./China and Greece/China pairs are represented by probabilities of 1.09% ($\lambda_L = 0.0109$) and 11.18% ($\lambda_U = 0.1118$), respectively.

Table 3
Selected copula models

Countries	Crisis period	Selected copula	Depend. parameter θ	Kendall τ	Tail λ_L	Tail λ_U	AIC
U.S./China	Pre-crisis	Frank	0.3951 (0.1550)	0.0438** (0.0171)	-	-	–1.1033
	Subprime financial crisis	Gumbel	1.0226** (0.0183)	0.0221** (0.0172)	-	0.0304** (0.0234)	1.2711
	European sovereign debt crisis	Clayton	0.1534** (0.0390)	0.0713** (0.0169)	0.0109** (0.0137)	-	0.0137
U.K./China	Pre-crisis	Clayton	0.0588** (0.0334)	0.0285** (0.0157)	7.56e-06*** (0.0016)	-	0.4356
	Subprime financial crisis	Gumbel	1.1131** (0.0227)	0.1016** (0.0184)	-	0.1360** (0.0237)	–13.691
	European sovereign debt crisis	Clayton	0.3412** (0.0466)	0.1457** (0.0170)	0.1312 (0.0357)	-	–39.914
Greece/China	Pre-crisis	Gumbel	1.1624** (0.0249)	0.1397** (0.0184)	-	0.1846** (0.0232)	–27.252
	European sovereign debt crisis	Gumbel	1.0905** (0.0241)	0.0830** (0.0180)	-	0.1118** (0.0236)	–9.2736

Note: **, *** mean significance at 5% and 1% levels, respectively.

Contagion identification

Results for assessment of contagion – Test 1

Contagion is defined as the significant change in the mechanisms of shock spread caused by one country or a group of countries. This change is in fact the same as generating new propagation channels, which leads to the existence of contagion in the sense of Forbes and Rigobon (2002). Hence, the existence of contagion is confirmed when the rise of Kendall's tau from the quiet period to the crisis one is statistically significant. Table 4 gives us the different indicated test results. In order to integrate the probability function for $\Delta\tau$, 1,000 subsamples have been conducted in the bootstrapping procedure (R = 1000). For each sub-sample, the values obtained are used to build a probability function. Then, this function is used to calculate the *p*-values assuming that the null hypothesis of the non-existence of contagion is ($H_0 : \Delta\tau \leq 0$). The *p*-values are obtained in a one-sided test, which reflects the left area of the probability of $\Delta\tau = 0$.

Table 4
Contagion test (Test 1)

Countries		*p*-value	Conclusion
2007 Subprime financial crisis			
U.S./China	–0.0217	0.8020	Undetected contagion, only interdependence
U.K./China	0.0731***	0.0010	Detected contagion
2010 European sovereign debt crisis			
U.S./China	0.0492**	0.0350	Detected contagion
U.K./China	0.0441**	0.0390	Detected contagion
Greece/China	–0.0567	0.9880	Undetected contagion, only interdependence

Note: **, *** mean significance at 5% and 1% levels, respectively.

The results show that during the subprime crisis there was no contagion between the U.S. stock market (S&P 500) and the Chinese one (SSEC). This conclusion has already been confirmed by several other studies (Hemche et al., 2016; Luchtenberg & Vu, 2015; Morales & Andreosso-O'Callaghan, 2012). Our results are also consistent with those of Bianconi et al. (2013) who reported that the financial stress effect of the U.S. on the Chinese stock market is insignificant. In addition, Da Fonseca and Ignatieva (2018) provided evidence that the increase in the correlation between the two markets was weak during this crisis. This result is consistent with the fact that the Chinese stock market fell by only 13%, compared to a 39% drop in the U.S. market during the financial crisis (Zouhair et al., 2014). The absence of this contagion effect could be explained by the low China's financial integration into the global

financial system. Despite the importance of foreign direct investment it attracts, its financial market remains relatively closed to foreign investors. The dynamics of the stock market does not reflect that of the Chinese economy.

Not only has the narrowness of its market spared the direct effects of the shocks that have affected Western stock markets, but China has also played a role in rescuing large international financial institutions. Thanks to the Chinese sovereign funds, considered as long-term public investment, several American short-of-cash banks and companies have been recapitalised. According to Morgan Stanley (2008), the China Investment Corporation (CIC) attracted attention for its stake in the American companies: Morgan Stanley (USD5 billion), Blackstone (USD3 billion), JC Flowers (USD3 billion), Reserve Primary Fund (USD5.4 billion), JPMorgan Prime Money Market Fund (USD2.3 billion), Invesco Aim Liquid Assets Portfolio (USD2.1 billion), and DWS Money Market Trust (USD1.5 billion).

