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ORIGINAL PAPER

Sovereign contagion risk measure across financial markets in the eurozone: a bivariate copulas and Markov Regime Switching ARMA based approaches

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Abstract

This paper analyzes sovereign risk contagion across financial markets in the eurozone during and after the European debt crisis. A particular focus is made on the causal impact of pre-Brexit and Covid-19 pandemic on the dependence between European markets. We use data set from 28 February 2008 to 11 March 2021 and combine copulas and MRS-ARMA techniques to measure dependence across financial markets and assessing asymmetric dependence structure and regime switching process. We develop a dynamic Kendall's tau correlation and provide evidence of time-varying dependence structure between several pairwise markets. The dependence structure shows a sharp rise on 23 June 2016, day of the referendum on Brexit. Results indicates that Covid-19 pandemic has intensified dependence and sovereign risk spillovers between sovereign CDS European markets. Significant time-varying characteristics of dynamic dependence structures suggests that fund managers and investors should consider in their investment strategies to manage systemic risk and high-risk investment. The identification of dependence structure regime between global financial markets would enhance response to major crises by investors and policy makers.

Keywords Pre-brexit · Covid-19 pandemic · Sovereign risk contagion · Copula's approach · Markov switching regime · ARMA models

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1 Introduction and related literature review

The transmission of uncertainty from one market, region, country to another remains an important field of research in light of major global economic, financial, geopolitical and public health crises.

This research represents an attempt to study the causal impact on the dependence structure between financial markets by major events or shocks such as, Brexit, Sovereign debt crisis, Subprime crisis, and Covid-19 pandemics.

Indeed, the announcement of withdraw of UK from the European Union and the transitional phase, namely pre-Brexit, would have a substantial effect on the linkages between European financial markets. Using data from 28 February 2008 to 11 March 2021, this work takes advantage of the announcement of UK withdraw from the EU and the subsequent transition process to test the impact on the dependence structure between European financial markets.

Undoubtedly, Brexit is a major event in the history of EU. Since its announcement, Brexit has urged individuals, businesses, and policy makers to anticipate possible scenarios including threats, opportunities, exit strategies. Brexit is, indeed, associated with a high degree of financial, economic risks and uncertainties that would substantially affect UK, EU markets. The impact of pre-Brexit on the dependence structure of EU markets has received little or no attention of the literature. This work constitutes an attempt to provide findings that carry important implications for the post-Brexit UK in transition and for European countries.

COVID-19 global pandemic exponential spread around the world has caused overwhelming challenges to global public health and left households and businesses counting economic losses. Since its eruption, this global pandemic has increased tremendously uncertainty and fear of human and economic losses. Moreover, it is not clear how full social and economic recovery would take place. The analysis of potential effects of this major pandemic on various economic and financial markets around the globe has received little or no attention from the literature. Our work attempts to shed lights on these fundamental aspects by measuring risk transmission and global market linkages.

The analysis of the European sovereign debt crisis of 2009, a major economic event of the recent years, has been the subject of increasing interest in the academic literature. The study of the dependence between eurozone financial markets and in particular the analysis of dependence among sovereign CDS markets represent both a theoretical and an empirical framework that capture sovereign default risk transmission among sovereign European CDS markets.

Sovereign Credit Derivative Swap (CDS) is a derivative instrument that allow investors to swap credit risk that a country may go into default or experience substantial difficulties. Sovereign CDS spreads express default sovereign risk. In this regard, high sovereign default risks are expressed by large sovereign CDS spreads.

Debt crisis has major adverse effects not only on political stability but also on and economic and financial stability but more importantly on individual welfare and social cohesion.

The Greek crisis spreads very quickly to Ireland, Spain, Italy and Portugal. As the turbulence spread over several euro-zone economies. Several reform programs and bailout plans have been proposed to rescue institutions and governments in particular for Greece (Fratzsher et al. 2016, Hryckiewicz 2014 and Kizys et al. 2016).

Nonetheless, linkages between financial markets have not received much attention as during the recent European debt crisis. Understanding the nature of linkages between markets and economies is fundamental for effective policy design and rational investment choices and it is not clear whether such model of uncertainty transmission exists or has been used.

Contagion is defined as the spread of a crisis from one market, region, or country to another. Because markets, regions or countries are interconnected, major events in one market region or country can impact others. Authors argue that contagion is characterized by an amplification and persistence of spillover effects (see Allen and Gale (2000), Dornbusch et al. (2000), Pericoli and Sbracia (2003) among others).

Potential effects of crisis transmission or contagion are measured based on historical data or information on existing relationships or linkages between financial markets. In assessing linkages between financial markets, authors distinguish between crisis period and tranquillity or calm period. In principle, during a crisis or stress period, transmission of uncertainty is supposed to increase in comparison to a calm or normal period. Links change depending upon the level of stress. Authors considers risk contagion is expressed by major co-movements and volatility spillovers (see, e.g., Sachs et al. (1996), Masson (1999a, b, c), Dornbusch et al. (2000), Pericoli and Sbracia (2003) and Dungey et al. (2006)).

One might argue that analysing the degree of the co-movement between financial markets during crisis periods, relative to that in calm periods may demonstrate the normal interdependence between financial markets and economies. Distinction is made between contagion and interdependence. Forbes and Rigobon (2002) define contagion as a significant increase in the cross-market linkages during a crisis or a common shock after controlling for fundamentals. Prior to Forbes and Rigobon (2002), authors chiefly address interdependence and not financial contagion. Since the publication of Forbes and Rigobon (2002), financial contagion has been examined mainly around the notion of "correlation breakdown". Financial contagion could be internal ,i.e., cross-markets but also global ,i.e., cross-borders. External shocks may affect any asset market in an economy, and then spread to asset markets in other countries as well. Internal shocks may spread out by inter-linkages to other domestic asset markets. If a crisis strikes a given financial market around the globe, negative shocks are transmitted from the source to other financial markets.

In the case of the European debt crisis, sovereign CDS were initially unaffected but as the crisis evolves the effect spread out to other financial markets. Most of the research studies financial contagion in the context of equity markets (Fry-McKibbin et al., 2021). Few existing empirical works focuses on contagion effect between sovereign CDS and commodity markets during a sovereign debt crisis. Research on sovereign CDS markets, analyses co-movement of sovereign CDS with other assets, mainly stocks and bonds. More recent studies analyse the development of correlations between commodities and financial assets in the aftermath of the global financial crisis (Sun et al., 2020). Authors focus more on contagion effect

between commodity and other financial markets (see Sharpe (1964), Grubel and Fadner (1971), King and Wadhwani (1990), Engle et al. (1990), Bekaert and Hodrick (1992), and later from Forbes and Rigobon (2002), Barberis et al. (2005), Hwang et al. (2013), Aloui and Hkiri (2014), Alotaibi and Mishra (2015), Ji et al. (2018a, b, c), Chen et al. (2020)).

Most authors have mainly focused on the transmission mechanism of sovereign risk. However, there is absence of consensus on the transmission pattern among the European countries, see Louzis (2015), Alter and Beyer (2014), De Bruyckere et al. (2013), Alter and Schuler (2012), Barth et al. (2012), Arezki et al. (2011), Caceres et al. (2010). For example, Brutti and Saure (2015) find that the exposure to Greek government debt and Greek banks' assets are main sources of strengthening transmission's risk. Kohonon (2014) argues that sovereign default risk was transmitted from the Greek bonds markets only at the early stage of the crisis. Using VAR, Dieblod and Yilmaz (2012, 2014) examine financial spillovers effects between various economies and markets. Apostolakis and Papadopoulos (2015) analyse the effects between the G7 banking, securities and foreign exchange markets, identifying interactions between them. Grammatikos and Vermeulen (2012) find strong evidence of a crisis transmission from US non-financials to European non-financials.

The analysis of the relevant literature shows scarcity of research on sovereign contagion risk between sovereign CDS and financial markets during the European debt crisis. Moreover, the analysis of sovereign contagion between sovereign CDS and commodity markets are even more scarce. Several authors discuss the nature of the co-movement or correlation or time-varying correlation among different sovereign CDS markets or between sovereign CDS and stock markets. Nonetheless, there absence of research on contagion between sovereign CDS and commodity markets. Moreover, authors analyse more global financial contagion and not contagion across domestic financial markets.

On technical issues, authors have privileged linear correlations approach to examine the linkages between international financial markets. More recently, researchers have turned to use various techniques to examine the dependence structures between assets across markets and countries, see Chen et al. (2020), Zhang et al. (), Daehler et al. (2021). Indeed, most of the linear correlation analysis is not time varying. In addition, it is difficult to analyse the asymmetric dependency between various markets by applying linear correlation. Also, linear correlation does not capture extreme downside risk spillovers. In contrast, copula methods allow to describe the dynamic and asymmetric dependency structures. The copula approach provides a tool to isolate the dependence pattern from the marginal distributions, and it is possible to obtain more conveniently dependency structure and contagion effects. Durante and Jaworski (2010), use copula methods to show that dependency between financial markets in the crisis period is higher than that of the tranquillity period.

In this paper, we attempt to examine the impact of major global crises, pre-Brexit, Covid-19 pandemic, sovereign debt crisis, on the dependence structure between financial markets. A particular focus is given to sovereign risk contagion by providing an alternative measure to linear correlation that go beyond the specification of the crisis and non-crisis periods via suitable thresholds. This measure is computed by non-parametric methods.

Also, we provide a detailed account of potential transmission channels sovereign default risk within the peripheral European countries, Ireland, Italy, Portugal and Spain. We use the Kendall's tau correlation instead of Pearson's correlation to detect the nonlinear dependency structure among financial markets and to examine Sovereign contagion risk during the European debt crisis. Using the Dynamic Conditional Kendall's tau correlation allow to study the dynamic dependency structure as well as the links between financial markets. Hence, we provide a dynamic dependence measure that shows the degree of dependence and exhibits associations between financial markets over time.

Financial contagion is detected when there is a change in the dependence structure between financial markets and not when there is persistent extreme dependence caused more by interdependence and not by contagion. The dependence between two markets is described by using the information contained in the copula and not by the means of the local correlation coefficients as in Bradley and Taqqu (2005) and Durante and Jaworski (2010).

First, we compute the daily conditional Kendall's tau correlation, using the information incorporated in copulas of couples' sovereign CDS indexes as proxy of sovereign default risk and various other financial markets indexes for stock, bonds, and commodity markets.

Second, we use Markov Regime Switching ARMA model for Daily conditional Kendall's tau correlation of different pairs to examine the changes in dependence structure during the European debt crisis. Dueker (1997), Hamilton and Susmel (1994), Lamoureux, and Lastrapes (1990) argue that Markov Regime Switching (MRS) model is a better to model time varying of the stock market return distribution.

We believe that modelling of dynamic daily conditional Kendall's tau correlation, using the MRS-ARMA model offer a novel approach to show the transmission of sovereign risk from the sovereign CDS markets to various financial markets (stock, government bonds and commodity markets) and indicate the presence of sovereign contagion risk during the European debt crisis.

This paper is structured as follows. The next section presents the methodology and describes the various copulas functions and Markov Switching Auto-Regressive Moving Average Model (MS-ARMA) model. Section 3 presents the estimation results. Section 4 provides conclusions.

2 Methodology

Our methodology is based on three important steps. In the first step, we select the proper copula family by goodness of fit tests. Various copula families have various characteristics of Kendall's tau correlation that allow identification of Kendall's Tau correlation between different pairs of data. In the second step, we compute the dynamic conditional Kendall's tau correlation by using the dynamic conditional linear correlation. DCC-GJR GARCH model allow to obtain the daily dynamic linear correlation. In the third step, we model the daily Kendall's tau correlation of different pairs, using Markov Switching Regime (MSR) model to show the dependence structure between financial markets movement over time in various markets.

2.1 Copula functions and dependence measures

In the context of dependence between variables is measured by a dependence function or copula function.

Let **F** be the joint marginal distribution function **(DF)** of a random vector $\boldsymbol{X} = (\boldsymbol{X}_1, \boldsymbol{X}_2, \ldots, \boldsymbol{X_d}) \epsilon \mathbb{R}^d$. Let $(\boldsymbol{F}_1, \boldsymbol{F}_2, \ldots, \boldsymbol{F_d})$ be their marginal **DFs** and let $\boldsymbol{X_i} \rightarrow \boldsymbol{F_i}(\boldsymbol{X_i}), \boldsymbol{i} = 1, ..., \boldsymbol{d}$, be the probability integral transformation to the standard uniform distribution. Then, the copula function is given by the following formula:

$$C(u_1, u_2, \ldots, u_d) = F\left(F_1^{-1}(u_1), F_2^{-1}(u_2), \ldots, F_d^{-1}(u_d)\right) \forall u = (u_1, \ldots, u_d) \in [0,1]^d$$

where $\mathbf{F}_i^{-1}$ are the inverse distribution functions of the marginal and $\boldsymbol{u_i} = \boldsymbol{F_i}(\boldsymbol{x_i})$ for $\boldsymbol{i} = 1, \ldots, \boldsymbol{d}$. Thus, the copula function is a multivariate distribution with uniform $[0,1]$ margins. The copula **C** completely identifies the distribution **F**, Sklar (1959), $\forall(\boldsymbol{X}_1, \boldsymbol{X}_2, \ldots, \boldsymbol{X_d}) \epsilon \mathbb{R}^d$:

$$\boldsymbol{F}(\boldsymbol{x}_1, \boldsymbol{x}_2, \boldsymbol{x}_3, \ldots, \boldsymbol{x_n}) = \boldsymbol{C}\left(\boldsymbol{F}_1(\boldsymbol{x}_1), \boldsymbol{F}_2(\boldsymbol{x}_2), \boldsymbol{F}_3(\boldsymbol{x}_3), \ldots, \boldsymbol{F_d}(\boldsymbol{x_d})\right)$$

Equations (1) and (2) show that the copula represents the multivariate dependence structure, which links the uniform marginal distributions. The copula of any **F** distribution captures and summarizes the different types of dependence between variables even when they are rescaled by strictly monotone transformations.

- The Gaussian copula (normal copula): $C^{\rho}_{Gaussian}$

$$C^{\rho}_{Gaussian}(u_1, u_2, \ldots, u_d) = \int_{-\infty}^{\Phi^{-1}(u_1)} \ldots \int_{-\infty}^{\Phi^{-1}(u_d)} \frac{1}{(2\pi)^{d/2}|R|^{1/2}} \exp\left(\frac{-1}{2} y' R^{-1} y\right) dy_1 \ldots dy_d$$

where $-1 < \rho < 1$ and Φ is the cumulative distribution function of a standard normal distribution, Φ_{Σ} is the multivariate normal cumulative distribution function with mean zero and $m \times m$ correlation matrix R, Φ^{-1} is the inverse function of the standard univariate normal distribution, $|R|$ is the determinant of the correlation matrix R and $y = y_1, \ldots, y_d$.

In the case of Gaussian copula, the Kendall's tau correlation is computed as follows:

$$\tau_{i,j} = \frac{2}{\pi} arcsin \rho_{i,j}$$

- The student-t copula: $C_t^{\rho,v}$

The d-dimensional student-t copula (or briefly t copula) function takes the form:

$$C_t^{\rho,v}(u_1,u_2,\ldots,u_d) = T_{R,v}\left(T^{-1}(u_1),T^{-1}(u_2),\ldots,T^{-1}(u_d)\right)$$
$$= \int_{-\infty}^{T^{-1}(u_1)} \cdots \int_{-\infty}^{T^{-1}(u_d)} \frac{\Gamma\left(\frac{v+d}{2}\right)|R|^{-\frac{1}{2}}}{\Gamma\left(\frac{v}{2}\right)(v\pi)^{\frac{d}{2}}}\left(1+\frac{1}{v}y'R^{-1}y\right)^{-\frac{v+d}{2}} dy_1\ldots dy_d$$

where $T_{R,v}$ the standardized multivariate student-t distribution function with $m \times m$ correlation matrix R of v degrees of freedom and T^{-1} is the inverse function of the standard univariate student-t distribution with v degrees of freedom. The Kendall's tau is the same as for the Gaussian copula.

- The Gumbel copula: C_{Gu}^{θ}

  Gumbel (1960) proposes the Gumbel copula with the following generator:

  $$\varphi(u) = (-\ln(u))^{\theta} \; where\; \theta > 1$$

  The d-dimensional Gumbel copula is defined as follows:

  $$C_{Gu}^{\theta}(u_1,u_2,\ldots,u_d;\theta) = \exp\left(-\left[\sum_{i=1}^{d}(-\ln u_i)^{\theta}\right]^{\frac{1}{\theta}}\right)$$

  The Kendall's tau formula is given by following expression:

  $$\tau_k = 1 - \frac{1}{\theta}$$

- The Clayton copula: C_{Cl}^{θ}

  Clayton (1978) develops the Clayton copula with the following generator:

  $$\varphi(u) = u^{-\theta} - 1 \; where\; \theta > 0$$

  The d-dimensional Clayton copula is defined as follows:

  $$C_{Cl}^{\theta}(u_1,u_2,\ldots,u_d;\theta) = \left(\sum_{i=1}^{d} u_i^{-\theta} - d + 1\right)^{-\frac{1}{\theta}}$$

  The Kendall's tau formula is given by the following expression:

  $$\tau_k = \frac{\theta}{\theta+2}$$

- The Frank copula: C_F^{θ}

The Frank copula (1979) is characterized by the following generator:

$$\varphi(t) = -\ln\left(e^{-\theta t} - 1/e^{-\theta} - 1\right), \text{ where } \theta \in]-\infty, 0[\cup]0, +\infty[$$

The Frank copula is defined by:

$$C_F^{\theta}(u_1, u_2; \theta) = \frac{-1}{\theta}\ln(1 + \frac{(e^{-\theta u_1} - 1)(e^{-\theta u_2} - 1)}{(e^{-\theta} - 1)})$$

The Kendall's tau: $\boldsymbol{\tau_k} = 1 - \frac{4}{\boldsymbol{\theta}}(1 - \boldsymbol{D}_1(\boldsymbol{\theta}))$

- The Placket copula: C_P^{θ}

Plackett (1965) introduces Plackett's copula.

$$C_P^{\theta}(u_1, u_2; \theta) = \frac{1 + (\theta - 1)(u_1 + u_2) - \sqrt{[1 + (\theta - 1)(u_1 + u_2)]^2 - 4\theta(\theta - 1)u_1 u_2}}{2(\theta - 1)}$$

If $\theta = 1$, then $C(u_1, u_2; \theta) = u_1 u_2$ which correspond to independence case.

- The symmetrized Joe Clayton copula: $C_{SJC}^{\tau_U, \tau_L}$

The Joe-Clayton copula is given by:

$$C_{JC}(u_1, u_2; \tau_U, \tau_L) = 1 - \left(\left\{\left[1 - (1 - u_1)^k\right]^{-\delta} + \left[1 - (1 - u_2)^k\right]^{-\delta} - 1\right\}^{\frac{-1}{\delta}}\right)^{\frac{1}{k}}$$

where $k = \frac{1}{log_2(2 - \tau_U)}$, $\delta = \frac{-1}{log_2(\tau_L)}$ and $\tau_U, \tau_L \in (0, 1)$

This copula has two parameters τ_U *and* τ_L, which are the coefficients of upper and lower tail dependence respectively, Patton (2004). The Joe-Clayton copula has a slight asymmetry when $\tau_U = \tau_L$, which is not convenient. To overcome this issue, the symmetrized Joe-Clayton copula (SJC) is introduced and defined as following:

$$C_{SJC}(u_1, u_2 \backslash \tau_U, \tau_L) = 0.5C_{JC}(u_1, u_2 \backslash \tau_U, \tau_L) + 0.5C_{JC}(1 - u_1, 1 - u_2 \backslash \tau_U, \tau_L) + u_1 + u_2 - 1$$

Which is symmetric when $\tau_U = \tau_L$.