Thus, the Chinese sovereign wealth funds and those of other emerging countries have contributed to strengthening the global banking system and confidence in the entire international financial system. Nevertheless, these rescue operations have been very costly, especially after the bankruptcy of Lehman Brothers. Accordingly, the CIC lost 60% of the value of investment in Blackstone and 26% of that of Morgan Stanley. These losses could largely explain what happened during the crisis of the sovereign debt.

In fact, during this latest crisis our empirical results show that the American and British stock markets had a negative effect on the Chinese stock market. Our results indicate that the correlation between the U.S./China and the U.K./China pairs increased during the crisis in the Euro area, which implies that the benefits of international portfolio diversification has declined significantly after this crisis. Ahmad et al. (2013) reported that China was among the countries mostly affected by the contagion impact during the period of the crisis of the Euro zone.

The crisis of sovereign debt in the Euro zone can prove to be a snare to lead China to bankruptcy. During this crisis, the contagion has not transmitted directly from the Greek market but across the American and British market, where China is much more present through the participation of sovereign wealth funds in several banks and businesses, or also through its massive purchases of sovereign bonds of these countries. Actually, since 2008, China has become the largest foreign creditor of the U.S. government.

The presence of financial contagion for the pairs (U.K./China, U.S./ China and U.K./China) means that the sovereign debt crisis and that of the subprime are transmitted via temporary channels. In this case, one can talk about pure (Masson, 1999) or shift contagion (Forbes & Rigobon, 2000). The mentioned authors predict that the investors' behaviour can bring about a change in the propagation channels during the crisis period and thus an increase of the links between financial markets. This type of mechanism is at the heart of the crisis contingent theories (Forbes & Rigobon, 2000). These theories mean that the transmission mechanism during the crisis (or just after) is fundamentally different from the one which existed before the crisis. The latter causes a structural change in such a way that the shocks are spread through a channel which does not exist in the periods of financial stability.

Tests of contagion intensity difference of the 2007 subprime financial crisis and the 2010 European sovereign debt crisis – Test 2

The results of Test 2 are shown in Table 5. Based on Test 2, proposed by Horta (2013), we have found that the subprime crisis was more contagious than the sovereign debt for Chinese economy. The null hypothesis of equal contagion intensity has been rejected in all cases with a 1% significance degree. This test allows identifying only the most contagious crisis, taking into account the countries originating from the crisis. Also, this test has assessed whether the stock markets of the sample were more affected by the subprime crisis (with the U.S. originating from the crisis) or by the European sovereign debt crisis (with Greece being the source country of the crisis).

Table 5
Tests of intensity difference of subprime and European debt crisis (Test 2)

$\Delta\tau_{Subprime-Debt}$ (i)	Value	Conclusion
$\Delta\tau_{Subprime}$ (US/China) – $\Delta\tau_{Debt}$ (Greece/China)	0.0350	Subprime crisis more intense than debt crisis
$\Delta\tau_{Subprime}$ (UK/China) – $\Delta\tau_{Debt}$ (Greece/China)	0.1298	Subprime crisis more intense than debt crisis

A major problem in the development of a financial contagion test is that there is little consensus in the literature related to the exact way of identifying this serious phenomenon. Since this is still an open debate in economics, inspired by Test 2—suggested by Horta (2013) —we have developed another test that can identify well the intensity of crises between two pairs of financial markets without considering the countries originating from the crisis. For example, for the U.S./ China pair we are going to compare whether it was mostly affected by the U.S. crisis or by the European one and we are going to apply this test for other pairs to get significant results.

Using the Kendall's tau:

$$\begin{cases} H_0: \Delta\tau_{Supprime,\,Debt}\left(\frac{\text{US}}{\text{China}}\right) = \left(\tau^{Subprime}_{Crisis}\left(\frac{\text{US}}{\text{China}}\right) - \tau^{Subprime}_{Calm}\left(\frac{\text{US}}{\text{China}}\right)\right) - \left(\tau^{Debt}_{Crisis}\left(\frac{\text{US}}{\text{China}}\right) - \tau^{Debt}_{Calm}\left(\frac{\text{US}}{\text{China}}\right)\right) < 0 \\ H_1: \Delta\tau_{Supprime,\,Debt}(\text{US/China}) = \left(\tau^{Subprime}_{Crisis}(\text{US/China}) - \tau^{Subprime}_{Calm}(\text{US/China})\right) - \left(\tau^{Debt}_{Crisis}(\text{US/China}) - \tau^{Debt}_{Calm}(\text{US/China})\right) > 1 \end{cases}$$

Where $\tau^{Subprime}_{Crisis}$ is the global dependence measure between the Standard & Poor's 500 (S&P 500) index and the Shanghai Stock Exchange Composite (SSEC) index, for the Subprime crisis period, and $\tau^{Debt}_{Crisis}(\text{US/China})$ refers to the global dependence measure between the S&P 500 and the SSEC, for the European sovereign debt crisis period.