2.2 Markov Switching Auto-Regressive Moving Average Model: MS-ARMA model

Markov Switching ARMA (MS-ARMA) processes are extensions of the ARMA processes allowing for time dependent ARMA coefficients, modelled as a chain Markov. Next, we first present the essence of MS-ARMA models and then the estimation process using maximum likelihood.

- MS-ARMA model:

MS-ARMA models provide an appropriate framework to analyse the representations with changes in regime. MS-ARMA allow to examine the dynamic structures, based on value of the state variable, *St*, that controls the varying mechanism between various states. Moreover, the underlying parameters may be varying in accordance with the regime prevailing at time *t*. The nonlinear and common factor structures of the cyclical processes are represented at the same time. We consider the following presentation of the MS-ARMA model:

$$\Delta y_t = \alpha(s_t) + \sum_{i=1}^{p} A_i(s_t)\Delta y_{t-i} + \sum_{j=1}^{q} B_j(s_t)\varepsilon_{t-j} + \varepsilon_t(s_t)$$

The MS-ARMA with regime switching in the conditional mean and variance are defined as a regime-switching model, Hamilton (1989), where an observed Markov chain governs the regime switchess_t, with ns states number and Ps transition probability matrix. The model is completed by specifying dynamics of the unobservable state variable s_t.

We assume that the model has two states (ns = 2). Therefore, α, A_i *and* B_j depend on the state variables_t, and the matrix Ps. The transition probabilities are collected in a 2×2, P_s given by:

$$\text{Ps} = \begin{pmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{pmatrix}$$

The link between the two states of the market is provided by a first order Markov process with following transition probabilities.

$$Pr(St = 1/St - 1 = 2) = P_{21}\, and\, Pr(St = 2/St - 1 = 1) = P_{12}$$

$$Pr(St = 1/St - 1 = 1) = P_{11}\, and\, Pr(St = 2/St - 1 = 2) = P_{22}$$

where $P_{12}(P_{21})$ indicates the probability that state 1(2) will followed by state 2(1), and P_{11} and P_{22} determine probabilities of staying in same regime. Additionally, P_{ij} controls the probability of transition from i state to j state at time $t + 1$.

To estimate the parameters of the MS-ARMA model by MLE the density of *Yt*, given the past information of ψ_{t-1} is:

$$f(y_t \backslash \psi_{t-1}, S_t) = \frac{1}{\sqrt{2\pi\sigma_{S_t}^2}} \exp\left(\frac{(y_t - (\alpha_{s_t} + \alpha_1, s_t y_{t-1} + \cdots + \alpha_p, s_t y_{t-p} + b_1, s_t \varepsilon_{t-1} + \cdots + b_q, s_t \varepsilon_{t-q}))^2}{2\sigma_{s_t}^2} \right)$$

The joint probability of y_t and S_t is then given by the product:

$$f(y_t, S_t = j \backslash \psi_{t-1}) = f(y_t \backslash S_t = j, \psi_{t-1}) P(S_t = j \backslash \psi_{t-1}); \quad j = 1, 2$$

The conditional density of the tth observation is the sum of these terms over all values of S_t for a two state cases:

$$f(y_t \backslash \psi_{t-1}) = \sum_{S_{t=1}}^{2} \sum_{S_{t-1}=1}^{2} f(y_t \backslash \psi_{t-1}, S_t) P(S_t \backslash \psi_{t-1})$$

Then, the log likelihood function is given by:

$\ln L = \sum_{t=1}^{T} ln\left(\sum_{S_t=0}^{1} f(y_t \backslash \psi_{t-1}, S_t) P(S_t \backslash \psi_{t-1}) \right)$ where $P(S_t \backslash \psi_{t-1})$ is filtered probabilities, which these probabilities are computed using the filter introduced by Hamilton (1989) for $t = 1 \ldots T$. these probabilities refer to inferences about S_t conditional on information up to t, ψ_t. So, the smoothed probabilities $P(S_t \backslash \psi_t)$ using all available information in the sample, ψ_t for $t = t-1, t-2 \ldots 1$ and given $P(S_t \backslash \psi_t)$ at the last iteration of the filter.

3 Empirical results

3.1 Data description

We examine data of a set of countries from Asia, China and Japan, the USA, from Africa South Africa, eight eurozone core countries, Belgium, Denmark, Poland, France, Germany, Netherlands, UK, and Sweden, and five peripheral countries Ireland, Italy, Greece, Portugal and Spain. For each country, we consider daily data of sovereign CDS, sovereign bonds and stock market indexes and eight commodities Crude Oil, Energy, Foodstuffs, Gold, Industrial Metals, Natural Gas, Nickel and Silver.

Data series are retrieved from Thomson Reuters (DataStream), covering the period from 28 February 2008 to 11 March 2021 so a total of 3400 observations. The data relative to the Greek sovereign bond is available until 08 March 2012 (1100 observations). The sample data period covers a wide range of major events.

The description of the daily market indexes is illustrated in the next Fig. 1. Indeed, we note a similar fluctuation pattern between sovereign CDS, sovereign bond, commodity, and stock market indexes for the selected countries. All financial market indexes trend together for the entire sample period. Some historical periods appear more riskier than others. For example, we observe a significant increase in sovereign CDS spreads since the start of the Greek debt crisis in March 2009 to 2013, mid-2014 to March 2020. Indeed, these periods cover respectively the European debt crisis 2009–2013, Arab spring, collapse of oil price, UK announcement of withdrawal from EU or pre-Brexit and Covid-19 pandemic. Data indicates a decrease in prices of sovereign bonds, stock and commodity markets. Furthermore, there is some indication of the existence of sovereign contagion risk as characterized by markets movements.

Descriptive statistics of daily return data are reported in Table 1. For changes in sovereign CDS and sovereign bonds spreads, Greece maintains the highest daily mean and volatility levels. As for the stock returns, Greece has the maximum and minimum returns, which indicates that the volatility in Greece's stock market is relatively higher.

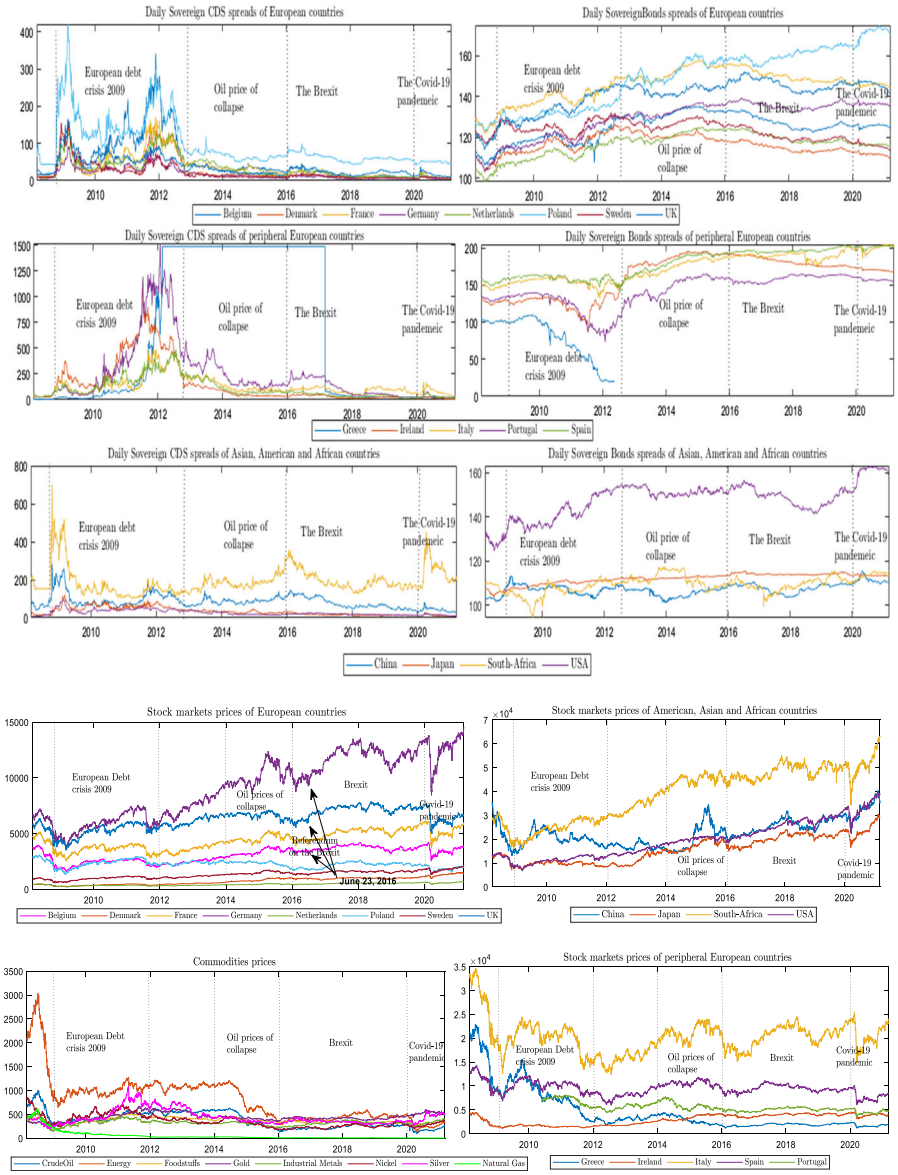

Fig. 1 Daily sovereign CDS spreads, sovereign bonds spreads, stock, and commodities prices

Moreover, the mean values are positive for all countries, except for Greece, Italy, Portugal, Spain, and Poland. For commodity returns, Crude-Oil, Energy, Natural Gaz, and Nickel have negative mean values. Nonetheless, standard deviation the Natural Gaz market is the highest, with the value of 2.61% followed by the Crude-Oil (2.15%).

Table 1 Descriptives statistics

		Mean	Maximum	Minimum	SD	Skewness	Kurtosis	Jarque-bera	ADF test	ARCH test	Observations
Sovereign CDS markets	Greece	0.0004	0.4028	− 2.8792	0.0586	− 34.9994	1722.0250	0.0000	0.0001	0.0000	3400
	Ireland	− 0.0005	0.4184	− 0.4184	0.0388	0.5691	27.1175	0.0000	0.0001	0.0000	3400
	Italy	− 0.0001	0.3679	− 0.4520	0.0439	0.0424	16.5460	0.0000	0.0001	0.0000	3400
	Portugal	− 0.0003	0.3211	− 0.5900	0.0419	− 0.2118	21.5103	0.0000	0.0001	0.0000	3400
	Spain	− 0.0003	0.5239	− 0.5508	0.0515	0.2017	23.8090	0.0000	0.0001	0.0000	3400
	Belgium	− 0.0004	0.4287	− 0.3352	0.0497	0.207	14.1138	0.0000	0.0001	0.0000	3400
	Denmark	− 0.0002	0.4090	− 0.3399	0.0607	0.1054	11.8176	0.0000	0.0001	0.0000	3400
	France	− 0.0002	0.7162	− 0.3424	0.0524	1.4922	22.9242	0.0000	0.0001	0.0000	3400
	Germany	− 0.0002	0.5901	− 0.5071	0.0608	0.1624	18.2507	0.0000	0.0001	0.0000	3400
	Netherland	− 0.0001	0.6501	− 0.2567	0.0346	2.4891	51.2358	0.0000	0.0001	0.0000	3400
	Poland	− 0.0001	1.0540	− 0.6539	0.0376	5.8113	229.4190	0.0000	0.0001	0.0000	3400
	Sweden	− 0.0002	0.5321	− 0.5139	0.0788	0.0460	13.8675	0.0000	0.0001	0.0000	3400
	UK	− 0.0002	0.3365	− 0.4796	0.0493	− 0.0743	11.7120	0.0000	0.0001	0.0000	3400
	USA	0.0000	0.6633	− 0.2877	0.0396	2.3143	51.9542	0.0000	0.0001	0.0000	3400
	China	− 0.0002	0.3023	− 0.2971	0.0364	0.5786	12.7955	0.0000	0.0001	0.0000	3400
	Japan	− 0.0002	1.3906	− 0.5108	0.0604	3.6947	95.7785	0.0000	0.0001	0.0000	3400
	South-Africa	0.0000	0.4737	− 0.5979	0.0363	0.0945	44.4629	0.0000	0.0001	0.0000	3400
Sovereign bonds Markets	Greece	0.0005	0.1357	− 0.2717	0.0089	− 5.9985	316.3701	0.0000	0.0000	0.0000	1100
	Ireland	0.0001	0.0715	− 0.0396	0.0039	4.3942	87.5119	0.0000	0.0000	0.0000	3400
	Italy	0.0001	0.0399	− 0.0494	0.0037	− 0.2761	29.7039	0.0000	0.0000	0.0000	3400
	Portugal	0.0000	0.0926	− 0.0898	0.0062	− 0.5510	59.6589	0.0000	0.0000	0.0000	3400
	Spain	0.0001	0.0480	− 0.0230	0.0030	1.9996	35.5089	0.0000	0.0000	0.0000	3400
	Belgium	0.0000	0.0210	− 0.0176	0.0019	0.1605	16.7750	0.0000	0.0000	0.0000	3400

Table 1 continued

		Mean	Maximum	Minimum	SD	Skewness	Kurtosis	Jarque-bera	ADF test	ARCH test	Observations
	Denmark	0.0000	0.0224	− 0.0138	0.0019	0.3850	16.5244	0.0000	0.0000	0.0000	3400
	France	0.0000	0.0130	− 0.0119	0.0018	− 0.0339	8.0386	0.0000	0.0000	0.0000	3400
	Germany	0.0001	0.0096	− 0.0114	0.0018	− 0.1176	6.3916	0.0000	0.0000	0.0000	3400
	Netherland	0.0000	0.0088	− 0.0101	0.0017	− 0.2010	6.4344	0.0000	0.0000	0.0000	3400
	Poland	0.0001	0.0326	− 0.0158	0.0022	0.9611	25.8833	0.0000	0.0000	0.0000	3400
	Sweden	0.0000	0.0175	− 0.0152	0.0017	0.0875	13.3724	0.0000	0.0000	0.0000	3400
	UK	0.0000	0.0142	− 0.0114	0.0020	0.0893	6.4282	0.0000	0.0000	0.0000	3400
	USA	0.0001	0.0217	− 0.0230	0.0025	− 0.0600	9.2764	0.0000	0.0000	0.0000	3400
	China	0.0000	0.0199	− 0.0274	0.0029	− 0.3637	16.5357	0.0000	0.0000	0.0000	3400
	Japan	0.0000	0.0052	− 0.0078	0.0008	− 0.6820	13.9464	0.0000	0.0000	0.0000	3400
	South-Africa	0.0000	0.0231	− 0.0542	0.0027	− 2.4826	53.8485	0.0000	0.0000	0.0000	3400
Stock markets	Greece	− 0.0007	0.1637	− 0.1726	0.0231	-0.2398	8.6567	0.0000	0.0001	0.0000	3400
	Ireland	0.0000	0.1325	− 0.1769	0.0177	− 0.6644	13.0687	0.0000	0.0001	0.0000	3400
	Italy	− 0.0001	0.1087	− 0.1854	0.0167	− 0.6610	12.4943	0.0000	0.0001	0.0000	3400
	Portugal	− 0.0001	0.0753	− 0.1027	0.0121	− 0.6151	8.0259	0.0000	0.0001	0.0000	3400
	Spain	− 0.0001	0.1012	− 0.1515	0.0152	− 0.5262	11.4958	0.0000	0.0001	0.0000	3400
	Belgium	0.0000	0.0922	− 0.1533	0.0132	− 0.7025	14.0328	0.0000	0.0001	0.0000	3400
	Denmark	0.0004	0.0950	− 0.1172	0.0128	− 0.3242	9.8802	0.0000	0.0001	0.0000	3400
	France	0.0001	0.1059	− 0.1310	0.0143	− 0.3153	11.3793	0.0000	0.0001	0.0000	3400
	Germany	0.0002	0.1080	− 0.1305	0.0141	− 0.1990	11.4873	0.0000	0.0001	0.0000	3400
	Netherland	0.0001	0.1003	− 0.1138	0.0133	− 0.4093	12.9876	0.0000	0.0001	0.0000	3400
	Poland	− 0.0001	0.0815	− 0.1425	0.0141	− 0.5531	9.8866	0.0000	0.0001	0.0000	3400
	Sweden	0.0002	0.0987	− 0.1117	0.0135	− 0.1234	9.4491	0.0000	0.0001	0.0000	3400
	UK	0.0000	0.0938	− 0.1151	0.0120	− 0.4289	13.9929	0.0000	0.0001	0.0000	3400

Table 1 continued

		Mean	Maximum	Minimum	SD	Skewness	Kurtosis	Jarque-bera	ADF test	ARCH test	Observations
	USA	0.0003	0.1096	− 0.1277	0.0130	− 0.5669	17.1019	0.0000	0.0001	0.0000	3400
	China	0.0000	0.0923	− 0.0985	0.0161	− 0.1896	7.5998	0.0000	0.0001	0.0000	3400
	Japan	0.0002	0.0949	− 0.1211	0.0144	− 0.6788	11.0466	0.0000	0.0001	0.0000	3400
	South-Africa	0.0002	0.1110	− 0.1251	0.0132	− 0.3385	12.8098	0.0000	0.0001	0.0000	3400
Commodity markets	Crude-Oil	− 0.0002	0.1312	− 0.1270	0.0215	− 0.1015	7.4297	0.0000	0.0000	0.0000	3400
	Energy	− 0.0004	0.1598	− 0.1711	0.0210	− 0.0662	9.4569	0.0000	0.0000	0.0000	3400
	Foodstuffs	0.0000	0.0378	− 0.0398	0.0067	− 0.1394	6.4371	0.0000	0.0000	0.0000	3400
	Gold	0.0001	0.0856	− 0.0682	0.0113	− 0.1403	8.2241	0.0000	0.0000	0.0000	3400
	Industrial Metals	0.0001	0.0856	− 0.0672	0.0112	− 0.0813	7.9991	0.0000	0.0000	0.0000	3400
	Natural Gas	− 0.0015	0.1665	− 0.1618	0.0261	0.1149	5.3790	0.0000	0.0000	0.0000	3400
	Nickel	− 0.0003	0.1272	− 0.1360	0.0213	− 0.0543	6.7647	0.0000	0.0000	0.0000	3400
	Silver	0.0001	0.1247	− 0.1383	0.0208	− 0.5571	8.2085	0.0000	0.0000	0.0000	3400

The time series are leptokurtic (Kurtosis statistic is greater than 3), indicating an asymmetric distribution. Jarque–Bera test reject the null hypothesis of normality of the entirety of return series, thus justifying an exploration of the correlations based on extreme dependence. Moreover, ADF tests indicate that all series are stationary and ARCH tests suggests the presence of heteroscedasticity phenomena, at significant level 1%.

3.2 Sovereign default risk proxy's analysis

We examine the relationship between sovereign CDS spreads and sovereign bonds spreads of peripheral countries. First, results show how sovereign bonds changes correlate with sovereign CDS changes for peripheral eurozone countries. Pearson correlation coefficients are calculated and reported in Table 2. Regarding internal correlations within the sovereign bond markets, the highest correlation coefficient appears in Italy-Spain pair (0.7), while the Italy-Greece pair reveals the lowest correlation coefficient (0.18). As far as internal interactions within sovereign CDS markets, Italy-Spain pair has the highest coefficient correlation (0.67), followed by Italy-Portugal pair (0.65). Finally, we focus on external interactions between sovereign bond and sovereign CDS markets. Results show that correlations are negative for all pairwise markets.

Second, we further explore the lead-lag relationships between sovereign CDS and sovereign bond markets and to identify the source of sovereign credit risk. Hence, we use the most widely utilized test that is the standard linear Granger-Causality test, Granger (1969), based on a vector autoregressive model VAR of order p (VAR(p)) that is given by the following equations:

$$X_t = \alpha_X + \sum_{i=1}^{k} \beta_{X,i} X_{t-i} + \sum_{j=1}^{k} \gamma_{X,j} Y_{t-j} + \varepsilon_{X,t}$$

$$Y_t = \alpha_Y + \sum_{i=1}^{k} \beta_{Y,i} Y_{t-i} + \sum_{i=1}^{k} \gamma_{X,j} X_{t-j} + \varepsilon_{Y,t}$$

where k represents the lag length set and the Xt and Yt represent respectively the stationary variables. Furthermore, a variable X Granger-cause another variable Y, if past values of X help predict the current level of Y better than past values of Y alone, proving that past values of X have some informational content that is not present in past values of Y. Using the VAR (1) model, we test for Granger-causality for all pairs. From the Table 3, we find 23 out of 25 causal relationships running from sovereign CDS markets to sovereign bond markets, while the number of causality linkages running from sovereign bond markets to sovereign CDS markets is 11.

Moreover, we find evidence of bidirectional causality between sovereign CDS and sovereign bond markets for each peripheral country. These results indicate most likely the sovereign CDS markets is the source of sovereign credit risk is the. This finding supports the usefulness of sovereign CDS spread as proxy of sovereign credit risk when analyzing sovereign contagion risk of sovereign CDS markets from peripheral eurozone countries to other financial markets.

Table 2 Correlation matrix

	Sov CDS-Greece	Sov bonds-Greece	Sov CDS-Italy	Sov bonds-Italy	Sov bonds-Ireland	Sov CDS-Ireland	Sov CDS-Spain	Sov bonds-Spain	Sov CDS-Portugal	Sov bonds-
Portugal										
Sov CDS-Greece	1.00									
Sov bonds-Greece	− 0.35	1.00								
Sov CDS-Italy	0.36	− 0.23	1.00							
Sov bonds-Italy	− 0.10	0.18	− 0.43	1.00						
Sov bonds-Ireland	− 0.18	0.35	− 0.20	0.26	1.00					
Sov CDS-Ireland	0.30	− 0.20	0.45	− 0.25	− 0.25	1.00				
Sov CDS-Spain	0.30	− 0.19	0.67	− 0.35	− 0.16	0.40	1.00			
Sov bonds-Spain	− 0.15	0.24	− 0.41	0.70	0.34	− 0.26	− 0.37	1.00		
Sov CDS-Portugal	0.37	− 0.29	0.65	− 0.31	− 0.25	0.47	0.60	− 0.32	1.00	
Sov bonds-Portugal	− 0.20	0.38	− 0.26	0.28	0.41	− 0.22	− 0.22	0.32	− 0.37	1.00

Table 3 Causal relationships

Causality running from sovereign CDS markets to sovereign bond markets			Causality running from sovereign bond markets to sovereign CDS markets		
CDS-Greece	Bond-Greece	Yes	Bond-Greece	CDS-Greece	Yes
	Bond-Ireland	Yes		CDS-Ireland	No
	Bond-Italy	No		CDS-Italy	No
	Bond-Spain	Yes		CDS-Spain	No
	Bond-Portugal	Yes		CDS-Portugal	No
CDS-Ireland	Bond-Greece	Yes	Bond-Ireland	CDS-Greece	No
	Bond-Ireland	Yes		CDS-Ireland	Yes
	Bond-Italy	No		CDS-Italy	No
	Bond-Spain	Yes		CDS-Spain	No
	Bond-Portugal	Yes		CDS-Portugal	No
CDS-Italy	Bond-Greece	Yes	Bond-Italy	CDS-Greece	Yes
	Bond-Ireland	Yes		CDS-Ireland	Yes
	Bond-Italy	Yes		CDS-Italy	Yes
	Bond-Spain	Yes		CDS-Spain	Yes
	Bond-Portugal	Yes		CDS-Portugal	Yes
CDS-Portugal	Bond-Greece	Yes	Bond-Portugal	CDS-Greece	Yes
	Bond-Ireland	Yes		CDS-Ireland	No
	Bond-Italy	Yes		CDS-Italy	No
	Bond-Spain	Yes		CDS-Spain	No
	Bond-Portugal	Yes		CDS-Portugal	Yes
CDS-Spain	Bond-Greece	Yes	Bond-Spain	CDS-Greece	Yes
	Bond-Ireland	Yes		CDS-Ireland	No
	Bond-Italy	Yes		CDS-Italy	No
	Bond-Spain	Yes		CDS-Spain	Yes
	Bond-Portugal	Yes		CDS-Portugal	No

3.3 Bivariate copulas and dependence measures

To identify the presence of sovereign contagion risk, we analyse the interactions between sovereign CDS and other financial markets, among peripheral Eurozone countries and other selected countries, using static correlation measures such as Pearson, Spearman rho and Kendall's tau. Then, we examine the dependence structure using bivariate Copulas models.

3.3.1 Correlation analysis

In this section, we first examine how sovereign CDS market correlate to sovereign bond market and stock market in peripheral eurozone countries, as well as to commodity markets. Indeed, Pearson, Spearman rho and Kendall's tau correlation

coefficients are computed and given in Tables 4, 5, 6, 7 (see "Appendix 1"). As for internal correlations within sovereign CDS market of peripheral eurozone countries, the coefficients of different correlations' measures are significant and negative for all pairwise markets. Furthermore, as for external interactions of sovereign CDS, namely interactions between sovereign CDS and sovereign bond markets, sovereign CDS and stock markets and sovereign CDS and commodity markets, results indicate that the coefficients of correlation are significant and negative for all pairwise markets. The exception is the correlation coefficients of sovereign CDS-Gold and sovereign CDS-Industrial Metals pairs, being positive. Next, we examine how sovereign CDS markets of core European, China and Japan, US, as well as South Africa correlate to sovereign CDS, sovereign bond and stock markets of periphery eurozone countries, as well as to commodity markets. First, correlations between sovereign CDS markets of peripheral countries and other selected countries are positive with significant and small coefficients. Second, correlations between sovereign bond market of peripheral eurozone countries and sovereign CDS market of other selected countries are negative for all pairwise markets. Third, all sovereign CDS markets are negatively and weakly correlated to the stock markets. Finally, when considering interactions between sovereign CDS and commodity markets, the correlation coefficients of all pairwise markets are negative, expect for sovereign CDS-Gold and sovereign CDS-industrial metals pairs. These findings indicate that sovereign CDS market are negatively correlated to all financial markets, expect the Gold and the Industrial metals. Negative correlation implies that sovereign CDS market is bull, while other financial market is bear, and vice versa.

3.3.2 Fitting copulas results

We use alternative bivariate copulas models with different features to assess the dependence structure among financial markets. These models include the normal copula, student-t copula, Placket, Frank, Gumbel, rotated Gumbel, and variants of Clayton copula. The parameter estimates of copulas models (see "Appendix 2") are all significant for all pairwise markets. In terms of goodness of fit, the student-t copula appears the most suited to examine the dependence structure between all pairwise markets. The bivariate copula parameter measures the strength of dependencies across different financial time series, in a positive or a negative single regime. However, the bivariate copula models do not allow us to see whether these markets have specific properties of risk during market stress or crash periods. This supports the importance of the time-varying dependence structure.

3.3.3 Time-varying dependence structure

Our study explores the time-varying dependence structure between sovereign CDS markets and other financial markets of selected countries. For this purpose, we compute daily Kendall's tau dynamic correlation of t-copula to examine time-varying dependence structure for all pairwise markets, using DCC-GARCH models. To capture the time varying dependence structure, we use the MRS-ARMA models

to model the daily Kendall's tau correlations. This allows us to capture the dependence structure for different markets.

The Kendall's tau correlation coefficient is given by this following formula:

$$\tau_k = 2\arcsin(\rho)/\pi$$

The motivation uses the Dynamic Conditional Correlation (DCC) to calculate daily conditional Kendall's tau coefficient τk for each pair. In addition, Dynamic Conditional Kendall's tau correlation coefficient is given by the following formula:

$$\tau_{DCK} = 2\arcsin(\rho\mathrm{DCC})/\pi$$

where ρDCC is a (1*N) dynamic conditional correlation coefficients vector. We compute DCC based on GARCH models. For this purpose, we consider three univariate models for the conditional variance process: a standard GARCH model, Bollerslev (1986), EGARCH model, Nelson (1991), and asymmetric GARCH model known as GJR-GARCH model, Glosten et al. (1993).

- *GARCH model*

The conditional variance following GARCH model of Bollerslev (1986) is assumed by this expression:

$$h_t = \alpha_0 + \sum_{i=1}^{p} \alpha\varepsilon_{t-i}^2 + \sum_{j=1}^{q} \beta h_{t-j}$$

In the conditional variance equation, h_t is 2×1 vector of daily conditional variances of financial time series at time t, respectively, α is the ARCH term that measures the effect of past innovations on current variance, β is the GARCH term, which measures the effect of past variances on current variance. The degree of persistence of the variance shock is measured by the sum of the ARCH and GARCH parameters$(\alpha + \beta)$. To ensure the stationary and the stability, the standard GARCH process must respect following requirements: $\alpha_0 \geq 0$; $\alpha > 0$; $\beta > 0$; $\alpha + \beta < 1$.

- *EGARCH model*

Nelson (1991) introduces the exponential GARCH model where the logarithm of the conditional variance is given by:

$$\ln h_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i(|\varepsilon_{t-i}| + \gamma_i\varepsilon_{t-i}) + \sum_{j=1}^{q} \beta_j \ln h_{t-j}$$

This specification considers that the leverage effect where past negative observations have a larger influence on the conditional volatility than past positive observations of the same magnitude, Black (1976), Christie (1982). Covariance-stationary is obtained by requiring that $\beta_j < 1$.

- *GJR-GARCH model*

Glosten et al. (1993) modified GARCH model considering the *leverage effect*. The GJR model is able to capture the asymmetry in the conditional variance process. This model is defined as follows:

$$h_t = \alpha_0 + \sum_{i=1}^{p} \alpha \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \beta h_{t-j} + \sum_{j=1}^{q} d\varepsilon_{t-j}^2 \mathrm{I}_{\varepsilon<0}(\varepsilon_{t-j})$$

In the case of asymmetric GJR-GARCH process, I represents a dummy variable the asymmetric response of the conditional variance to unexpected price decrease. $\mathrm{I} = 0$ in response to positive shocks and $\mathrm{I} = 1$ in response to negative shocks. A positive and significant value of d indicates shocks indicating increase in future conditional variance more than a positive shock at the same magnitude. The stability and stationarity of the asymmetric process are obtained by requiring that: $\alpha_0 > 0;\ \alpha \geq 0;\ \beta \geq 0;\ \beta + d \geq 0;\ \alpha + \beta + 0.5d < 1$.

The estimation of DCC consist of two steps: First is estimation of a univariate GARCH model, second is estimation of time-varying conditional correlations. The multivariate DCC-GARCH is defined as follows:

$$\begin{cases} H_t = D_t R_t D_t \\ D_t = diag\left(\sqrt{h_{11t}}, \sqrt{h_{22t}}, \ldots, \sqrt{h_{NNt}}\right) \\ R_t = (diagQ_t)^{-1/2} Q_t (diagQ_t)^{-1/2} \end{cases}$$

where H_t is the multivariate conditional variance, and D_t is a diagonal matrix of conditional standard deviations obtained from estimating univariate GARCH. The different elements contained in D_t are generated by a GJR-GARCH (p, q), given by:

$$H_t = \begin{pmatrix} \sqrt{h_{it}} & 0 \\ 0 & \sqrt{h_{0t}} \end{pmatrix} \begin{pmatrix} 1 & \rho_{i0,t} \\ \rho_{i0,t} & 1 \end{pmatrix} \begin{pmatrix} \sqrt{h_{it}} & 0 \\ 0 & \sqrt{h_{0t}} \end{pmatrix}$$

where $h_{it} = c_i + \sum_{p=1}^{P_i} (\alpha_{ip} \varepsilon_{it-p}^2 + \lambda \mathrm{I}_{[\varepsilon_{t-1<0}]} \varepsilon_{t-i}^2) + \beta_j \sum_{q=1}^{Q} \beta_{iq} h_{it-q}$; and i = 1, 2…, N. where Rt = [$\rho_{ij,t}$] represents the matrix of constant conditional correlation coefficients,

$Q_t = [q_{ij,t}]$ is the covariance matrix of standardized residuals, of (N X N) dimension, symmetric and positive definite.

$$q_{ij,t} = \overline{\rho}_{i,j} + \alpha\left(Z_{i,t-1} Z_{j,t-1} - \overline{\rho}_{i,j}\right) + \beta(q_{ij,t-1} - \overline{\rho}_{i,j})$$

$\overline{\rho}_{i,j}$ represents the unconditional correlations and $\rho_{ij,t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t} q_{jj,t}}}$ represents dynamic conditional correlations. The parameters are estimated using quasi-maximum likelihood method (QMLE) introduced by Bollerselv et al., (1992). Under the Gaussian assumption, the log-likelihood of the estimators is:

$$l(\vartheta) = -\frac{1}{2}\sum_{t=1}^{T}[(nlog(2\pi) + log|D_t|^2 + \varepsilon_t^{'}D_t^{-1}D_t^{-1}\varepsilon_t) + (log|R_t| + \delta_t^{'}R_t^{-1}\delta_t - \delta_t^{'}\delta_t)]$$

where n is the number of equations, T is the number of observations, ϑ is the vector of parameters to be estimated.

The first step of the DCC-GJRGARCH estimation process is to fit the univariate GARCH specification for sovereign CDS spreads, sovereign bond spreads, stock market and commodities returns. We estimate the univariate GARCH, EGARCH and GJR-GARCH models. We find evidence of asymmetry in the conditional variance of all financial market indexes. The results (see "Appendix 3") highlight the autoregressive conditional heteroscedasticity effects and the persistence of volatility through the significance of variance equations' parameters (α and β). Moreover, the parameter of asymmetry λ is also significant for all financial market indexes, providing evidence of asymmetry in conditional volatility. Consequently, the parameters are statistically significant and log-likelihood values suggest that the GJR-GARCH (1, 1) model is appropriate for sovereign CDS indexes, while the EGARCH (1,1) is adequate to model sovereign bond, stock market and commodities indexes.

In the second stage, the DCC specification is modified to account for the structural breaks in unconditional correlations.

3.3.4 Analysis of dynamic conditional Kendall's tau

Figures 2, 3 and 4 show the pairwise daily Kendall's tau correlations among sovereign CDS markets and sovereign bond, stock, and commodities markets. As for the dependence structure within the sovereign CDS market of peripheral countries, the coefficients of daily Kendall's tau correlations are significant and positive for all pairwise markets, implying that sovereign CDS markets are highly interdependent and move in the same direction. This indicates that the dependence structure is not static but changes over time. Moreover, Fig. 2 reports how dependence structure among sovereign CDS markets of peripheral EU countries has changed, especially during the global financial crisis 2008 (GFC), the European debt crisis 2009–2012, oil price crisis 2014–2016, pre-Brexit period 2016–2020 and Covid-19 pandemic. We find that most peaks are associated with the emergence of major economic, financial, political, or public health events or crisis, enhancing the linkages between these peripheral European countries. As shown in Fig. 2, we notice that dependence between sovereign CDS and sovereign bonds within peripheral European countries is low before the global financial crisis 2008, however a gradual uptrend is taking place post 2008, suggesting that the various financial, economic, political and public health events have intensified this dependence.

The dynamic Kendall' tau correlation allows us to capture the dependence over time between all pairwise markets. Results show that, the dependence between sovereign CDS and sovereign bonds is negative. A bear sovereign bond market condition is associated with a bull sovereign CDS market. As shown in Fig. 3, the dependence structure between sovereign CDS markets of peripheral countries and the other countries present significant time-varying behavior during the sample

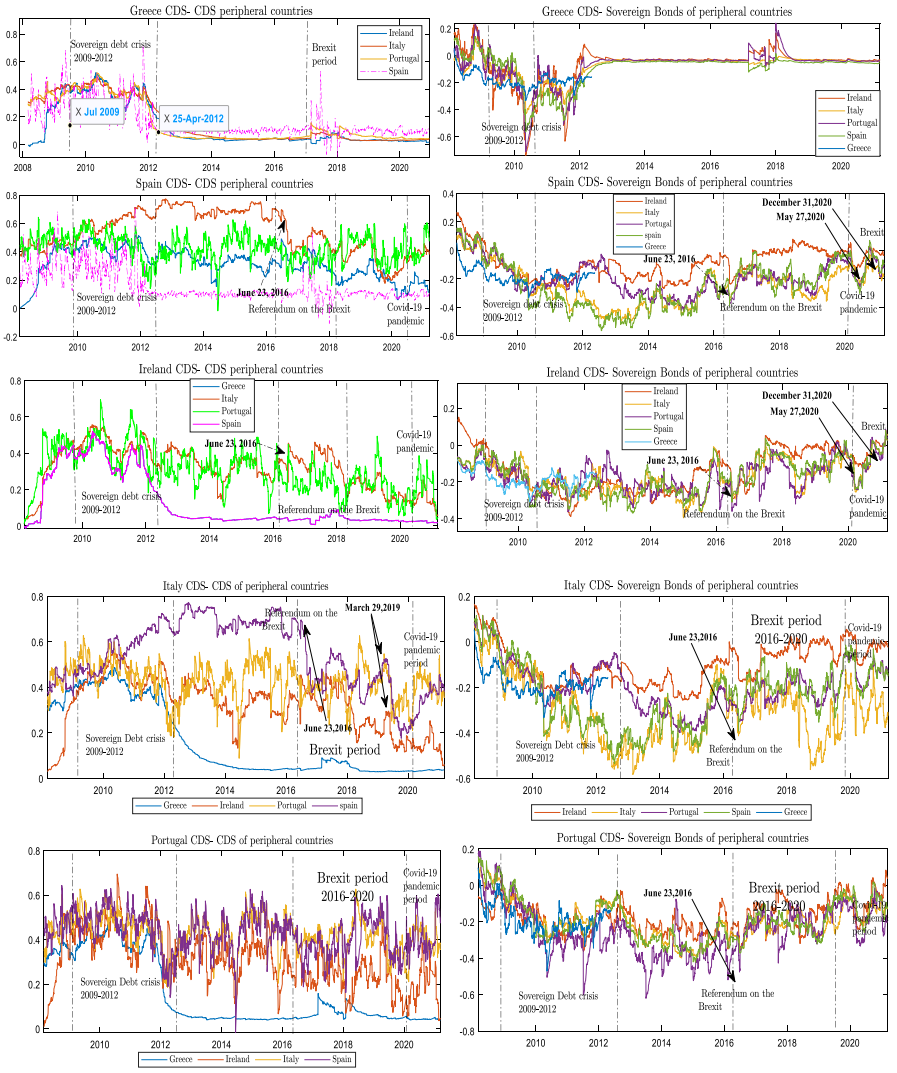

Fig. 2 Daily Kendall's tau correlations within sovereign CDS and sovereign bonds of peripheral European countries

period and a sharp rise during the GFC 2008, European debt crisis 2009–2014, 2016–2020 pre-Brexit and Covid-19 pandemic period. This suggests that major crisis events have a significant enhancement effect on the interdependence among sovereign CDS markets. Nevertheless, the US sovereign CDS and Portuguese sovereign CDS markets exhibits relatively very low dependence, almost zero, indicating an absence of sovereign risk spillovers between these markets. As per the dependence structure between peripheral's sovereign bond markets and sovereign CDS markets of other selected countries, we find that the dependence between all the pairwise markets are significantly negative, presents time-varying characteristics