On the one hand, it is expected that the results of our test indicate that the crisis in the euro zone was heavier than that of the subprime for the S&P 500/SSES stock market. The negative statistics values of Table 6 confirm these results. On the other hand, if we exclude the case of the U.S./China pair, we note that the tests carried out in this section prove that the Greek crisis was not as important as the subprime crisis, in terms of contagion, for the U.K./China pair (Table 6). The securities regulators could therefore have fewer worries and take less restrictive measures to contain the contagion in the stock markets facing a debt crisis. It is emphasised that in the context of the subprime crisis, the securities regulators took some measures to contain the signs of contagion in stock markets (Horta, 2013).

Table 6

Tests of intensity difference of subprime and European debt crisis (Our test)

$\Delta\tau_{Subprime-Debt}$(i)	Value	Conclusion
$\Delta\tau_{Subprime}$ (U.S./China) – $\Delta\tau_{Debt}$ (U.S./China)	–0.0709	Debt crisis more intense than Subprime crisis
$\Delta\tau_{Subprime}$ (U.K./China) – $\Delta\tau_{Debt}$ (U.K./China)	0.0290	Subprime crisis more intense than Debt crisis

According to our test, we have demonstrated that the intensity of the sovereign debt crisis is greater than that of the subprime crisis for the U.S./China pair, contrary to the U.K./China pair. This result is in harmony with the reality of the financial situation in China. We can conclude that our test allows identifying precisely the intensity of contagion between the crises—not the case for the test of Horta et al. (2014). This shows the advantage of our contribution.

CONCLUSION

In this paper, we have analysed the contagion effect of the American, the British and Greek stock markets on the Chinese stock market for both the U.S. and European financial crises between 2007 and 2010, using a new modeling approach. Therefore, we have applied the copula theory, in particularly the Archimedean copulas. We have followed the methodology of Horta et al. (2010; 2014) which underlines the importance of modelling financial interdependence in order to test the stability of the propagation mechanisms.

Using the Archimedean copula, we have performed two contagion tests. The first is to check if there is contagion and if the dependence between markets is more intense during the crisis. The second test is a comparison between the contagion intensity during the subprime and the sovereign debt crises. The results of the first test show the transmission of price shocks through pure contagion from both FTSE 100 to the SSEC during the subprime crisis and from the S&P 500 to SSEC index during the sovereign debt crisis, which means that the transmission occurred through temporary channels.

Unlike the S&P 500, where we have detected a price shock transmission through the S&P 500 index interdependence link to the SSEC during the subprime crisis. This indicates that there are permanent channels between the S&P 500 and the SSEC. The same interpretation has been made for the GSEC during the sovereign debt crisis. It should be noted that the measurement of contagion risk and its prediction will be a major asset for the management of the systemic risk. In other words, controlling this risk will help central banks implement more effective intervention policies in the case of market stress. The second test shows that the contagion effects of the 2007 subprime crisis are much more intense than the ones caused by the sovereign debt crisis.

The results of this research have important implications in terms of economic policies. The latter show a vital interest in the decisions of the monetary authorities. They affect the types of measures to be implemented so as to prevent contagion and reduce vulnerability to external shocks. If crises are largely transmitted through temporary channels that exist only during the crisis, as is the case of contagion, the authorities find it profitable to adopt short term curative strategies. However, these strategies are more transitional as they are applied only during crisis periods, such as the case of the application of capital control. Conversely, if the crises are constantly transmitted through permanent channels which exist both during the period of stability and that of the crisis, these short-term strategies may not be enough to always prevent the crises. Hence, global solutions should be referred by strengthening international coordination,

particularly, to reduce, for example, the excessive fluctuations of the exchange and interest rates.

The results of this study may be interesting for international investors and portfolio managers since the high correlation coefficients during the crisis may change their expectations, cause the concerned economy to change from a good balance to a poor one, lead to portfolio rebalancing and reduce their earnings. Otherwise, these changes in an information asymmetry context can be changed and then transfer the crisis to other markets.