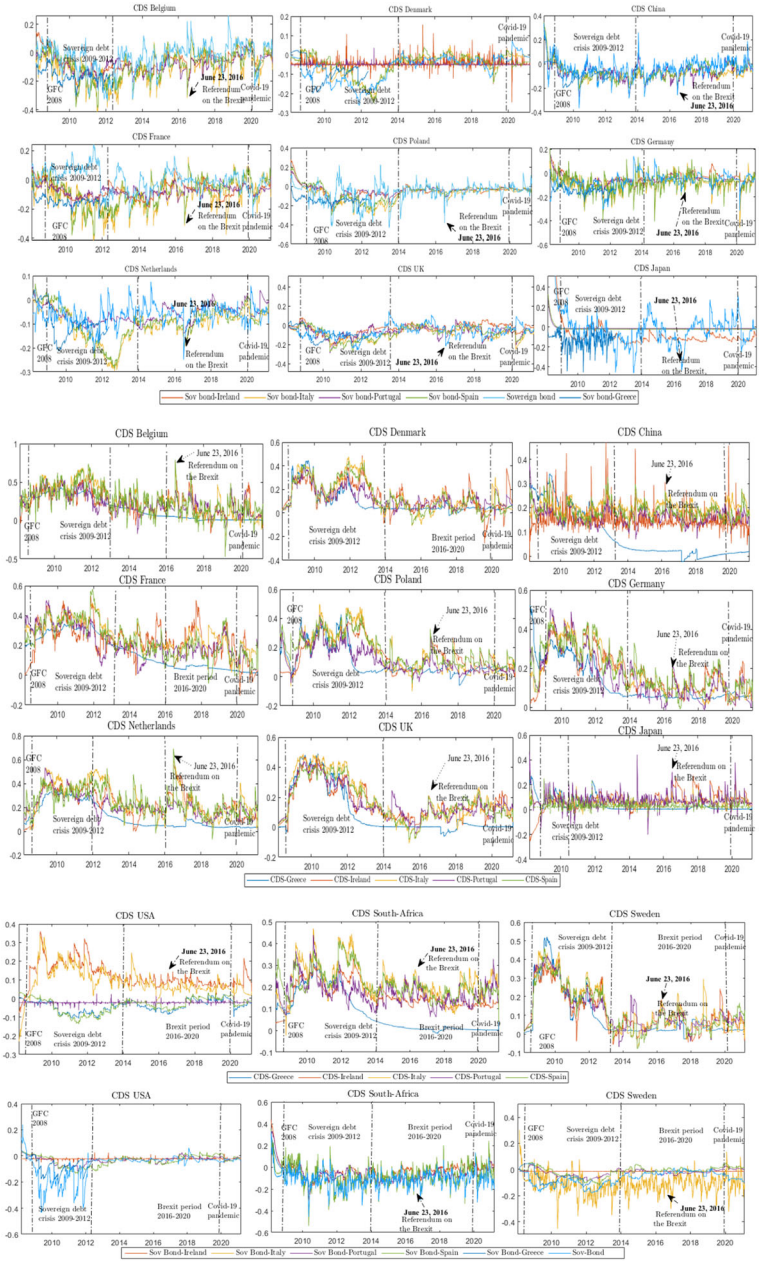

Fig. 3 Daily Kendall's tau correlations among sovereign CDS of European, American, Asian, and African countries and sovereign CDS and sovereign bonds of peripheral European countries

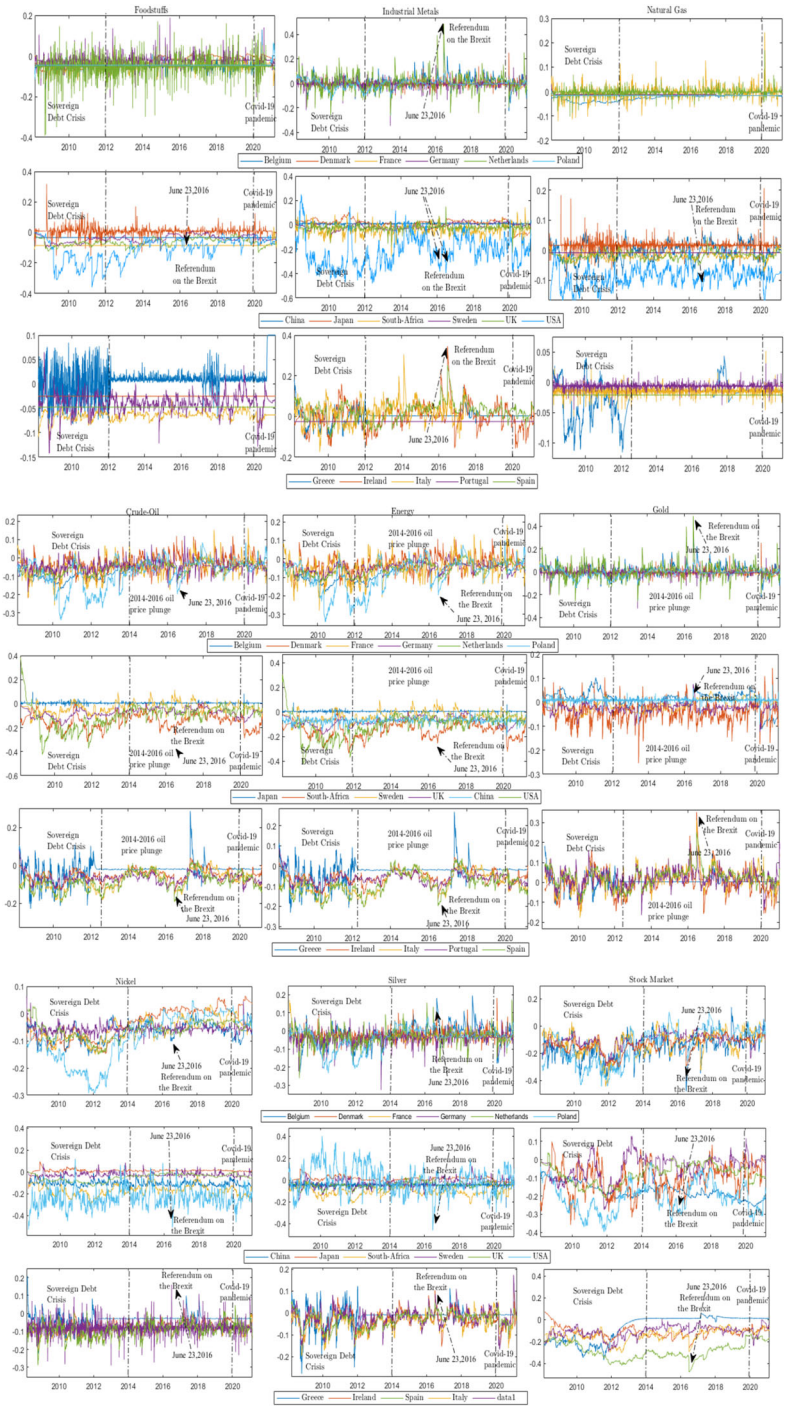

Fig. 4 Daily Kendall's tau correlations between sovereign CDS markets, stock, and commodity markets

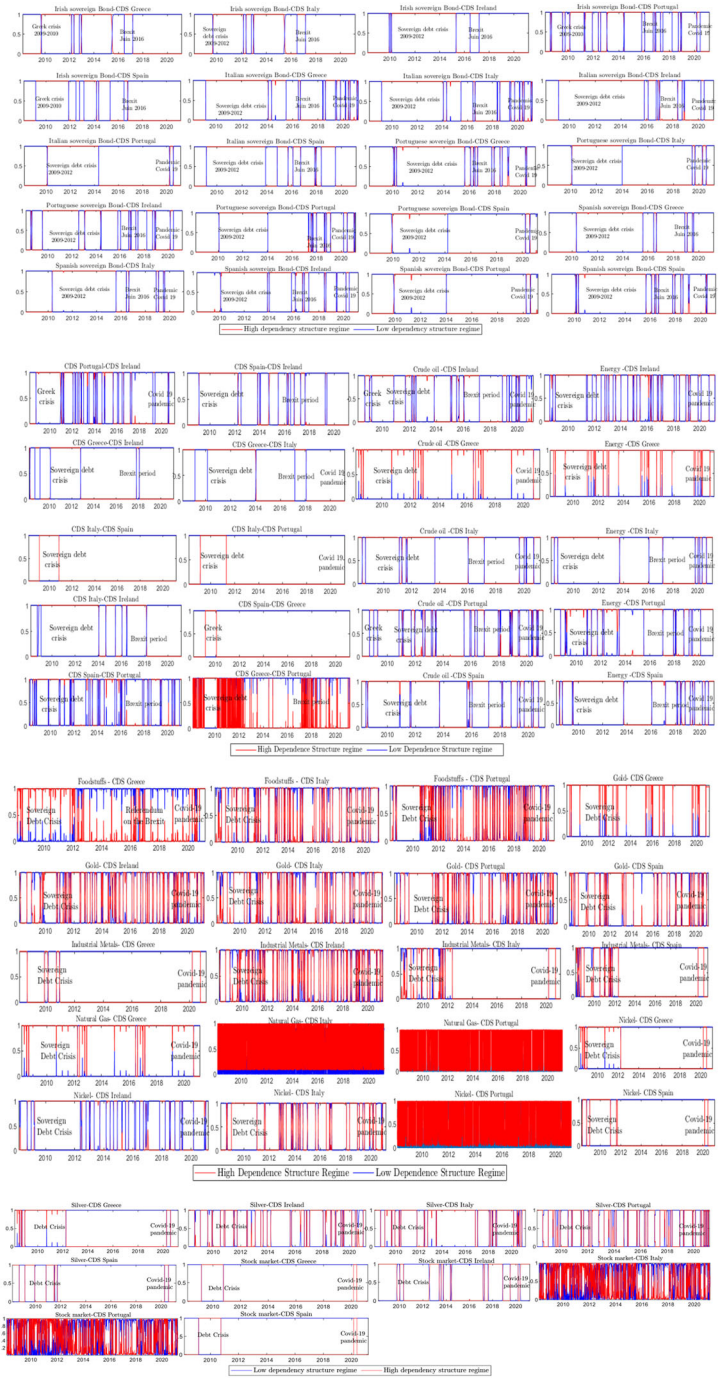

Fig. 5 Plots of switching regime of Kendall's tau correlations between peripheral European sovereign CDS markets with other financial markets

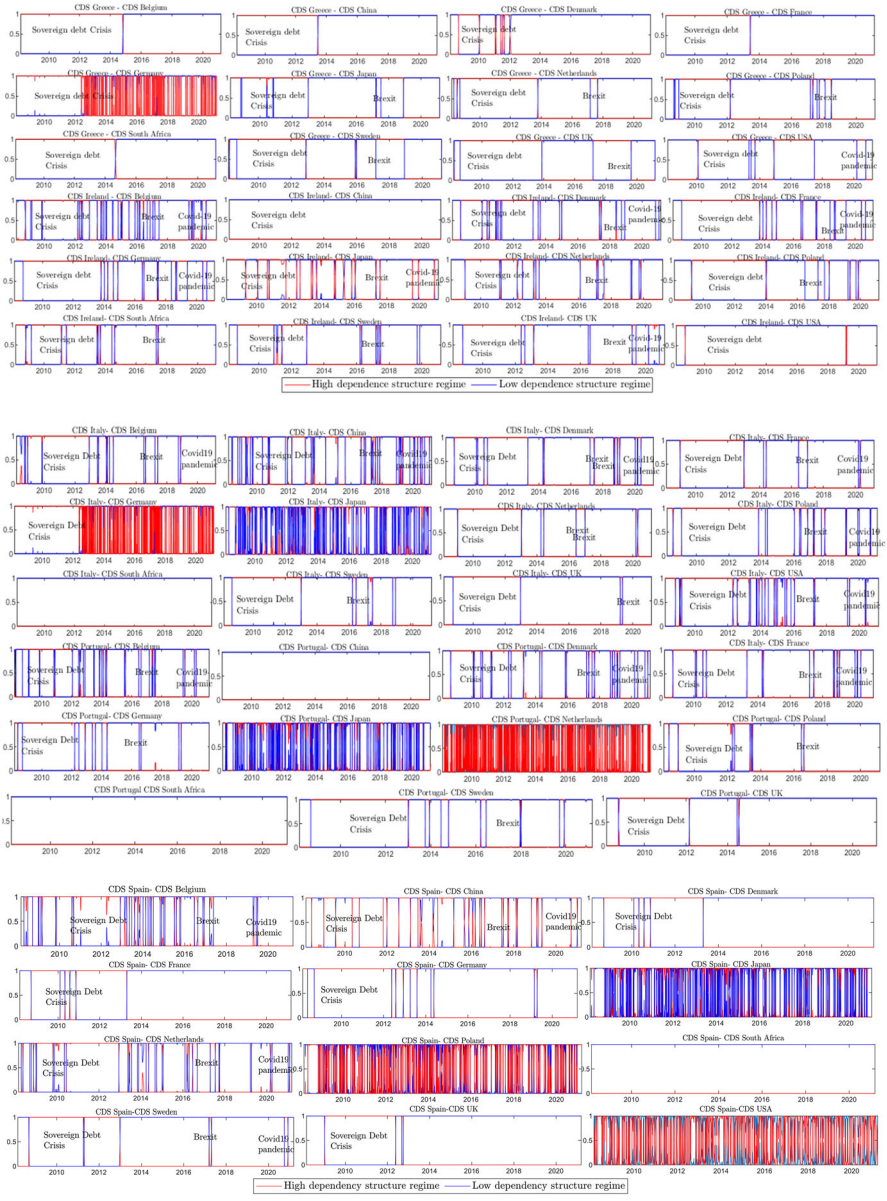

Fig. 6 Plots of switching regime of Kendall's tau correlations within sovereign CDS markets of peripheral European countries and other countries

with a sharp rise during the GFC 2008, sovereign debt crisis 2009–2014, 2016–2020 pre-Brexit and Covid-19 pandemic period, suggesting that sovereign risk spillovers between these markets has been amplified by these global events. However, the coefficients of daily Kendall's tau correlations for American sovereign CDS- Irish sovereign bond, Swedish sovereign CDS-Irish sovereign bond, Japanese sovereign

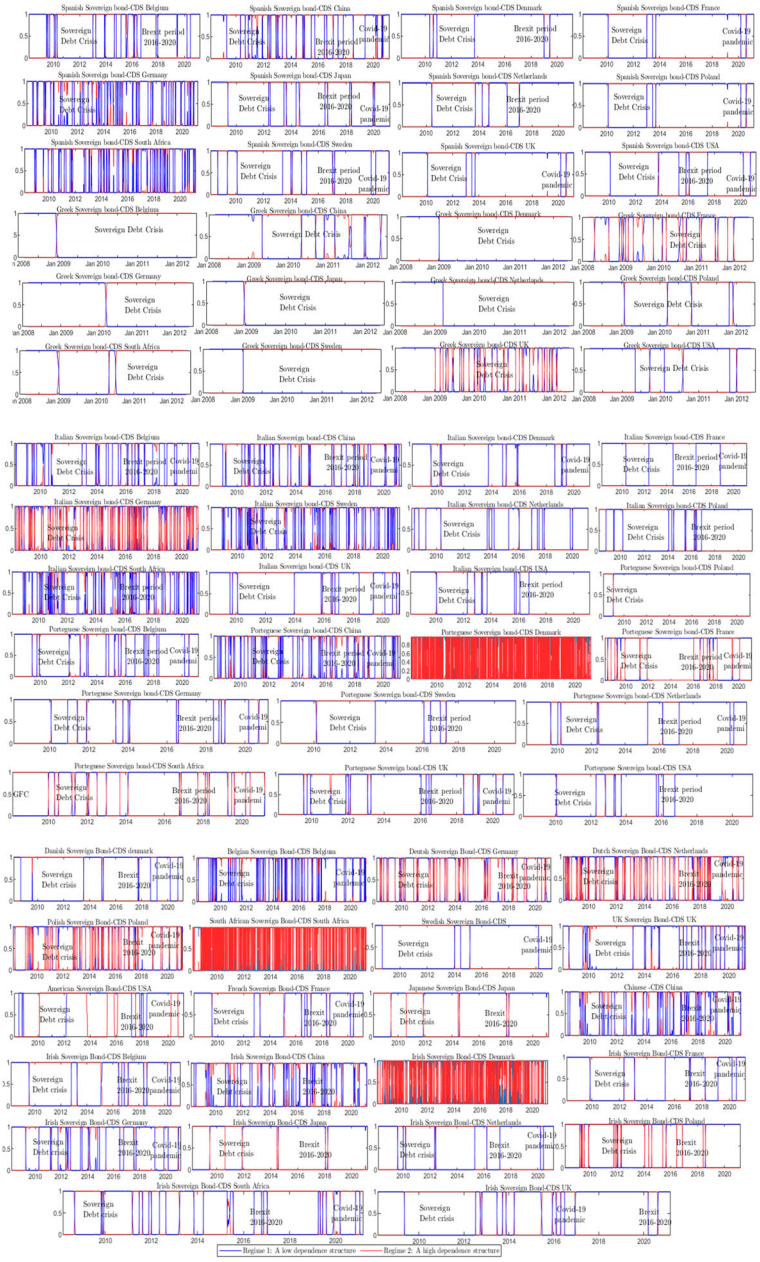

Fig. 7 Plots of Switching regime of Kendall's tau correlations between sovereign CDS markets of European, Asian, American, and African countries and sovereign bond markets of peripheral European countries

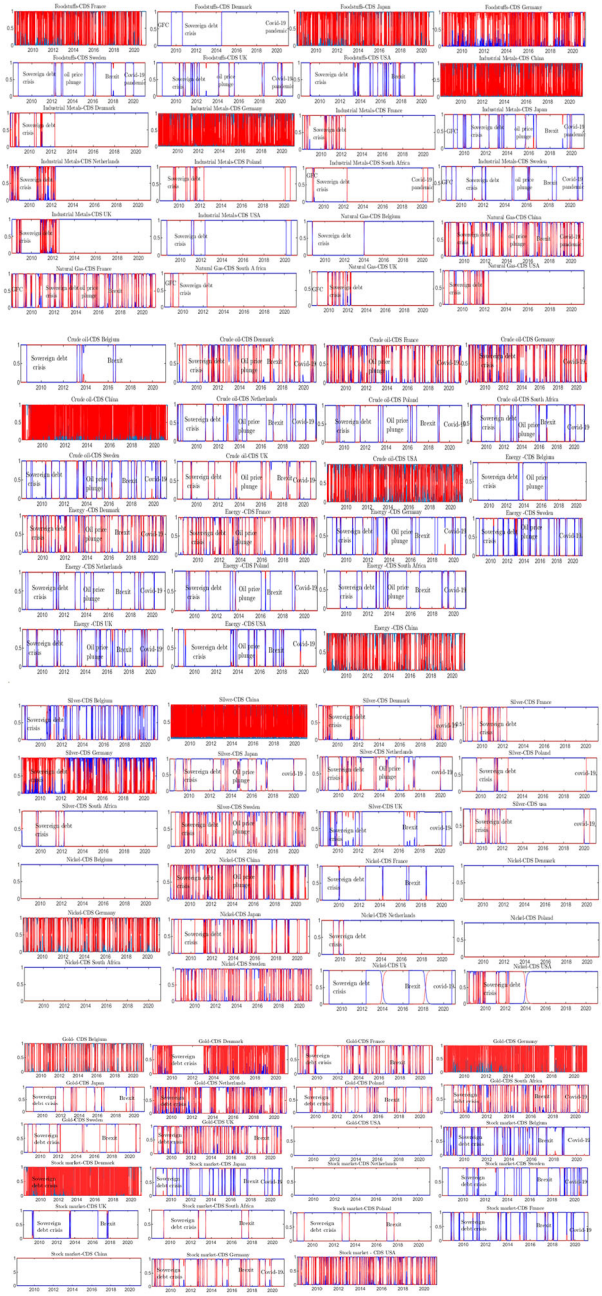

Fig. 8 Plots of switching regime of Kendall's tau correlations between sovereign CDS markets of European, Asian, American, and African countries and commodity and stock markets

CDS-Italian sovereign bond and Japanese sovereign CDS-Portuguese sovereign bond are significant and equal to zero, indicating the absence of sovereign risk spillover effects among these markets.