Finally, we can conclude that contagion episodes mainly occur during periods of financial crisis (Liu et al., 2019). In other words, in light of the calm and turbulence of the global and emerging stock markets during the recent years due to domestic, macroeconomic and political events as well as financial crisis, this urged a deeper investigation of the nature of the relationship between stock markets in different economies, especially after major changes. Moreover, diverse possible transmission mechanisms may be in place across different stock markets, particularly during the periods of financial crises. For instance, according to Dornbusch et al. (2000a), trade links can play an important role in the interconnexion between different economies. Considering volatility spillover, trade links can be seen as the respective macroeconomic transmission channel. Gómez-Puig and Sosvilla-Rivero (2016) found that contagion between equity markets is explained by inflation and information asymmetry between investors in the global financial crisis and the Euro crisis. It shows that irrational investors' behaviour could lead to financial panics in crises and to volatility spillover increases in excess of macroeconomic fundamentals. This study can be further developed in future research.

ACKNOWLEDGEMENTS

The authors would like to thank the editors and two anonymous reviewers for helpful comments on earlier versions of this paper that enhanced its quality.

NOTES

1. In 2012, the Shanghai Stock Exchange is the largest stock market in the People's Republic of China, compared to the stock markets of Hong Kong and Shenzhen, and is 6th in the world in terms of capitalisation.
2. http://go.worldbank.org/JIBDRK3YC0

REFERENCES

Abdennadher, E., & Helara, S. (2021). Volatility spillovers and contagion between stock markets. *International Journal of Business*, *4*(1), 1–8.

Abdennadher, E., & Hellara, S. (2018). Causality and contagion in emerging stock markets. *Borsa Istanbul Review*, *18*(4), 300–311. https://doi.org/10.1016/j.bir.2018.07.001

Agénor, P.-R., & Aizenman, J. (1998). Contagion and volatility with imperfect credit markets. *Staff Papers*, *45*(2), 207–235. https://doi.org/10.2307/3867389

Ahmad, W., Sehgal, S., & Bhanumurthy, N. R. (2013). Eurozone crisis and BRIICKS stock markets: Contagion or market interdependence? *Economic Modelling*, *33*, 209–225. https://doi.org/10.1016/j.econmod.2013.04.009

Aloui, R., Aïssa, M. S. Ben, & Nguyen, D. K. (2011). Global financial crisis, extreme interdependences, and contagion effects: The role of economic structure? *Journal of Banking & Finance*, *35*(1), 130–141. https://doi.org/10.1016/j.jbankfin.2010.07.021

Aloui, R., Hammoudeh, S., & Nguyen, D. K. (2013). A time-varying copula approach to oil and stock market dependence: The case of transition economies. *Energy Economics*, *39*, 208–221. https://doi.org/10.1016/j.eneco.2013.04.012

Arghyrou, M. G., & Kontonikas, A. (2012). The EMU sovereign-debt crisis: Fundamentals, expectations and contagion. *Journal of International Financial Markets, Institutions and Money*, *22*(4), 658–677. https://doi.org/10.1016/j.intfin.2012.03.003

Baig, T., & Goldfajn, I. (1999). Financial market contagion in the Asian crisis. *IMF Staff Papers*, *46*(2), 167–195. https://doi.org/10.2139/ssrn.142285

Banerjee, A. V. (1992). A simple model of herd behavior. *The Quarterly Journal of Economics*, *107*(3), 797–817. https://doi.org/10.2307/2118364

Baur, D. G. (2013). The structure and degree of dependence: A quantile regression approach. *Journal of Banking & Finance*, *37*(3), 786–798. https://doi.org/10.1016/j.jbankfin.2012.10.015

Beirne, J., & Fratzscher, M. (2013). The pricing of sovereign risk and contagion during the European sovereign debt crisis. *Journal of International Money and Finance*, *34*, 60–82. https://doi.org/10.1016/j.jimonfin.2012.11.004

Bekaert, G., Harvey, C. R., Lundblad, C. T., & Siegel, S. (2011). What segments equity markets? *The Review of Financial Studies*, *24*(12), 3841–3890. https://doi.org/10.1093/rfs/hhr082

Bianconi, M., Yoshino, J. A., & De Sousa, M. O. M. (2013). BRIC and the US financial crisis: An empirical investigation of stock and bond markets. *Emerging Markets Review*, *14*, 76–109. https://doi.org/10.1016/j.ememar.2012.11.002

Billio, M., & Pelizzon, L. (2003). Volatility and shocks spillover before and after EMU in European stock markets. *Journal of Multinational Financial Management*, *13*(4–5), 323–340. https://doi.org/10.1016/S1042-444X(03)00014-8

Calvo, G. A., & Mendoza, E. G. (2000). Rational contagion and the globalization of securities markets. *Journal of International Economics*, *51*(1), 79–113. https://doi.org/10.1016/S0022-1996(99)00038-0

Caramazza, F., Ricci, L., & Salgado, R. (2004). International financial contagion in currency crises. *Journal of International Money and Finance*, *23*(1), 51–70. https://doi.org/10.1016/j.jimonfin.2003.10.001

Changqing, L., Chi, X., Cong, Y., & Yan, X. (2015). Measuring financial market risk contagion using dynamic MRS-Copula models: The case of Chinese and other international stock markets. *Economic Modelling*, *51*, 657–671. https://doi.org/10.1016/j.econmod.2015.09.021

Chen, C., Iyengar, G., & Moallemi, C. C. (2014). *Asset-based contagion models for systemic risk*. Working paper, Colombia Business School.