We observe that crude-oil and energy markets illustrate negative and significant time-varying dependence with all sovereign CDS markets of both peripheral and non-peripheral countries, with a steady dependence with Japanese sovereign CDS market (see Fig. 4), Moreover, the level of dependence is initially low before mid-2008 but has been followed by a gradual uptrend after the GFC 2008. Some positive and negative jumps of the dynamic dependence are observed during the turmoil periods. This finding supports the presence of sovereign risk spillover effects between these markets. As per the natural gas market, we find that the dependence present significant time-varying feature only with sovereign CDS markets of Greece, Italy, Portugal, Belgium, France, Uk, USA, South-Africa and China. Besides, the natural gas market illustrates higher dependence with US sovereign CDS market while exhibits a relatively low dependence with others sovereign CDS markets.

Similarly, the foodstuffs market exhibits a relatively higher dependence with the US sovereign CDS market than with the sovereign CDS markets of Greece, Italy, Portugal, France, Denmark, Germany, Sweden, UK, and Japan. Furthermore, we find that the dependence structure between industrial-metals market and sovereign CDS markets present dynamic feature. Portugal is an exception with a weak and static dependence. For the metals markets, we find that dependence structure between sovereign CDS-Gold, Sovereign CDS-Silver and sovereign CDS-Nickel pairs swing to either positive or negative directions, except the Chinese sovereign CDS-Gold pair. Similarly, the coefficients of daily Kendall's tau correlations of all sovereign CDS-stock market pairs are significant and negative, revealing that these markets move in opposite direction. During 2009, sovereign CDS markets reveal a turbulent rise. Stock market prices has experienced a sharp decline, indicating a negative dependence among these markets. More interestingly, as shown in Fig. 4, the dependence structure experienced a sharp rise on 23 June 2016, which is the day of UK referendum on Brexit, as well as during the Covid-19 pandemic period. This indicates that major geopolitical and public health events intensify dependence among sovereign CDS markets and other financial markets. This clearly suggests the presence of sovereign risk spillover effects during these stress periods.

3.4 Sovereign contagion risk analysis

To determine whether there is interdependence or contagion between the markets, we model the dynamic Kendall's tau correlations time series using MRS-ARMA modelling. We consider time series of daily Kendall's tau correlations with a time-varying characteristics and exclude series that have a steady feature over-time from this analysis. We summarize in "Appendix 4" the MRS-ARMA findings and showing the estimated transition probabilities (P11 and P22) being all significant and different from zero. This indicates that the dependence of different pairwise markets switches between two regimes: a low and a high dependence structure regime. We define the regime 1 with a low volatility as regime of a low dependence structure and the regime 2 with a high volatility as the regime of a high dependence structure.

To assess sovereign contagion risk, we first test if the dependence structure switches from a low dependence structure regime to a high dependence structure regime and if all pairwise markets remain in the same regime of a high dependence structure during the major events chronologically the GFC 2008, European debt crisis 2009, pre-Brexit 20,016–2020 and Covid-19 pandemic period. The results support the evidence of sovereign risk contagion during these major events.

Regarding the dependence structure within peripheral's sovereign CDS markets, the results reported in the "Appendix 4", show that all series are modelled by a MRS model. The exceptions are Italian CDS-Portuguese CDS pair and Italian CDS-Spanish CDS pair modelled respectively by MRS-ARMA (1,1) and MRS-MA (1). The estimated parameters values are all significant at 1% significance level and estimated transition probabilities (P_{11} and P_{22}) are all high enough and close to one. This implies that the dependence structure differs greatly between the two regimes. As shown Fig. 5, we observe that the dependence structure remains in the regime 1 of a low dependence structure until last quarter of 2008 for all pairwise markets, then changes take place in joint probabilities and the dependence structure switches to regime 2 from mid-2009. Furthermore, we observe that all pairwise markets remain in the same regime of high dependence structure during the European debt crisis 2009–2012, indicating the presence of sovereign risk contagion. In addition, we find out that the dependence structure moves from regime 1 to regime 2 during the pre-Brexit period, with less persistence in regime 2 of high dependence structure. Also, we notice that the date of switching of regimes is far apart among pairwise markets.

The dependence of Italian CDS-Portuguese CDS, Italian CDS-Spanish CDS and Spanish CDS-Greek CDS pairs remain in the same regime of low dependence structure till the end of sample period. This allow us to conclude that there is strong interdependence between peripheral's sovereign CDS markets during pre-Brexit and Covid-19 pandemic events. As per the dependence structure between sovereign CDS and sovereign bond markets within peripheral European countries, the results depicted in (see "Appendix 4"), we find that all estimated parameters values are significant at 1% significance level and the estimated transition probabilities P11 and P22 are all high and close to one. This implies that if the sovereign CDS and sovereign bond markets are highly dependent, it is more likely to be persistent (99%) and there is small probability to 1% of moving to low dependent regime 1. So, there is indication that the dependence structure of all pairwise markets is characterized by two separate regimes.

As seen in Fig. 5, the dependence structure for all pairwise move from low to high dependence structure regime, and then remain in high regime during the European debt crisis, pre-Brexit, Covid-19 pandemic events. These results confirm the presence of sovereign risk spillovers running from sovereign CDS to sovereign bonds markets within peripheral European countries, providing evidence of sovereign risk contagion during these crises. The results regarding the dependence structure between sovereign CDS markets of peripherals European countries and other countries, are included in (see "Appendix 4"). For the eurozone countries, we find that the estimated transition probabilities are all high and close to one, implying that the dependence structure switches among the two regimes. The exceptions are the German sovereign CDS-Italian sovereign CDS dependence structure and

Spanish sovereign CDS-Polish sovereign CDS dependence structure, which have low probabilities of being in regime1 during our sample period, respectively 0.41 and 0.47. We observe that regime 2 of high dependence structure is more persistent for all pairwise markets. In addition, we note from Fig. 6 that the dependence structure moves from low to high dependence structure regime, and then stabilize in high dependence during the European debt crisis, indicating that all sovereign CDS markets have been impacted by this major event. We note that there is a regime switch due to pre-Brexit for most pairwise markets, supporting that sovereign CDS markets of core and non-core countries are highly dependent with at least a peripheral country during the pre-Brexit. Therefore, these dependencies confirm the strong interlinkages between core and peripheral countries in the eurozone and support the presence of sovereign risk contagion during pre-Brexit. Moreover, the dependence structure moves from regime 1 to regime 2 during Covid-19 pandemic period suggesting that there is sovereign risk spillovers among sovereign CDS markets which provides evidence of sovereign risk contagion. In the case of US, we note changes of dependence regime with Italy and Ireland to high dependence structure until last quarter of 2008 and a switch to regime of low dependence, and thus indicating a sovereign risk contagion during the GFC. More interestingly, we observe that the dependence structure with Greece remains in the regime of high dependence structure during the period from the first quarter of 2010 until the last quarter of 2013, the sovereign debt crisis, during the last quarter of 2014 to last quarter of 2017, the oil price crisis 2014–2016, pre-Brexit 2016–2020, and finally during the Covid-19 pandemic period. Obviously, these findings provide some evidence major events have caused sovereign risk contagion across sovereign CDS markets of USA and Greece. In the South African case, we observe that dependence structure with Greece remains in the regime of high dependence structure until the first quarter of 2014 and a move to regime of low dependence structure implying the presence of sovereign contagion. Moreover, the dependence structure with Ireland, initially remain in regime 2 until the last quarter of 2008 (GFC 2008), then moves to regime 2 starting the first quarter of 2009 till the last quarter of 2013 in concomitance with the sovereign debt crisis. This regime change reveals strong linkages with Irish sovereign risk, and evidence of sovereign risk contagion. For the dependence structure with Italy, Portugal, and Spain, we find that it remains in the regime of low dependence during the entire sample period, and thus indicating a weak interdependence and not a contagion phenomenon. For Japan, we find no sovereign risk contagion with Italy, Portugal, and Spain. However, the dependence structure with Greece remains in regime 2 until the last quarter of 2012 and then moves to regime of low dependence, revealing sovereign risk contagion during the GFC 2008 and the European debt crisis 2009–2012. In addition, we find evidence of contagion since the dependence structure with Ireland remains at regime 2 during the sovereign debt crisis, oil prices crisis, pre-Brexit, and Covid-19 pandemic period. For China, the Chinese sovereign risk is highly dependent with Greek sovereign risk during the GFC and European debt crisis. Furthermore, we observe also that there is strong interdependence with sovereign risk of Italy and Spain, while a weak interdependence with sovereign risks of Portugal and Ireland. Hence contagion took place only with Greece and Ireland.

Regarding the dependence structure among sovereign bond and sovereign CDS markets, we find, as included in (see "Appendix 4"), that the estimations values of all parameters are significant at 1% significance level. The estimated transition probabilities (P_{11} and P_{22}) are all high and close to one, implying that the occurrence of switches between low and high dependence regimes are infrequent. For the CDS-Bond of South Africa and Irish sovereign bond-Danish sovereign CDS, where the probabilities of being is regime 1 (P_{11}) are respectively 0.5 and 0.47, indicating that regime 2 is more persistent than regime 1 during our sample period, and thus, we have no contagion. Figure 7, indicates that dependency structure of all pairwise markets remain in high regime during the sovereign debt crisis, showing that the sovereign debt crisis has contagious feature and is transmitted from peripheral European countries to other countries. Moreover, results confirm that sovereign risk. In addition, we note the US sovereign risk is highly dependent with the sovereign risk in EU peripherical countries. In China case, we find evidence of sovereign risk contagion during the following periods: the sovereign debt crisis, the collapse of oil price, the Brexit and the Covid pandemic, where there is switching of dependence structure from a low to high regimes. In Japan's case, we confirm that there is strong sovereign risk contagion from peripheral's countries Spain, Greece, and Ireland during the European debt crisis, but weak sovereign contagion during the following periods: collapse of oil price, the GFC, the Brexit and the Covid-19 pandemic.

Regarding the dependence structure between sovereign CDS and commodity markets, we find that all estimation parameters values are significant at 1% significance level. As per the dependence structure between the sovereign CDS and foodstuffs markets, the estimated transition probabilities (P_{11} and P_{22}) are all significantly high, indicating that the dependence structure moves greatly among two regimes. the figures depict that the regime 2 of high dependence structure is more persistent and all pairwise markets remain in regime 2, during the European debt crisis, thus there is strong sovereign risk contagion with sovereign CDS markets of Denmark, Sweden, UK, USA, Greece, Italy, and Portugal, and simply strong interdependence with France, Germany, Japan. Interestingly, there is no contagion effect in the case of dependence between foodstuffs- sovereign CDS of UK and USA since it remains in the regime of low dependency structure, respectively during the Brexit and GFC periods.

For Energy markets, we find a strong interdependence between Natural gas market and peripheral countries sovereign CDS markets. The dependence structure remains in regime of high dependence structure during the entire sample period. For natural gas markets, we note a sovereign contagion effect from sovereign CDS markets of France and China during the oil price collapse, pre-Brexit, and Covid-19 pandemic. Regarding the dependence structure between sovereign CDS and crude oil markets, we find evidence of contagion for all countries during the sovereign debt crisis 2009–2012, Brexit period and Covid-19 pandemic period, except the Poland and Belgium. Furthermore, we observe again a contagion effect during the collapse of oil price for all countries, except peripheral's European countries, Belgium, Poland, and South Africa.

As for the internal dependence structure, we consider the dependence between sovereign CDS and stock markets for various countries. Figures 5 and 8 depict that sovereign CDS markets have strong linkages with stock markets, especially in Italy,

Portugal, Denmark, Netherlands, China, and USA, where we observe that the regime of high dependence structure is more persistent. indicating strong interdependence between sovereign CDS and stock markets in these countries.

4 Conclusion

In this paper, we explore the impact of major crises on the dependence structure between financial markets. A particular focus is made on sovereign risk contagion and transmission across financial markets during major crisis, Sovereign debt crisis, pre-Brexit and Covid-19 pandemic. Using a methodology that test for the existence of possible time-varying dependence among sovereign CDS, stock markets, as well as commodity markets, using a dynamic Kendall's tau correlation that is developed using the copula and the DCC-GARCH models. We identify breakpoints of the daily Kendall's tau correlations series and dependence structure, using Markov Regime-Switching ARMA models. We identify the presence of sovereign risk contagion by testing whether there is a switching of dependence from low to high dependence structure regimes. Results indicate that sovereign CDS indexes can serve as hedge assets against risks in various markets. Moreover, there is evidence of time-varying dependence structure among all pairwise markets, implying that investors and portfolio managers should frequently revise their investment strategies. Using MRS-ARMA modelling, we find that the dependence structure switches regimes from low dependence structure, or weak interdependence, to regime of high dependence structure, or strong interdependence. Moreover, we find that there is switching of regimes, and the dependence structure moves to a high regime during major crisis events, such as pre-Brexit, the European debt crisis 2009–2012, and Covid-19 pandemic. This indicates that the major global crisis events have intensified the sovereign risk spillovers effects among financial markets of the peripheral's European countries and other countries.

An accurate modelling of dependence structure between financial markets is major importance for investors and policy makers and supports hedging strategies and public policy design. Investors ought to be aware of the type of regime change and the duration of the dependence during different market states. This methodology would help to determining the appropriate assets to manage extreme risks. Significant time-varying characteristics of dynamic dependence structures suggests that fund managers and investors should take into account in their investment strategies to manage systemic risk estimation and high-risk investment. Enhancing the mechanism of response to major crisis is of fundamental importance allowing market participants to properly react to global crisis in a timely manner and take appropriate strategies, to minimize risk and losses. Indeed, our methodology offers a proper tool to provide information regarding time-varying characteristics of dependence structure between sovereign CDS markets and other financial markets.

Appendix 1: Pearson. Spearman rho and Kendall's tau correlations

See Tables 4, 5, 6, 7.

Table 4 Correlation matrix of peripheral European countries

		Pearson correlation					Spearman rho				
		Sovereign CDS									
		Greece	Ireland	Italy	Portugal	Spain	Greece	Ireland	Italy	Portugal	Spain
Sovereign CDS	Greece	1.000					1.000				
	Ireland	0.305	1.000				0.273	1.000			
	Italy	0.358	0.446	1.000			0.317	0.476	1.000		
	Portugal	0.367	0.469	0.653	1.000		0.305	0.471	0.627	1.000	
	Spain	0.298	0.399	0.668	0.598	1.000	0.305	0.479	0.741	0.630	1.000
Sovereign bonds	Greece	− 0.349	− 0.201	− 0.226	− 0.286	− 0.188	− 0.270	− 0.138	− 0.139	− 0.155	− 0.149
	Ireland	− 0.176	− 0.255	− 0.203	− 0.247	− 0.163	− 0.099	− 0.185	− 0.169	− 0.184	− 0.157
	Italy	− 0.101	− 0.251	− 0.430	− 0.308	− 0.350	− 0.077	− 0.221	− 0.461	− 0.311	− 0.376
	Portugal	− 0.196	− 0.222	− 0.257	− 0.367	− 0.224	− 0.102	− 0.224	− 0.275	− 0.345	− 0.252
	Spain	− 0.151	− 0.258	− 0.408	− 0.316	− 0.366	− 0.090	− 0.214	− 0.357	− 0.267	− 0.351
Stock markets	Greece	− 0.211	− 0.247	− 0.343	− 0.325	− 0.289	− 0.179	− 0.202	− 0.299	− 0.267	− 0.275
	Ireland	− 0.146	− 0.167	− 0.265	− 0.224	− 0.247	− 0.132	− 0.182	− 0.264	− 0.221	− 0.263
	Italy	− 0.193	− 0.283	− 0.458	− 0.385	− 0.389	− 0.167	− 0.262	− 0.444	− 0.353	− 0.412
	Spain	− 0.187	− 0.287	− 0.452	− 0.384	− 0.402	− 0.172	− 0.285	− 0.441	− 0.367	− 0.419
	Portugal	− 0.08	− 0.25	− 0.40	− 0.38	− 0.33	− 0.075	− 0.270	− 0.389	− 0.338	− 0.367
Commodity markets	Crude-Oil	− 0.079	− 0.128	− 0.138	− 0.153	− 0.144	− 0.074	− 0.090	− 0.138	− 0.117	− 0.130
	Energy	− 0.083	− 0.146	− 0.142	− 0.152	− 0.154	− 0.085	− 0.101	− 0.150	− 0.125	− 0.143

Table 4 continued

		Pearson correlation					Spearman rho				
		Sovereign CDS									
		Greece	Ireland	Italy	Portugal	Spain	Greece	Ireland	Italy	Portugal	Spain
	Foodstuffs	− 0.045	− 0.061	− 0.120	− 0.089	− 0.093	− 0.057	− 0.041	− 0.104	− 0.065	− 0.095
	Gold	0.025	0.041	0.017	0.018	0.001	0.026	0.032	0.008	0.021	0.022
	Industrial metals	0.025	0.041	0.017	0.018	0.001	0.026	0.031	0.008	0.021	0.022
	Natural gas	− 0.059	− 0.050	− 0.062	− 0.052	− 0.049	− 0.030	− 0.037	− 0.045	− 0.033	− 0.033
	Nickel	− 0.092	− 0.113	− 0.162	− 0.145	− 0.154	− 0.094	− 0.117	− 0.156	− 0.139	− 0.152
	Silver	− 0.068	− 0.105	− 0.119	− 0.098	− 0.094	− 0.058	− 0.034	− 0.075	− 0.062	− 0.067

		Kendall's tau				
		Sovereign CDS				
		Greece	Ireland	Italy	Portugal	Spain
Sovereign CDS	Greece	1.000				
	Ireland	0.214	1.000			
	Italy	0.247	0.348	1.000		
	Portugal	0.239	0.343	0.468	1.000	
	Spain	0.238	0.353	0.579	0.475	1.000
Sovereign bonds	Greece	− 0.238	− 0.106	− 0.107	− 0.119	− 0.116
	Ireland	− 0.077	− 0.127	− 0.116	− 0.126	− 0.108
	Italy	− 0.059	− 0.151	− 0.327	− 0.214	− 0.263
	Portugal	− 0.077	− 0.154	− 0.191	− 0.241	− 0.174
	Spain	− 0.069	− 0.147	− 0.250	− 0.185	− 0.246

Table 4 continued

		Kendall's tau				
		Sovereign CDS				
		Greece	Ireland	Italy	Portugal	Spain
Stock markets	Greece	− 0.137	− 0.139	− 0.206	− 0.184	− 0.188
	Ireland	− 0.101	− 0.125	− 0.182	− 0.151	− 0.181
	Italy	− 0.128	− 0.181	− 0.312	− 0.246	− 0.288
	Spain	− 0.132	− 0.198	− 0.309	− 0.255	− 0.294
	Portugal	− 0.058	− 0.185	− 0.269	− 0.233	− 0.255
Commodity markets	Crude-Oil	− 0.056	− 0.061	− 0.094	− 0.080	− 0.089
	Energy	− 0.064	− 0.069	− 0.102	− 0.085	− 0.097
	Foodstuffs	− 0.043	− 0.028	− 0.070	− 0.044	− 0.064
	Gold	0.020	0.022	0.005	0.014	0.015
	Industrial metals	0.020	0.022	0.005	0.014	0.015
	Natural gas	− 0.022	− 0.025	− 0.030	− 0.022	− 0.022
	Nickel	− 0.072	− 0.081	− 0.107	− 0.095	− 0.104
	Silver	− 0.045	− 0.023	− 0.051	− 0.043	− 0.045

All parameters are significant at 5% level of significance

Table 5 Pearson correlation matrix of changes of sovereign CDC spreads of European, Asian, American and African countries among changes of sovereign CDS and bonds spreads, stock and commodities returns

		Sovereign CDS											
		Belgium	Denmark	France	Germany	Netherlands	Poland	Sweden	UK	USA	China	Japan	South Africa
Sovereign CDS	Greece	0.247	0.162	0.269	0.210	0.257	0.279	0.119	0.175	0.155	0.198	0.072	0.234
	Ireland	0.334	0.193	0.330	0.249	0.343	0.247	0.128	0.261	0.179	0.187	0.065	0.264
	Italy	0.406	0.199	0.429	0.274	0.400	0.354	0.151	0.296	0.199	0.301	0.091	0.422
	Portugal	0.390	0.206	0.402	0.263	0.384	0.280	0.143	0.277	0.195	0.279	0.093	0.333
	Spain	0.355	0.179	0.356	0.259	0.340	0.301	0.132	0.247	0.202	0.250	0.073	0.327
	sov-bond	− 0.1288	− 0.112	− 0.0101	− 0.1276	− 0.048	− 0.109	− 0.102	− 0.092	− 0.035	− 0.007	− 0.108	− 0.001
Sovereign bonds	Greece	− 0.157	− 0.072	− 0.124	− 0.099	− 0.095	− 0.150	− 0.035	− 0.100	− 0.073	− 0.127	− 0.022	− 0.134
	Ireland	− 0.127	− 0.059	− 0.096	− 0.075	− 0.087	− 0.094	− 0.036	− 0.066	− 0.048	− 0.061	− 0.004	− 0.067
	Italy	− 0.178	− 0.088	− 0.170	− 0.156	− 0.163	− 0.145	− 0.050	− 0.144	− 0.063	− 0.121	− 0.012	− 0.187
	Portugal	− 0.143	− 0.071	− 0.106	− 0.100	− 0.098	− 0.113	− 0.052	− 0.083	− 0.054	− 0.123	− 0.033	− 0.110
	Spain	− 0.195	− 0.088	− 0.182	− 0.133	− 0.169	− 0.150	− 0.056	− 0.124	− 0.074	− 0.123	− 0.015	− 0.160
Stock markets	Greece	− 0.212	− 0.102	− 0.179	− 0.171	− 0.211	− 0.234	− 0.064	− 0.166	− 0.134	− 0.265	− 0.040	− 0.336
	Ireland	− 0.149	− 0.081	− 0.145	− 0.123	− 0.153	− 0.277	− 0.049	− 0.125	− 0.161	− 0.241	− 0.005	− 0.361
	Italy	− 0.264	− 0.123	− 0.234	− 0.201	− 0.270	− 0.307	− 0.088	− 0.170	− 0.156	− 0.276	− 0.007	− 0.448
	Portugal	− 0.212	− 0.093	− 0.1778	− 0.157	− 0.244	− 0.288	− 0.065	− 0.148	− 0.101	− 0.311	− 0.060	− 0.469
	Spain	− 0.263	− 0.131	− 0.218	− 0.200	− 0.276	− 0.315	− 0.095	− 0.166	− 0.179	− 0.298	− 0.009	− 0.468
	Stock market	− 0.235	− 0.0651	− 0.2009	− 0.171	− 0.118	− 0.239	− 0.087	− 0.149	− 0.096	− 0.244	− 0.296	− 0.392
	Crude-Oil	− 0.116	− 0.050	− 0.095	− 0.067	− 0.125	− 0.136	− 0.043	− 0.118	− 0.082	− 0.139	− 0.015	− 0.244

Table 5 continued

		Sovereign CDS											
		Belgium	Denmark	France	Germany	Netherlands	Poland	Sweden	UK	USA	China	Japan	South Africa
Commodity markets	Energy	− 0.125	− 0.055	− 0.090	− 0.080	− 0.110	− 0.145	− 0.047	− 0.121	− 0.083	− 0.135	− 0.010	− 0.247
	Foodstuffs	− 0.098	− 0.054	− 0.090	− 0.052	− 0.123	− 0.093	− 0.065	− 0.102	− 0.058	− 0.074	− 0.018	− 0.142
	Gold	0.030	0.034	0.054	0.026	0.048	0.033	0.026	0.032	0.024	0.022	0.026	0.084
	Industrial metals	0.030	0.034	0.053	0.026	0.048	0.033	0.026	0.032	0.024	0.022	0.027	0.083
	Natural Gas	− 0.038	− 0.028	− 0.021	− 0.027	− 0.024	− 0.044	− 0.007	− 0.048	− 0.043	− 0.031	− 0.019	− 0.050
	Nickel	− 0.105	− 0.052	− 0.094	− 0.104	− 0.134	− 0.202	− 0.032	− 0.087	− 0.108	− 0.167	− 0.051	− 0.262
	Silver	− 0.083	− 0.057	− 0.111	− 0.073	− 0.130	− 0.108	− 0.046	− 0.083	− 0.031	− 0.093	− 0.032	− 0.193

Table 6 Spearman rho correlation matrix of changes of sovereign CDC spreads of European, Asian, American and African countries among changes of sovereign CDS and bonds spreads, and stock and commodities returns

		Sovereign CDS											
		Belgium	Denmark	France	Germany	Netherlands	Poland	Sweden	UK	USA	China	Japan	South Africa
Sovereign CDS	Greece	0.270	0.202	0.240	0.236	0.238	0.230	0.196	0.217	0.159	0.141	0.105	0.197
	Ireland	0.428	0.281	0.405	0.309	0.382	0.292	0.285	0.302	0.232	0.226	0.111	0.247
	Italy	0.432	0.286	0.408	0.336	0.376	0.315	0.269	0.334	0.247	0.310	0.117	0.376
	Portugal	0.399	0.232	0.374	0.292	0.348	0.266	0.279	0.283	0.217	0.252	0.145	0.304
	Spain	0.439	0.277	0.423	0.329	0.368	0.303	0.268	0.297	0.236	0.285	0.120	0.340
Sovereign bonds	sov-bond	− 0.015	− 0.175	− 0.025	− 0.160	− 0.128	− 0.102	− 0.163	− 0.108	− 0.103	− 0.005	− 0.077	− 0.004
	Greece	− 0.134	− 0.093	− 0.115	− 0.098	− 0.118	− 0.119	− 0.078	− 0.079	− 0.086	− 0.085	− 0.015	− 0.068
	Ireland	− 0.092	− 0.044	− 0.104	− 0.081	− 0.069	− 0.098	− 0.014	− 0.093	− 0.051	− 0.078	− 0.047	− 0.058
	Italy	− 0.166	− 0.095	− 0.201	− 0.158	− 0.166	− 0.141	− 0.073	− 0.145	− 0.097	− 0.133	− 0.022	− 0.189
	Portugal	− 0.134	− 0.081	− 0.120	− 0.103	− 0.104	− 0.102	− 0.055	− 0.116	− 0.050	− 0.122	− 0.058	− 0.105
	Spain	− 0.145	− 0.089	− 0.182	− 0.143	− 0.147	− 0.122	− 0.042	− 0.134	− 0.096	− 0.110	− 0.028	− 0.133
Stock markets	Stock market	− 0.152	− 0.059	− 0.222	− 0.195	− 0.226	− 0.256	− 0.1587	− 0.147	− 0.094	− 0.246	− 0.234	− 0.350
	Greece	− 0.219	− 0.132	− 0.188	− 0.159	− 0.194	− 0.188	− 0.148	− 0.141	− 0.116	− 0.236	− 0.105	− 0.278
	Ireland	− 0.184	− 0.094	− 0.178	− 0.123	− 0.164	− 0.202	− 0.122	− 0.102	− 0.107	− 0.194	− 0.044	− 0.322
	Italy	− 0.298	− 0.181	− 0.249	− 0.220	− 0.248	− 0.271	− 0.191	− 0.164	− 0.163	− 0.224	− 0.082	− 0.409
	Portugal	− 0.251	− 0.147	− 0.204	− 0.174	− 0.205	− 0.240	− 0.174	− 0.148	− 0.141	− 0.267	− 0.100	− 0.399
	Spain	− 0.295	− 0.183	− 0.251	− 0.215	− 0.249	− 0.281	− 0.182	− 0.170	− 0.169	− 0.250	− 0.062	− 0.436
Commodity markets	Crude-Oil	− 0.120	− 0.085	− 0.102	− 0.098	− 0.099	− 0.153	− 0.096	− 0.112	− 0.106	− 0.105	− 0.021	− 0.238
	Energy	− 0.131	− 0.083	− 0.101	− 0.103	− 0.104	− 0.165	− 0.107	− 0.119	− 0.109	− 0.105	− 0.032	− 0.249

Table 6 continued

	Sovereign CDS											
	Belgium	Denmark	France	Germany	Netherlands	Poland	Sweden	UK	USA	China	Japan	South Africa
Foodstuffs	− 0.081	− 0.065	− 0.084	− 0.057	− 0.072	− 0.081	− 0.070	− 0.091	− 0.038	− 0.049	− 0.022	− 0.129
Gold	0.036	0.014	0.013	0.003	0.012	0.006	0.020	0.009	0.025	0.029	0.013	0.085
Industrial metals	0.036	0.015	0.013	0.003	0.012	0.006	0.020	0.009	0.026	0.029	0.013	0.085
Natural gas	− 0.035	− 0.018	− 0.022	− 0.042	− 0.012	− 0.036	− 0.021	− 0.022	− 0.029	− 0.012	− 0.002	− 0.018
Nickel	− 0.110	− 0.062	− 0.096	− 0.113	− 0.105	− 0.159	− 0.090	− 0.091	− 0.105	− 0.150	− 0.032	− 0.258
Silver	− 0.038	− 0.033	− 0.073	− 0.060	− 0.043	− 0.063	− 0.036	− 0.056	− 0.025	− 0.041	− 0.022	− 0.174

Table 7 Kendall's tau correlation matrix of changes of sovereign CDC spreads of European, Asian, American and African countries among changes of sovereign CDS and bonds spreads, and stock and commodities returns

		Sovereign CDS											
		Belgium	Denmark	France	Germany	Netherlands	Poland	Sweden	UK	USA	China	Japan	South Africa
Sovereign CDS	Greece	0.211	0.164	0.193	0.192	0.192	0.180	0.158	0.169	0.131	0.108	0.082	0.152
	Ireland	0.324	0.215	0.307	0.234	0.289	0.215	0.216	0.217	0.176	0.158	0.078	0.172
	Italy	0.312	0.211	0.306	0.248	0.276	0.224	0.196	0.238	0.183	0.216	0.082	0.264
	Portugal	0.289	0.171	0.280	0.215	0.257	0.188	0.208	0.200	0.160	0.175	0.102	0.212
	Spain	0.319	0.205	0.317	0.244	0.271	0.217	0.196	0.210	0.175	0.198	0.084	0.237
Sovereign bonds	sov-bond	− 0.008	− 0.127	− 0.018	− 0.115	− 0.091	− 0.070	− 0.117	− 0.074	− 0.0744	− 0.003	− 0.053	− 0.003
	Greece	− 0.104	− 0.075	− 0.093	− 0.079	− 0.095	− 0.094	− 0.063	− 0.061	− 0.071	− 0.065	− 0.011	− 0.052
	Ireland	− 0.061	− 0.030	− 0.073	− 0.057	− 0.047	− 0.068	− 0.008	− 0.064	− 0.036	− 0.053	− 0.033	− 0.039
	Italy	− 0.113	− 0.066	− 0.144	− 0.112	− 0.117	− 0.097	− 0.051	− 0.100	− 0.070	− 0.091	− 0.015	− 0.129
	Portugal	− 0.092	− 0.057	− 0.086	− 0.074	− 0.073	− 0.071	− 0.039	− 0.080	− 0.036	− 0.084	− 0.041	− 0.071
	Spain	− 0.099	− 0.063	− 0.130	− 0.102	− 0.104	− 0.084	− 0.029	− 0.093	− 0.069	− 0.075	− 0.019	− 0.091
Stock markets	Stock market	− 0.188	− 0.042	− 0.159	− 0.140	− 0.161	− 0.179	− 0.113	− 0.101	− 0.0681	− 0.169	− 0.162	− 0.2426
	Greece	− 0.150	− 0.094	− 0.133	− 0.113	− 0.137	− 0.130	− 0.106	− 0.097	− 0.084	− 0.161	− 0.072	− 0.191
	Ireland	− 0.126	− 0.066	− 0.127	− 0.087	− 0.116	− 0.141	− 0.087	− 0.070	− 0.078	− 0.133	− 0.030	− 0.223
	Italy	− 0.206	− 0.130	− 0.177	− 0.158	− 0.176	− 0.190	− 0.137	− 0.114	− 0.118	− 0.153	− 0.056	− 0.287
	Portugal	− 0.171	− 0.104	− 0.144	− 0.123	− 0.143	− 0.167	− 0.124	− 0.100	− 0.101	− 0.184	− 0.068	− 0.278
	Spain	− 0.204	− 0.132	− 0.180	− 0.155	− 0.178	− 0.198	− 0.130	− 0.118	− 0.123	− 0.172	− 0.043	− 0.306
Commodity markets	Crude-Oil	− 0.081	− 0.061	− 0.072	− 0.070	− 0.070	− 0.105	− 0.068	− 0.077	− 0.077	− 0.071	− 0.014	− 0.164
	Energy	− 0.089	− 0.059	− 0.071	− 0.074	− 0.073	− 0.114	− 0.075	− 0.082	− 0.079	− 0.071	− 0.022	− 0.171

Table 7 continued

	Sovereign CDS											
	Belgium	Denmark	France	Germany	Netherlands	Poland	Sweden	UK	USA	China	Japan	South Africa
Foodstuffs	− 0.055	− 0.047	− 0.059	− 0.040	− 0.051	− 0.056	− 0.050	− 0.062	− 0.027	− 0.033	− 0.016	− 0.088
Gold	0.025	0.010	0.009	0.003	0.008	0.004	0.015	0.006	0.018	0.020	0.009	0.059
Industrial metals	0.025	0.010	0.009	0.002	0.008	0.004	0.015	0.006	0.019	0.020	0.009	0.059
Natural Gas	− 0.024	− 0.013	− 0.016	− 0.030	− 0.008	− 0.025	− 0.015	− 0.015	− 0.021	− 0.008	0.002	− 0.012
Nickel	− 0.075	− 0.045	− 0.068	− 0.080	− 0.074	− 0.111	− 0.064	− 0.063	− 0.077	− 0.103	− 0.022	− 0.177
Silver	− 0.026	− 0.023	− 0.051	− 0.043	− 0.030	− 0.043	− 0.026	− 0.038	− 0.018	− 0.028	− 0.015	− 0.120

Appendix 2: The bivariate copula estimations of sovereign CDS markets and other financial markets. The parameters of different copulas ρ, θ, N, τ_U and τ_L are all significant at 5% level of significance. The LL represents the loglikelihood

See Tables 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23.