Cheung, W., Fung, S., & Tsai, S.-C. (2010). Global capital market interdependence and spillover effect of credit risk: evidence from the 2007–2009 global financial crisis. *Applied Financial Economics*, *20*(1–2), 85–103. https://doi.org/10.1080/09603100903262962

Chudik, A., & Fratzscher, M. (2011). Identifying the global transmission of the 2007–2009 financial crisis in a GVAR model. *European Economic Review*, *55*(3), 325–339. https://doi.org/10.1016/j.euroecorev.2010.12.003

Claeys, P., & Vašíček, B. (2014). Measuring bilateral spillover and testing contagion on sovereign bond markets in Europe. *Journal of Banking & Finance*, *46*, 151–165. https://doi.org/10.1016/j.jbankfin.2014.05.011

Clayton, D. G. (1978). A model for association in bivariate life tables and its application in epidemiological studies of familial tendency in chronic disease incidence. *Biometrika*, *65*(1), 141–151. https://doi.org/10.1093/biomet/65.1.141

Cook, R. D., & Johnson, M. E. (1981). A family of distributions for modelling non-elliptically symmetric multivariate data. *Journal of the Royal Statistical Society: Series B (Methodological)*, *43*(2), 210–218. https://doi.org/10.1111/j.2517-6161.1981.tb01173.x

Da Fonseca, J., & Ignatieva, K. (2018). Volatility spillovers and connectedness among credit default swap sector indexes. *Applied Economics*, *50*(36), 3923–3936. https://doi.org/10.1080/00036846.2018.1430344

Dias, A., & Embrechts, P. (2004). *Dynamic copula models for multivariate high-frequency data in finance.* Manuscript, ETH Zurich, 81.

Dimitriou, D., Kenourgios, D., & Simos, T. (2013). Global financial crisis and emerging stock market contagion: A multivariate FIAPARCH–DCC approach. *International Review of Financial Analysis*, *30*, 46–56. https://doi.org/10.1016/j.irfa.2013.05.008

Dornbusch, R., Park, Y. C., & Claessens, S. (2000a). Contagion: How it spreads and how it can be stopped. *World Bank Research Observer*, *15*(2), 177–197. https://doi.org/10.1093/wbro/15.2.177

Dornbusch, R., Park, Y. C., & Claessens, S. (2000b). Contagion: Understanding how it spreads. *The World Bank Research Observer*, *15*(2), 177–197. https://doi.org/10.1093/wbro/15.2.177

Dungey, M., & Gajurel, D. (2014). Equity market contagion during the global financial crisis: Evidence from the world's eight largest economies. *Economic Systems*, *38*(2), 161–177. https://doi.org/10.1016/j.ecosys.2013.10.003

Dungey, M., Fry, R., González-Hermosillo, B., & Martin, V. L. (2005). Empirical modelling of contagion: a review of methodologies. *Quantitative Finance*, *5*(1), 9–24. https://doi.org/10.1080/14697680500142045

Eichengreen, B., Rose, A. K., & Wyplosz, C. (1996). *Contagious currency crises*. Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w5681

Elkhaldi, A., & Abelfatteh, Y. B. (2014). Testing herding effects on financial assets pricing: The case of the Tunisian stock market. *French Journal of Scientific and Educational Research*, *2*(12), 180–192.

Elkhaldi, A., Chebbi, T., & Naoui, K. (2014). Measuring contagious effects on Euro area debt crisis using daily CDS spreads changes. *Procedia Economics and Finance*, *13*, 14–29. https://doi.org/10.1016/S2212-5671(14)00427-4

Elkhaldi, Abderrazek, & Daadaa, W. (2015). Economic determinants of corporate capital structure: The case of Tunisian firms. *International Journal of Economics and Finance*, *7*(9), 193–199. https://doi.org/10.9734/BJEMT/2014/8973

Engle, R. F. (1982). Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. *Econometrica, 50*, 987–1007.

Forbes, K. J., & Rigobon, R. (2002). No contagion, only interdependence: measuring stock market comovements. *The Journal of Finance*, *57*(5), 2223–2261. https://doi.org/10.1111/0022-1082.00494

Forbes, K., & Rigobon, R. (2000). *Contagion in Latin America: Definitions, measurement, and policy implications*. Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w7885

Frank, M. J. (1979). On the simultaneous associativity of F(x, y) and x + y − F(x, y). *Aequationes Mathematicae*, *19*(1), 194–226. https://doi.org/10.1007/BF02189866

Fry, R., Martin, V. L., & Tang, C. (2010). A new class of tests of contagion with applications. *Journal of Business & Economic Statistics*, *28*(3), 423–437. https://doi.org/10.1198/jbes.2010.06060

Gallegati, M. (2012). A wavelet-based approach to test for financial market contagion. *Computational Statistics & Data Analysis*, *56*(11), 3491–3497. https://doi.org/10.1016/j.csda.2010.11.003

Genest, C., & MacKay, J. (1986). The joy of copulas: Bivariate distributions with uniform marginals. *The American Statistician*, *40*(4), 280–283. https://doi.org/10.1080/00031305.1986.10475414

Gerlach, S., & Smets, F. (1995). Contagious speculative attacks. *European Journal of Political Economy*, *11*(1), 45–63. https://doi.org/10.1016/0176-2680(94)00055-O

Ghorbel, A., & Trabelsi, A. (2009). Measure of financial risk using conditional extreme value copulas with EVT margins. *Journal of Risk*, *11*(4), 51. https://doi.org/10.21314/JOR.2009.196

Glick, R., & Hutchison, M. (2013). China's financial linkages with Asia and the global financial crisis. *Journal of International Money and Finance*, *39*, 186–206. https://doi.org/10.1016/j.jimonfin.2013.06.025

Glick, R., & Rose, A. K. (1999). Contagion and trade: why are currency crises regional? *Journal of International Money and Finance*, *18*(4), 603–617. https://doi.org/10.1016/S0261-5606(99)00023-6

Goldstein, I., & Pauzner, A. (2004). Contagion of self-fulfilling financial crises due to diversification of investment portfolios. *Journal of Economic Theory*, *119*(1), 151–183. https://doi.org/10.1016/j.jet.2004.03.004

Gómez-Puig, M., & Sosvilla-Rivero, S. (2016). Causes and hazards of the euro area sovereign debt crisis: Pure and fundamentals-based contagion. *Economic Modelling*, *56,* 133–147. https://doi.org/10.1016/j.econmod.2016.03.017

Gorea, D., & Radev, D. (2014). The euro area sovereign debt crisis: Can contagion spread from the periphery to the core? *International Review of Economics & Finance*, *30*, 78–100. https://doi.org/10.1016/j.iref.2013.10.003

Haile, F., & Pozo, S. (2008). Currency crisis contagion and the identification of transmission channels. *International Review of Economics & Finance*, *17*(4), 572–588. https://doi.org/10.1016/j.iref.2007.05.005

Hamao, Y., Masulis, R. W., & Ng, V. (1990). Correlations in price changes and volatility across international stock markets. *The Review of Financial Studies*, *3*(2), 281–307. https://doi.org/10.1093/rfs/3.2.281

Hemche, O., Jawadi, F., Maliki, S. B., & Cheffou, A. I. (2016). On the study of contagion in the context of the subprime crisis: A dynamic conditional correlation–multivariate GARCH approach. *Economic Modelling*, *52*, 292–299. https://doi.org/10.1016/j.econmod.2014.09.004

Horta, P. (2013). Contagion effects in the European NYSE Euronext stock markets in the context of the 2010 sovereign debt crisis. *Investment Management and Financial Innovations*, *10*(4), 114–124.

Horta, P., Lagoa, S., & Martins, L. (2014). The impact of the 2008 and 2010 financial crises on the Hurst exponents of international stock markets: Implications for efficiency and contagion. *International Review of Financial Analysis*, *35*, 140–153. https://doi.org/10.1016/j.irfa.2014.08.002

Horta, P., Mendes, C., & Vieira, I. (2010). Contagion effects of the subprime crisis in the European NYSE Euronext markets. *Portuguese Economic Journal*, *9*(2), 115–140. https://doi.org/10.1007/s10258-010-0056-6

Jayech, S. (2016). The contagion channels of July–August-2011 stock market crash: A DAG-copula based approach. *European Journal of Operational Research*, *249*(2), 631–646. https://doi.org/10.1016/j.ejor.2015.08.061

Jayech, S., & Zina, N. B. (2012). Measuring financial contagion in the stock markets using a copula approach. *International Journal of Data Analysis Techniques and Strategies*, *4*(2), 154–180. https://doi.org/10.1504/IJDATS.2012.046790

Jeanne, O. (1997). Are currency crises self-fulfilling? A test. *Journal of International Economics*, *43*(3–4), 263–286.