Table 8 Bivariate Copula estimation of Spanish sovereign CDS market and other markets

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.299	159.207	0.334	117.072	0.390	157.235	2.372	127.216	1.637	115.420	1.229	182.406
	Ireland	0.489	464.684	0.753	396.285	0.790	424.165	6.248	555.149	3.588	478.566	1.513	530.305
	Italy	0.742	1359.643	1.723	1163.005	1.848	1262.998	23.023	1697.453	7.489	1461.108	2.274	1535.471
	Portugal	0.646	916.145	1.192	750.732	1.309	846.435	12.514	1085.911	5.401	930.201	1.866	1023.623
Sovereign bonds	Greece	− 0.148	37.761	0.147	29.299	0.201	51.934	1.547	29.636	0.775	26.023	1.116	63.090
	Ireland	− 0.179	55.364	0.000	0.041	0.000	0.036	0.561	52.986	0.000	0.009	1.100	100.016
	Italy	− 0.390	280.818	0.000	0.110	0.000	0.111	0.277	293.846	0.002	0.396	1.100	189.885
	Portugal	− 0.267	125.227	0.000	0.063	0.000	0.065	0.411	132.481	0.000	0.014	1.100	143.474
	Spain	− 0.383	269.933	0.000	0.105	0.000	0.108	0.292	263.922	0.002	0.384	1.100	187.401
Commodity markets	Crude–Oil	− 0.144	35.787	0.000	0.033	0.000	0.034	0.654	31.498	0.003	0.254	1.100	43.000
	Energy	− 0.155	41.600	0.000	0.033	0.000	0.037	0.628	38.006	0.000	0.010	1.100	57.792
	Foodstuffs	− 0.105	18.724	0.000	0.025	0.000	0.026	0.739	16.447	0.004	0.212	1.100	11.817
	Gold	− 0.015	0.358	0.025	1.029	0.032	1.673	1.078	0.952	0.140	0.887	1.100	18.917
	Industrial metals	− 0.015	0.364	0.026	1.108	0.032	1.673	1.078	0.957	0.141	0.892	1.100	18.840
	Natural gas	− 0.044	3.227	0.000	0.013	0.000	0.011	0.903	1.933	0.000	0.003	1.100	56.520
	Nickel	− 0.162	45.345	0.000	0.042	0.000	0.036	0.608	43.429	0.003	0.277	1.100	102.600
	Silver	− 0.058	5.797	0.072	7.921	0.069	7.123	1.221	6.504	0.366	5.952	1.100	1.081

Table 8 continued

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
	Stock market	− 0.436	358.598	0.000	0.117	0.000	0.119	0.248	357.861	0.002	0.411	1.100	212.523

		Rotated Gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.211	158.574	0.278	5.312	294.555	0.184	0.108	200.779
	Ireland	1.498	507.993	0.522	3.068	621.309	0.358	0.317	554.765
	Italy	2.237	1475.539	0.786	2.359	1729.035	0.622	0.575	1540.840
	Portugal	1.834	963.618	0.678	2.615	1140.342	0.525	0.456	1047.207
Sovereign bonds	Greece	1.100	47.656	− 0.133	4.617	89.954	0.080	0.013	63.996
	Ireland	1.100	99.686	− 0.174	4.884	106.387	0.000	0.000	20.686
	Italy	1.100	191.502	− 0.400	5.895	330.905	0.000	0.000	41.287
	Portugal	1.100	143.977	− 0.272	6.696	152.863	0.000	0.000	30.703
	Spain	1.100	181.306	− 0.380	5.577	312.275	0.000	0.000	45.004
Commodity markets	Crude–Oil	1.100	41.943	− 0.141	9.283	52.843	0.000	0.000	17.581
	Energy	1.100	55.203	− 0.154	8.563	62.468	0.000	0.000	19.405
	Foodstuffs	1.100	11.790	− 0.104	17.827	23.409	0.000	0.000	13.806
	Gold	1.100	23.440	− 0.021	8.233	30.068	0.000	0.000	1.975
	Industrial metals	1.100	23.240	− 0.021	8.155	27.660	0.000	0.000	2.014
	Natural Gas	1.100	61.799	− 0.043	69.471	73.552	0.000	0.000	5.372
	Nickel	1.100	106.659	− 0.163	10.767	157.260	0.000	0.000	21.167
	Silver	1.100	0.448	− 0.060	7.368	28.612	0.000	0.002	10.725
	Stock market	1.100	209.042	− 0.442	6.952	393.844	0.000	0.000	49.201

Table 9 Bivariate copula estimation of Greek sovereign CDS market and other markets

		Normal		Clayton		Rotated Clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Ireland	0.298	158.339	0.340	119.983	0.398	163.340	2.382	125.833	1.620	112.189	1.234	193.498
	Italy	0.319	182.832	0.370	144.366	0.405	169.825	2.378	131.483	1.669	121.131	1.238	199.104
	Portugal	0.313	174.832	0.369	140.069	0.409	167.473	2.416	135.748	1.697	124.751	1.241	202.436
	Spain	0.299	159.207	0.334	117.072	0.390	157.235	2.372	127.216	1.637	115.420	1.229	182.406
	Greece	− 0.424	337.043	0.925	415.046	0.988	471.660	117.328	2228.536	5.636	703.031	1.737	688.085
Sovereign bonds	Ireland	− 0.140	33.708	0.000	0.019	0.000	0.020	0.557	42.641	0.003	0.242	1.100	57.400
	Italy	− 0.079	10.692	0.000	0.014	0.000	0.023	0.812	7.666	0.000	0.004	1.100	69.002
	Portugal	− 0.138	32.859	0.000	0.013	0.000	0.042	0.654	28.229	0.004	0.235	1.100	88.003
	Spain	− 0.103	18.071	0.000	0.001	0.000	0.033	0.726	15.516	0.000	0.005	1.100	70.840
	Crude-Oil	− 0.068	7.796	0.000	0.025	0.000	0.011	0.873	3.323	0.000	0.003	1.100	59.916
Commodity markets	Energy	− 0.077	10.216	0.000	0.026	0.000	0.014	0.839	5.526	0.000	0.003	1.100	64.936
	Foodstuffs	− 0.050	4.198	0.000	0.006	0.000	0.007	0.878	2.693	0.000	0.002	1.100	46.767
	Gold	− 0.023	0.897	0.001	0.001	0.003	0.019	0.958	0.291	0.000	0.002	1.100	33.467
	Industrial metals	− 0.023	0.936	0.001	0.000	0.003	0.019	0.958	0.296	0.000	0.002	1.100	33.518
	Natural gas	− 0.050	4.202	0.000	0.006	0.000	0.018	0.890	2.350	0.000	0.003	1.100	62.553
	Nickel	− 0.080	10.897	0.000	0.018	0.000	0.009	0.817	6.341	0.000	0.003	1.100	49.910
	Silver	− 0.050	4.265	0.000	0.013	0.008	0.118	0.867	3.027	0.000	0.002	1.100	33.755
	Stock market	− 0.279	138.032	0.000	0.068	0.000	0.067	0.424	136.540	0.002	0.362	1.100	155.153

		Rotated Gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Ireland	1.217	166.072	0.270	4.169	216.085	0.191	0.115	212.124
	Italy	1.226	183.607	0.287	5.457	266.647	0.183	0.137	229.867

Table 9 continued

		Rotated Gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
	Portugal	1.227	182.216	0.288	4.721	243.287	0.189	0.133	228.006
	Spain	1.211	158.574	0.278	5.312	294.555	0.184	0.108	200.779
	Greece	1.729	663.932	− 0.892	2.100	1793.471	0.444	0.391	647.863
Sovereign bonds	Ireland	1.100	61.765	− 0.134	2.286	236.923	0.000	0.000	11.498
	Italy	1.100	63.566	− 0.073	10.618	73.762	0.000	0.000	7.209
	Portugal	1.100	71.582	− 0.126	4.572	94.430	0.000	0.000	10.713
	Spain	1.100	54.620	− 0.094	4.148	86.881	0.000	0.000	7.521
	Crude-Oil	1.100	68.172	− 0.062	24.205	70.071	0.000	0.000	7.410
Commodity markets	Energy	1.100	71.070	− 0.072	21.062	83.094	0.000	0.000	8.057
	Foodstuffs	1.100	46.694	− 0.041	6.044	56.897	0.000	0.000	5.092
	Gold	1.100	35.890	− 0.015	6.159	43.257	0.000	0.000	1.668
	Industrial metals	1.100	35.798	− 0.015	6.127	53.849	0.000	0.000	1.689
	Natural gas	1.100	52.823	− 0.045	18.718	77.722	0.000	0.000	5.655
	Nickel	1.100	59.329	− 0.061	4.845	62.505	0.000	0.000	5.854
	Silver	1.100	48.622	− 0.039	4.696	55.093	0.000	0.000	3.368
	Stock market	1.100	154.962	− 0.286	10.529	163.270	0.000	0.000	32.116

Table 10 Bivariate copula estimation of Portuguese sovereign CDS market and other markets

		Normal		Clayton		Rotated Clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.313	174.832	0.369	140.069	0.409	167.473	2.416	135.748	1.697	124.751	1.241	202.436
	Ireland	0.498	484.394	0.719	375.008	0.837	471.323	5.997	533.122	3.498	461.079	1.523	561.782
	Italy	0.652	939.103	1.166	748.431	1.267	839.187	11.215	1028.095	5.269	906.188	1.840	1003.276
	Spain	0.646	916.145	1.192	750.732	1.309	846.435	12.514	1085.911	5.401	930.201	1.866	1023.623
Sovereign bonds	Greece	− 0.175	52.896	0.181	44.253	0.224	64.596	1.597	35.119	0.847	31.313	1.129	77.972
	Ireland	− 0.214	79.890	0.000	0.052	0.000	0.047	0.515	70.878	0.000	0.011	1.100	111.868
	Italy	− 0.325	190.151	0.000	0.099	0.000	0.100	0.358	189.423	0.002	0.375	1.100	166.341
	Portugal	− 0.368	247.086	0.000	0.104	0.000	0.105	0.301	251.288	0.000	0.020	1.100	181.672
	Spain	− 0.295	154.657	0.000	0.064	0.000	0.094	0.395	147.011	0.002	0.352	1.100	152.898
Commodity markets	Crude-Oil	− 0.136	31.519	0.000	0.033	0.000	0.030	0.686	24.849	0.004	0.238	1.100	87.360
	Energy	− 0.139	33.386	0.000	0.032	0.000	0.032	0.670	28.073	0.004	0.247	1.100	91.453
	Foodstuffs	− 0.079	10.510	0.000	0.018	0.000	0.018	0.808	7.938	0.000	0.004	1.100	65.748
	Gold	− 0.009	0.125	0.018	0.534	0.029	1.365	1.073	0.846	0.132	0.791	1.100	20.530
	Industrial metals	− 0.009	0.127	0.019	0.585	0.029	1.365	1.074	0.853	0.133	0.797	1.100	20.456
	Natural gas	− 0.042	2.996	0.000	0.010	0.000	0.013	0.904	1.892	0.000	0.002	1.100	56.977
	Nickel	− 0.147	37.341	0.000	0.037	0.000	0.030	0.634	36.120	0.003	0.263	1.100	88.075
	Silver	− 0.019	0.597	0.043	2.970	0.022	0.786	1.080	0.970	0.141	0.894	1.100	25.072
	Stock market	− 0.076	8.251	0.000	0.024	0.000	0.001	0.805	6.693	0.000	0.003	1.100	43.509

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.227	182.216	0.288	4.721	323.287	0.189	0.133	228.006
	Ireland	1.487	494.996	0.512	3.111	616.095	0.397	0.280	581.157

Table 10 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
	Italy	1.812	950.633	0.667	3.289	1087.791	0.514	0.450	1039.371
	Spain	1.834	963.618	0.678	2.615	1140.342	0.525	0.456	1047.207
Sovereign bonds	Greece	1.113	62.670	− 0.145	4.739	103.979	0.089	0.031	84.912
	Ireland	1.100	117.911	− 0.201	5.565	217.111	0.000	0.000	26.489
	Italy	1.100	168.396	− 0.329	8.361	212.380	0.000	0.000	36.382
	Portugal	1.100	182.402	− 0.370	6.224	280.809	0.000	0.000	42.334
	Spain	1.100	146.579	− 0.289	6.012	189.447	0.000	0.000	36.210
Commodity markets	Crude-Oil	1.100	88.501	− 0.127	8.836	150.027	0.000	0.000	17.146
	Energy	1.100	89.592	− 0.134	8.840	152.398	0.000	0.000	16.568
	Foodstuffs	1.100	66.915	− 0.074	12.040	120.295	0.000	0.000	10.070
	Gold	1.100	24.921	− 0.019	7.761	123.156	0.000	0.000	1.418
	Industrial metals	1.100	24.707	− 0.019	7.692	123.781	0.000	0.000	1.456
	Natural gas	1.100	56.421	− 0.040	33.645	104.333	0.000	0.000	6.875
	Nickel	1.100	98.842	− 0.147	8.435	156.686	0.000	0.000	12.393
	Silver	1.100	16.214	− 0.021	8.032	119.449	0.000	0.000	2.909
	Stock market	1.100	61.523	− 0.073	8.905	123.138	0.000	0.000	5.561

Table 11 Bivariate copula estimation of Italian sovereign CDS market and other markets

		Normal		Clayton		Rotated Clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.319	182.832	0.370	144.366	0.405	169.825	2.378	131.483	1.669	121.131	1.238	199.104
	Ireland	0.502	492.563	0.781	419.159	0.797	444.206	6.195	557.064	3.585	477.617	1.517	544.813
	Portugal	0.652	939.103	1.166	748.431	1.267	839.187	11.215	1028.095	5.269	906.188	1.840	1003.276
	Spain	0.742	1359.643	1.723	1163.005	1.848	1262.998	23.023	1697.453	7.489	1461.108	2.274	1535.471
Sovereign bonds	Greece	− 0.151	39.129	0.171	41.092	0.193	49.140	1.499	24.875	0.707	21.471	1.116	65.975
	Ireland	− 0.199	68.440	0.000	0.050	0.000	0.037	0.538	60.887	0.003	0.287	1.100	102.490
	Italy	− 0.484	454.596	0.000	0.129	0.000	0.126	0.202	463.779	0.002	0.417	1.100	224.754
	Portugal	− 0.288	146.956	0.000	0.067	0.000	0.067	0.376	159.537	0.002	0.355	1.100	147.250
	Spain	− 0.397	290.832	0.000	0.106	0.000	0.109	0.288	271.550	0.000	0.020	1.100	189.532
Commodity markets	Crude-Oil	− 0.148	37.689	0.000	0.036	0.000	0.032	0.640	35.034	0.003	0.263	1.100	94.454
	Energy	− 0.159	43.680	0.000	0.035	0.000	0.037	0.614	41.866	0.000	0.009	1.100	99.894
	Foodstuffs	− 0.117	23.599	0.000	0.028	0.000	0.030	0.719	19.735	0.000	0.006	1.100	87.658
	Gold	− 0.002	0.006	0.004	0.032	0.026	1.160	1.022	0.079	0.040	0.074	1.100	25.105
	Industrial metals	− 0.002	0.006	0.005	0.047	0.026	1.160	1.022	0.080	0.041	0.075	1.100	25.038
	Natural gas	− 0.058	5.821	0.000	0.013	0.000	0.019	0.867	3.740	0.000	0.004	1.100	65.841
	Nickel	− 0.166	47.643	0.000	0.044	0.000	0.035	0.597	45.833	0.000	0.011	1.100	99.045
	Silver	− 0.069	8.169	0.071	7.715	0.076	8.581	1.213	6.604	0.372	6.337	1.100	4.991
	Stock market	− 0.469	422.926	0.000	0.127	0.000	0.123	0.229	405.519	0.002	0.417	1.100	219.853

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.226	183.607	0.287	5.457	316.647	0.183	0.137	229.867
	Ireland	1.514	537.890	0.517	3.007	642.493	0.359	0.335	587.545

Table 11 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
	Portugal	1.812	950.633	0.667	3.289	1087.791	0.514	0.450	1039.371
	Spain	2.237	1475.539	0.786	2.359	1729.035	0.622	0.575	1540.840
Sovereign bonds	Greece	1.107	61.703	− 0.118	3.807	115.210	0.066	0.038	73.019
	Ireland	1.100	110.859	− 0.187	4.450	127.532	0.000	0.000	15.645
	Italy	1.100	228.467	− 0.492	5.551	506.968	0.000	0.000	53.766
	Portugal	1.100	148.912	− 0.295	5.387	194.169	0.000	0.000	28.928
	Spain	1.100	186.889	− 0.388	5.426	332.630	0.000	0.000	44.219
Commodity markets	Crude-Oil	1.100	97.196	− 0.147	9.874	154.063	0.000	0.000	18.614
	Energy	1.100	98.866	− 0.160	8.773	165.095	0.000	0.000	18.776
	Foodstuffs	1.100	84.788	− 0.115	16.186	129.315	0.000	0.000	16.251
	Gold	1.100	32.572	0.004	8.093	121.084	0.000	0.000	0.582
	Industrial metals	1.100	32.386	0.004	8.013	121.738	0.000	0.000	0.615
	Natural gas	1.100	64.232	− 0.058	57.818	106.244	0.000	0.000	6.572
	Nickel	1.100	108.991	− 0.167	8.927	164.569	0.000	0.000	14.114
	Silver	1.100	3.028	− 0.067	14.037	15.445	0.001	0.001	11.361
	Stock market	1.100	224.317	− 0.471	6.872	458.573	0.000	0.000	52.407

Table 12 Bivariate copula estimation of Irish sovereign CDS market and other markets

	Ireland	Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.298	158.339	0.340	119.983	0.398	163.340	2.382	125.833	1.620	112.189	1.234	193.498
	Italy	0.502	492.563	0.781	419.159	0.797	444.206	6.195	557.064	3.585	477.617	1.517	544.813
	Portugal	0.498	484.394	0.719	375.008	0.837	471.323	5.997	533.122	3.498	461.079	1.523	561.782
	Spain	0.489	464.684	0.753	396.285	0.790	424.165	6.248	555.149	3.588	478.566	1.513	530.305
Sovereign bonds	Greece	− 0.156	41.774	0.171	38.700	0.199	51.108	1.597	33.508	0.822	29.014	1.120	65.126
	Ireland	− 0.229	91.926	0.000	0.055	0.000	0.051	0.522	70.038	0.003	0.299	0.003	114.528
	Italy	− 0.245	105.500	0.000	0.064	0.000	0.055	0.483	93.394	0.003	0.327	1.100	131.566
	Portugal	− 0.249	109.165	0.000	0.055	0.000	0.063	0.464	100.699	0.000	0.013	1.100	136.154
	Spain	− 0.252	111.148	0.000	0.058	0.000	0.064	0.490	89.260	0.003	0.322	1.100	133.455
Commodity markets	Crude-Oil	− 0.113	21.971	0.000	0.029	0.000	0.027	0.757	14.197	0.004	0.204	1.100	80.171
	Energy	− 0.124	26.268	0.000	0.029	0.000	0.031	0.731	17.853	0.004	0.219	1.100	86.202
	Foodstuffs	− 0.054	4.894	0.000	0.011	0.000	0.013	0.875	3.124	0.000	0.003	1.100	55.410
	Gold	− 0.003	0.014	0.000	0.002	0.027	1.119	1.098	1.563	0.181	1.507	1.100	21.677
	Industrial metals	− 0.002	0.008	0.000	0.002	0.027	1.116	1.098	1.552	0.180	1.496	1.100	21.747
	Natural gas	− 0.051	4.500	0.000	0.012	0.000	0.016	0.887	2.649	0.000	0.002	1.100	61.800
	Nickel	− 0.123	25.928	0.000	0.031	0.000	0.025	0.684	24.665	0.004	0.236	1.100	80.168
	Silver	− 0.006	0.065	0.029	1.501	0.033	1.890	1.022	0.076	0.039	0.068	1.100	20.141
	Stock market	− 0.189	61.683	0.000	0.046	0.000	0.040	0.556	60.296	0.003	0.300	1.100	106.417

	Ireland	Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.217	166.072	0.270	4.169	316.085	0.191	0.115	212.124
	Italy	1.514	537.890	0.517	3.007	642.493	0.359	0.335	587.545

Table 12 continued

	Ireland	Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
	Portugal	1.487	494.996	0.512	3.111	616.095	0.397	0.280	581.157
	Spain	1.498	507.993	0.522	3.068	621.309	0.358	0.317	554.765
Sovereign bonds	Greece	1.110	56.889	− 0.138	4.240	104.772	0.069	0.031	69.121
	Ireland	1.100	122.087	− 0.204	5.029	136.979	0.000	0.000	27.137
	Italy	1.100	138.131	− 0.240	8.848	222.608	0.000	0.000	31.283
	Portugal	1.100	131.021	− 0.245	6.477	238.630	0.000	0.000	31.109
	Spain	1.100	132.582	− 0.238	7.913	230.310	0.000	0.000	31.045
Commodity markets	Crude-Oil	1.100	83.851	− 0.105	13.713	130.137	0.000	0.000	15.567
	Energy	1.100	86.517	− 0.116	12.622	136.073	0.000	0.000	15.351
	Foodstuffs	1.100	55.629	− 0.049	13.163	112.624	0.000	0.000	5.237
	Gold	1.100	36.100	− 0.018	10.262	114.052	0.000	0.000	0.321
	Industrial metals	1.100	36.053	− 0.018	10.147	114.435	0.000	0.000	0.504
	Natural gas	1.100	61.539	− 0.050	34.189	105.747	0.000	0.000	5.769
	Nickel	1.100	90.255	− 0.123	8.859	143.007	0.000	0.000	10.539
	Silver	1.100	18.861	− 0.007	5.567	141.553	0.000	0.000	2.466
	Stock market	1.100	114.775	− 0.192	7.350	189.105	0.000	0.000	15.157

Table 13 Bivariate copula estimation of Belgian sovereign CDS market and other markets