Jebran, K., Chen, S., Ullah, I., & Mirza, S. S. (2017). Does volatility spillover among stock markets varies from normal to turbulent periods? Evidence from emerging markets of Asia. *The Journal of Finance and Data Science*, *3*(1–4), 20–30. https://doi.org/10.1016/j.jfds.2017.06.001

Jin, X., & An, X. (2016). Global financial crisis and emerging stock market contagion: A volatility impulse response function approach. *Research in International Business and Finance*, *36*, 179–195. https://doi.org/10.1016/j.ribaf.2015.09.019

Joe, H. (1997). *Multivariate models and multivariate dependence concepts*. Chapman and Hall/CRC. https://doi.org/10.1201/b13150

Jung, R. C., & Maderitsch, R. (2014). Structural breaks in volatility spillovers between international financial markets: Contagion or mere interdependence? *Journal of Banking & Finance*, *47*, 331–342. https://doi.org/10.1016/j.jbankfin.2013.12.023

Kaminsky, G. L., & Reinhart, C. M. (1999). The twin crises: the causes of banking and balance-of-payments problems. *American Economic Review*, *89*(3), 473–500. https://doi.org/10.1257/aer.89.3.473

Kenourgios, D. (2014). On financial contagion and implied market volatility. *International Review of Financial Analysis*, *34*, 21–30. https://doi.org/10.1016/j.irfa.2014.05.001

Kenourgios, D., & Dimitriou, D. (2015). Contagion of the Global Financial Crisis and the real economy: A regional analysis. *Economic Modelling*, *44*, 283–293. https://doi.org/10.1016/j.econmod.2014.10.048

Kenourgios, D., & Padhi, P. (2012). Emerging markets and financial crises: regional, global or isolated shocks? *Journal of Multinational Financial Management*, *22*(1–2), 24–38. https://doi.org/10.1016/j.mulfin.2012.01.002

Kenourgios, D., Christopoulos, A. G., & Dimitriou, D. I. (2013). Asset markets contagion during the global financial crisis. *Multinational Finance Journal*, *17*(1/2), 49–76. https://doi.org/10.17578/17-1/2-2

Kenourgios, D., Samitas, A., & Paltalidis, N. (2011). Financial crises and stock market contagion in a multivariate time-varying asymmetric framework. *Journal of International Financial Markets, Institutions and Money*, *21*(1), 92–106. https://doi.org/10.1016/j.intfin.2010.08.005

Kim, W., & Wei, S.-J. (2002). Foreign portfolio investors before and during a crisis. *Journal of International Economics*, *56*(1), 77–96. https://doi.org/10.1016/S0022-1996(01)00109-X

Kim, Y., Li, H., & Li, S. (2014). Corporate social responsibility and stock price crash risk. *Journal of Banking & Finance*, *43*, 1–13. https://doi.org/10.1016/j.jbankfin.2014.02.013

Kimeldorf, G., & Sampson, A. R. (1989). A framework for positive dependence. *Annals of the Institute of Statistical Mathematics*, *41*(1), 31–45.

Lee, W. S., & Lee, H. S. (2021). Asymmetric volatility transmission across Northeast Asian stock markets. *Borsa Istanbul Review,* 22(2), 341–351 . https://doi.org/10.1016/j.bir.2021.06.004

Liu, Z., Zhou, Y., & Zhou, Z. (2019). International financial contagion during the subprime crisis: Evidence from UK financial markets. In I. Venezia (Ed.), *Behavioral finance: The coming of age* (pp. 245–284). World Scientific. https://doi.org/10.1142/9789813279469_0008

Longstaff, F. A. (2010). The subprime credit crisis and contagion in financial markets. *Journal of Financial Economics*, *97*(3), 436–450. https://doi.org/10.1016/j.jfineco.2010.01.002

Luchtenberg, K. F., & Vu, Q. V. (2015). The 2008 financial crisis: Stock market contagion and its determinants. *Research in International Business and Finance*, *33*, 178–203. https://doi.org/10.1016/j.ribaf.2014.09.007

Masson, M. P. R. (1998). *Contagion: Monsoonal effects, spillovers, and jumps between multiple equilibria*. International Monetary Fund. https://doi.org/10.5089/9781451856224.001

Masson, P. (1999). Contagion: Macroeconomic models with multiple equilibria. *Journal of International Money and Finance*, *18*(4), 587–602. https://doi.org/10.1016/S0261-5606(99)00016-9

Metiu, N. (2012). Sovereign risk contagion in the Eurozone. *Economics Letters*, *117*(1), 35–38. https://doi.org/10.1016/j.econlet.2012.04.074

Morales, L., & Andreosso-O'Callaghan, B. (2012). The current global financial crisis: Do Asian stock markets show contagion or interdependence effects? *Journal of Asian Economics*, *23*(6), 616–626. https://doi.org/10.1016/j.asieco.2012.09.002

Morgan Stanley (2008). Annual report on form 10-K. https://www.morganstanley.com/about-us-ir/shareholder/10k113008/10k1108.pdf

Nelsen, C. J., Murtaugh, M. P., & Faaberg, K. S. (1999). Porcine reproductive and respiratory syndrome virus comparison: divergent evolution on two continents. *Journal of Virology*, *73*(1), 270–280. https://doi.org/10.1128/JVI.73.1.270-280.1999

Pais, A., & Stork, P. A. (2011). Contagion risk in the Australian banking and property sectors. *Journal of Banking & Finance*, *35*(3), 681–697. https://doi.org/10.1016/j.jbankfin.2010.05.012

Pham, C. D. (2020). Is estimating the Capital Asset Pricing Model using monthly and short-horizon data a good choice? *Heliyon*, *6*(7), e04339. https://doi.org/10.1016/j.heliyon.2020.e04339

Phuoc, L. T., Kim, K. S., & Su, Y. (2018). Reexamination of estimating beta coecient as a risk measure in CAPM. *The Journal of Asian Finance, Economics, and Business*, *5*(1), 11–16. https://doi.org/10.13106/jafeb.2018.vol5.no1.11

Pomfret, R. (2014). *The economies of central Asia*. Princeton University Press.

Pritsker, M. (2001). The channels for financial contagion. In S. Claessens, & K. J. Forbes (Eds.), *International financial contagion* (pp. 67–95). Springer. https://doi.org/10.1007/978-1-4757-3314-3_4

Rigobon, R. (1999). *On the measurement of the international propagation of shocks*. National Bureau of Economic Research Cambridge, Mass., USA. https://doi.org/10.3386/w7354

Samitas, A., & Tsakalos, I. (2013). How can a small country affect the European economy? The Greek contagion phenomenon. *Journal of International Financial Markets, Institutions and Money*, *25*, 18–32. https://doi.org/10.1016/j.intfin.2013.01.005

Serra, R. G., & Martelanc, R. (2013). Estimation of betas of stocks with low liquidity. *Brazilian Business Review*, *10*(1), 49–78. https://doi.org/10.15728/bbr.2013.10.1.3

Shen, P.-L., Li, W., Wang, X.-T., & Su, C.-W. (2015). Contagion effect of the European financial crisis on China's stock markets: Interdependence and pure contagion. *Economic Modelling*, *50*, 193–199. https://doi.org/10.1016/j.econmod.2015.06.017

Shiller, R. J. (1995). Conversation, information, and herd behavior. *The American Economic Review*, *85*(2), 181–185.

Trivedi, P. K., & Zimmer, D. M. (2005). *Copula modelling: An introduction for practitioners, foundations and trends.* Hanover, MA: Now Publishers.

Van Rijckeghem, C., & Weder, B. (2001). Sources of contagion: is it finance or trade? *Journal of International Economics*, *54*(2), 293–308. https://doi.org/10.1016/S0022-1996(00)00095-7

Wang, Y., Jodoin, P.-M., Porikli, F., Konrad, J., Benezeth, Y., & Ishwar, P. (2014). CDnet 2014: An expanded change detection benchmark dataset. *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops*, 387–394. https://doi.org/10.1109/CVPRW.2014.126

Wen, X., Wei, Y., & Huang, D. (2012). Measuring contagion between energy market and stock market during financial crisis: A copula approach. *Energy Economics*, *34*(5), 1435–1446. https://doi.org/10.1016/j.eneco.2012.06.021

Yamamoto, S. (2014). Transmission of US financial and trade shocks to Asian economies: Implications for spillover of the 2007–2009 US financial crisis. *The North American Journal of Economics and Finance*, *27*, 88–103. https://doi.org/10.1016/j.najef.2013.12.002

Ye, W., Liu, X., & Miao, B. (2012). Measuring the subprime crisis contagion: Evidence of change point analysis of copula functions. *European Journal of Operational Research*, *222*(1), 96–103. https://doi.org/10.1016/j.ejor.2012.04.004

Zouhair, M., Lanouar, C., & Ajmi, A. N. (2014). Contagion versus interdependence: The case of the BRIC countries during the subprime crises. In M. Arouri, S. Boubaker, & D. Nguyen (Eds.), *Emerging markets and the global economy* (pp. 555–582). Elsevier. https://doi.org/10.1016/B978-0-12-411549-1.00023-5