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.277	135.901	0.326	108.949	0.352	129.181	2.425	127.486	1.627	111.814	1.216	159.953
	Ireland	0.423	334.387	0.628	288.320	0.662	319.208	6.129	475.554	3.211	381.209	1.434	410.157
	Italy	0.449	382.869	0.640	309.303	0.704	366.726	4.914	429.647	3.110	376.421	1.442	444.932
	Portugal	0.414	319.242	0.539	239.550	0.611	302.788	4.392	359.310	2.823	315.878	1.382	359.868
	Spain	0.444	373.382	0.636	304.365	0.686	347.861	5.029	438.498	3.153	385.873	1.438	428.885
Sovereign bonds	Greece	− 0.147	37.134	0.158	32.765	0.183	42.697	1.589	33.057	0.818	28.823	1.113	55.944
	Ireland	− 0.121	25.163	0.000	0.031	0.000	0.022	0.715	17.702	0.004	0.205	1.100	72.751
	Italy	− 0.189	62.052	0.000	0.044	0.000	0.043	0.571	53.518	0.003	0.285	1.100	110.214
	Portugal	− 0.151	39.339	0.000	0.028	0.000	0.038	0.607	38.620	0.003	0.255	1.100	95.622
	Spain	− 0.183	57.986	0.000	0.037	0.000	0.045	0.593	43.726	0.003	0.265	1.100	105.070
	Belgium	− 0.066	7.396	0.000	0.013	0.000	0.017	0.944	0.534	0.000	0.002	1.100	52.345
Commodity markets	Crude-Oil	− 0.131	29.577	0.000	0.035	0.000	0.030	0.693	24.906	0.004	0.243	1.100	92.335
	Energy	− 0.140	33.710	0.000	0.036	0.000	0.034	0.670	29.715	0.003	0.256	1.100	98.398
	Foodstuffs	− 0.093	14.834	0.000	0.021	0.000	0.025	0.773	11.704	0.000	0.006	1.100	75.907
	Gold	− 0.018	0.539	0.000	0.000	0.042	2.706	1.119	2.228	0.216	2.145	1.100	18.721
	Industrial metals	− 0.018	0.545	0.001	0.001	0.042	2.707	1.119	2.240	0.217	2.157	1.100	18.651
	Natural gas	− 0.043	3.174	0.000	0.007	0.000	0.016	0.896	2.250	0.000	0.003	1.100	61.575
	Nickel	− 0.118	23.679	0.000	0.033	0.000	0.023	0.700	22.208	0.000	0.006	1.100	80.674
	Silver	− 0.055	5.159	0.000	0.018	0.000	0.006	0.881	2.778	0.000	0.003	1.100	51.028
	Stock market	− 0.182	57.408	0.000	0.035	0.000	0.053	0.631	35.960	0.003	0.259	1.100	108.342

Table 13 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.209	147.641	0.269	4.396	187.854	0.154	0.116	172.414
	Ireland	1.423	390.755	0.490	2.629	520.399	0.308	0.264	418.595
	Italy	1.425	409.035	0.469	3.332	512.035	0.333	0.260	464.902
	Portugal	1.362	320.555	0.431	4.227	396.504	0.296	0.202	370.005
	Spain	1.422	400.766	0.475	3.534	493.864	0.322	0.259	442.873
Sovereign bonds	Greece	1.103	48.769	− 0.140	4.841	82.073	0.059	0.024	57.194
	Ireland	1.100	78.607	− 0.104	5.434	92.751	0.000	0.000	9.952
	Italy	1.100	107.105	− 0.183	7.054	189.745	0.000	0.000	20.231
	Portugal	1.100	86.488	− 0.149	5.304	178.228	0.000	0.000	12.288
	Spain	1.100	97.968	− 0.163	5.072	101.740	0.000	0.000	14.682
	Belgium	1.100	54.700	− 0.031	6.986	131.678	0.000	0.000	9.003
Commodity markets	Crude-Oil	1.100	95.475	− 0.130	19.891	133.822	0.000	0.000	18.196
	Energy	1.100	98.933	− 0.140	20.611	137.642	0.000	0.000	17.982
	Foodstuffs	1.100	72.785	− 0.090	14.675	121.079	0.000	0.000	8.758
	Gold	1.100	32.560	− 0.026	14.214	77.950	0.001	0.000	1.740
	Industrial metals	1.100	32.403	− 0.026	13.931	78.346	0.000	0.000	2.034
	Natural gas	1.100	58.074	− 0.043	64.668	73.551	0.000	0.000	5.293
	Nickel	1.100	92.651	− 0.118	12.657	131.592	0.000	0.000	10.760
	Silver	1.100	65.384	− 0.049	12.225	114.093	0.000	0.000	5.738
	Stock market	1.100	101.869	− 0.160	6.776	181.727	0.000	0.000	15.643

Table 14 Bivariate copula estimation of French sovereign CDS market and other markets

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.271	129.768	0.317	105.393	0.335	120.046	2.499	128.382	1.625	110.521	1.208	147.288
	Ireland	0.404	302.148	0.588	268.761	0.604	276.843	5.031	398.359	2.937	329.119	1.395	362.373
	Italy	0.416	322.639	0.588	278.542	0.617	296.332	4.541	371.398	2.856	318.006	1.394	374.633
	Portugal	0.384	270.602	0.502	219.352	0.551	252.555	4.063	311.435	2.596	266.776	1.347	314.656
	Spain	0.410	312.632	0.589	272.437	0.606	282.100	4.706	389.908	2.944	336.777	1.394	362.290
Sovereign bonds	Greece	− 0.143	35.173	0.159	32.282	0.181	41.297	1.740	43.282	0.926	35.922	1.116	55.923
	Ireland	− 0.118	23.648	0.000	0.026	0.000	0.026	0.675	24.609	0.000	0.006	1.100	77.914
	Italy	− 0.207	74.562	0.000	0.052	0.000	0.042	0.510	76.473	0.003	0.310	1.100	113.036
	Portugal	− 0.125	26.684	0.000	0.026	0.000	0.027	0.645	30.577	0.004	0.243	1.100	82.510
	Spain	0.000	0.045	0.000	0.047	0.528	67.409	0.003	0.299	1.100	111.670	1.100	111.497
	France	0.012	0.234	0.035	1.914	0.022	0.754	1.062	0.588	0.110	0.537	1.100	19.386
Commodity markets	Crude-Oil	− 0.105	18.824	0.000	0.027	0.000	0.024	0.738	16.338	0.000	0.005	1.100	78.363
	Energy	− 0.104	18.437	0.000	0.026	0.000	0.022	0.739	16.190	0.004	0.210	1.100	76.968
	Foodstuffs	− 0.095	15.328	0.000	0.019	0.000	0.028	0.765	12.661	0.000	0.005	1.100	80.130
	Gold	− 0.026	1.171	0.000	0.002	0.000	0.006	0.968	0.186	0.000	0.002	1.100	43.866
	Industrial metals	− 0.026	1.106	0.000	0.002	0.000	0.006	0.968	0.179	0.000	0.002	1.100	43.738
	Natural gas	− 0.033	1.798	0.000	0.008	0.000	0.009	0.930	0.965	0.000	0.002	1.100	54.550
	Nickel	− 0.105	18.805	0.000	0.026	0.000	0.024	0.739	15.716	0.004	0.206	1.100	78.194
	Silver	− 0.090	13.944	0.000	0.022	0.000	0.021	0.793	9.222	0.000	0.004	1.100	70.056
	Stock market	− 0.222	85.990	0.000	0.053	0.000	0.050	0.487	88.809	0.003	0.324	1.100	123.802

Table 14 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.201	139.663	0.266	4.783	174.743	0.139	0.110	161.847
	Ireland	1.387	352.002	0.451	2.852	459.676	0.277	0.253	377.775
	Italy	1.383	357.459	0.435	3.175	453.316	0.285	0.249	399.185
	Portugal	1.331	284.432	0.400	3.608	366.454	0.260	0.196	327.419
	Spain	1.384	351.364	0.448	3.374	442.580	0.276	0.249	378.317
Sovereign bonds	Greece	1.105	48.630	− 0.153	4.143	96.491	0.058	0.022	55.186
	Ireland	1.100	82.669	− 0.119	6.939	146.675	0.000	0.000	14.176
	Italy	1.100	122.004	− 0.211	6.744	105.563	0.000	0.000	16.608
	Portugal	1.100	83.549	− 0.130	6.518	154.551	0.000	0.000	14.423
	Spain	− 0.197	6.060	− 0.197	6.060	126.161	0.000	0.000	23.348
	France	1.100	24.389	− 0.017	7.296	25.379	0.000	0.000	1.875
Commodity markets	Crude-Oil	1.100	81.531	− 0.103	13.701	126.717	0.000	0.000	9.430
	Energy	1.100	80.024	− 0.103	11.677	129.542	0.000	0.000	9.066
	Foodstuffs	1.100	75.426	− 0.093	18.562	118.889	0.000	0.000	9.318
	Gold	1.100	41.524	− 0.018	11.887	110.687	0.000	0.000	2.923
	Industrial metals	1.100	41.322	− 0.017	11.905	110.621	0.000	0.000	2.853
	Natural gas	1.100	52.040	− 0.031	42.782	102.561	0.000	0.000	6.421
	Nickel	1.100	82.364	− 0.103	12.191	127.204	0.000	0.000	13.953
	Silver	1.100	70.189	− 0.082	10.606	125.682	0.000	0.000	11.571
	Stock market	1.100	128.997	− 0.230	6.681	177.370	0.000	0.000	26.113

Table 15 Bivariate copula estimation of German sovereign CDS market and other markets

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.266	124.770	0.323	106.077	0.308	96.155	2.627	146.224	1.754	129.846	1.202	128.854
	Ireland	0.310	171.491	0.379	129.831	0.441	176.735	3.348	219.616	2.139	183.635	1.274	219.089
	Italy	0.335	201.974	0.423	166.388	0.435	173.151	3.140	220.260	2.182	197.730	1.276	219.062
	Portugal	0.292	151.510	0.349	120.220	0.377	139.146	2.705	164.013	1.868	147.578	1.233	171.135
	Spain	0.320	183.119	0.397	144.490	0.424	167.376	3.033	204.341	2.095	183.167	1.263	206.187
Sovereign bonds	Greece	− 0.134	30.609	0.166	34.049	0.134	22.282	1.753	45.142	0.950	38.237	1.100	38.313
	Ireland	− 0.098	16.245	0.000	0.024	0.000	0.020	0.726	16.402	0.004	0.203	1.100	72.131
	Italy	− 0.169	49.426	0.000	0.039	0.000	0.040	0.586	46.643	0.003	0.273	1.100	102.217
	Portugal	− 0.114	22.323	0.000	0.021	0.000	0.027	0.680	23.444	0.004	0.224	1.100	79.064
	Spain	− 0.159	43.733	0.000	0.033	0.000	0.041	0.601	41.680	0.003	0.264	1.100	100.646
	Germany	− 0.158	43.193	0.168	35.166	0.179	39.853	1.673	43.666	0.951	39.845	1.112	53.374
Commodity markets	Crude-Oil	− 0.088	13.335	0.000	0.025	0.000	0.015	0.756	13.929	0.000	0.005	1.100	71.431
	Energy	− 0.095	15.409	0.000	0.026	0.000	0.018	0.746	15.342	0.004	0.207	1.100	76.452
	Foodstuffs	− 0.060	6.156	0.000	0.008	0.000	0.022	0.848	4.885	0.000	0.003	1.100	69.844
	Gold	− 0.007	0.094	0.000	0.004	0.006	0.054	1.017	0.049	0.032	0.047	1.100	36.781
	Industrial metals	− 0.008	0.115	0.000	0.003	0.006	0.053	1.016	0.046	0.031	0.044	1.100	36.892
	Natural gas	− 0.041	2.892	0.000	0.001	0.000	0.016	0.874	3.340	0.000	0.003	1.100	61.331
	Nickel	− 0.114	22.212	0.000	0.030	0.000	0.027	0.719	19.487	0.004	0.223	1.100	85.362
	Silver	− 0.068	7.777	0.000	0.021	0.000	0.012	0.830	6.023	0.000	0.004	1.100	63.988
	Stock market	− 0.195	65.790	0.000	0.048	0.000	0.045	0.546	64.303	0.000	0.011	1.100	114.097

Table 15 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.200	128.882	0.279	6.999	147.590	0.108	0.117	138.328
	Ireland	1.260	189.449	0.345	3.504	265.062	0.214	0.126	219.064
	Italy	1.269	209.117	0.348	5.195	252.045	0.186	0.167	232.393
	Portugal	1.226	159.388	0.304	5.232	199.346	0.162	0.120	181.575
	Spain	1.259	193.872	0.338	4.978	237.251	0.184	0.150	216.547
Sovereign bonds	Greece	1.100	40.022	− 0.152	5.705	60.362	0.014	0.038	39.998
	Ireland	1.100	76.795	− 0.100	7.880	134.200	0.000	0.000	8.429
	Italy	1.100	103.226	− 0.167	7.274	172.123	0.000	0.000	19.688
	Portugal	1.100	74.368	− 0.115	6.145	153.848	0.000	0.000	9.258
	Spain	1.100	95.033	− 0.157	6.931	166.886	0.000	0.000	13.409
	Germany	1.102	41.450	− 0.160	8.108	160.769	0.052	0.020	53.037
Commodity markets	Crude-Oil	1.100	79.082	− 0.091	13.172	121.608	0.000	0.000	8.108
	Energy	1.100	82.008	− 0.097	13.966	122.722	0.000	0.000	8.722
	Foodstuffs	1.100	61.104	− 0.059	31.327	77.534	0.000	0.000	6.729
	Gold	1.100	43.611	− 0.004	19.232	53.808	0.000	0.000	2.056
	Industrial metals	1.100	43.641	− 0.004	18.921	53.978	0.000	0.000	2.133
	Natural gas	1.100	52.319	− 0.043	24.313	65.747	0.000	0.000	4.333
	Nickel	1.100	90.385	− 0.114	21.100	125.204	0.000	0.000	16.451
	Silver	1.100	70.861	− 0.066	18.072	111.706	0.000	0.000	6.994
	Stock market	1.100	119.425	− 0.197	9.071	183.019	0.000	0.000	24.009

Table 16 Bivariate copula estimation of Dutch sovereign CDS market and other markets

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.285	143.705	0.343	120.831	0.371	141.517	2.701	145.154	1.715	120.898	1.231	179.872
	Ireland	0.401	297.131	0.522	227.547	0.594	286.343	4.308	335.697	2.696	286.414	1.370	347.515
	Italy	0.412	316.424	0.543	253.509	0.591	290.280	3.803	302.685	2.568	267.265	1.363	350.657
	Portugal	0.374	256.736	0.455	188.127	0.533	249.659	3.519	258.106	2.357	226.716	1.322	295.857
	Spain	0.387	276.395	0.498	217.457	0.533	245.356	3.636	281.325	2.482	251.777	1.332	300.336
Sovereign bonds	Greece	− 0.147	37.242	0.169	36.409	0.182	42.234	1.716	41.549	0.908	34.629	1.117	59.058
	Ireland	− 0.098	16.327	0.000	0.024	0.000	0.016	0.769	10.840	0.000	0.005	1.100	60.349
	Italy	− 0.186	59.712	0.000	0.048	0.000	0.040	0.573	51.960	0.000	0.010	1.100	105.544
	Portugal	− 0.120	24.725	0.000	0.026	0.000	0.025	0.685	22.668	0.000	0.006	1.100	75.120
	Spain	− 0.183	57.823	0.000	0.038	0.000	0.048	0.598	43.903	0.003	0.270	1.100	107.171
	Netherlands	− 0.128	27.998	0.133	22.944	0.151	30.295	1.484	26.912	0.750	25.363	1.100	41.271
Commodity markets	Crude-Oil	− 0.106	19.225	0.000	0.027	0.000	0.025	0.759	13.819	0.000	0.006	1.100	82.226
	Energy	− 0.104	18.506	0.000	0.023	0.000	0.026	0.750	15.017	0.004	0.207	1.100	81.879
	Foodstuffs	− 0.090	13.782	0.000	0.016	0.000	0.028	0.797	9.215	0.000	0.004	1.100	77.170
	Gold	− 0.001	0.004	0.004	0.033	0.026	1.151	1.042	0.292	0.078	0.281	1.100	24.160
	Industrial metals	− 0.001	0.002	0.006	0.052	0.026	1.153	1.042	0.299	0.079	0.287	1.100	24.055
	Natural gas	− 0.021	0.741	0.001	0.000	0.000	0.009	0.963	0.263	0.000	0.001	1.100	48.828
	Nickel	− 0.120	24.806	0.000	0.030	0.000	0.026	0.732	16.998	0.000	0.005	1.100	78.115
	Silver	− 0.066	7.319	0.000	0.013	0.000	0.010	0.867	3.465	0.000	0.003	1.100	54.626
	Stock market	− 0.245	105.519	0.000	0.063	0.000	0.054	0.488	91.359	0.003	0.329	1.100	128.823

Table 16 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.219	160.000	0.277	3.623	224.950	0.168	0.123	193.199
	Ireland	1.349	306.457	0.416	3.536	388.379	0.288	0.199	358.664
	Italy	1.349	323.684	0.401	3.911	390.889	0.279	0.222	381.798
	Portugal	1.301	249.984	0.373	4.348	315.330	0.261	0.160	309.110
	Spain	1.322	278.485	0.390	4.706	329.689	0.245	0.200	319.229
Sovereign bonds	Greece	1.108	49.329	− 0.148	4.072	102.199	0.058	0.027	58.099
	Ireland	1.100	71.207	− 0.082	5.832	148.997	0.000	0.000	8.119
	Italy	1.100	111.343	− 0.179	7.708	180.983	0.000	0.000	15.441
	Portugal	1.100	81.691	− 0.115	6.059	157.194	0.000	0.000	14.521
	Spain	1.100	101.409	− 0.167	6.918	183.072	0.000	0.000	15.222
	Netherlands	1.100	26.562	− 0.129	7.993	150.857	0.044	0.006	39.808
Commodity markets	Crude-Oil	1.100	81.987	− 0.101	15.019	126.016	0.000	0.000	14.161
	Energy	1.100	77.977	− 0.102	12.340	129.246	0.000	0.000	13.734
	Foodstuffs	1.100	71.031	− 0.084	14.282	120.736	0.000	0.000	8.814
	Gold	1.100	33.153	− 0.008	8.678	120.721	0.000	0.000	0.706
	Industrial metals	1.100	32.934	− 0.008	8.630	121.061	0.000	0.000	0.324
	Natural gas	1.100	47.003	− 0.019	32.114	82.421	0.000	0.000	3.057
	Nickel	1.100	86.755	− 0.112	9.253	140.836	0.000	0.000	10.392
	Silver	1.100	58.352	− 0.053	7.316	133.971	0.000	0.000	5.378
	Stock market	1.100	141.969	− 0.241	7.982	227.411	0.000	0.000	20.041

Table 17 Bivariate copula estimation of UK sovereign CDS market and other markets

	UK	Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.208	75.366	0.213	53.232	0.242	68.115	1.823	64.238	1.166	61.003	1.143	78.221
	Ireland	0.309	170.209	0.363	122.163	0.433	174.380	3.164	207.145	2.088	177.545	1.266	209.925
	Italy	0.343	213.022	0.429	170.172	0.450	184.230	3.319	240.365	2.286	214.955	1.285	226.462
	Portugal	0.298	157.566	0.349	122.063	0.382	143.817	2.787	171.120	1.905	151.906	1.237	174.814
	Spain	0.299	159.537	0.353	120.096	0.392	146.870	2.837	182.511	1.982	165.332	1.242	179.586
Sovereign bonds	Greece	− 0.079	10.707	0.075	8.720	0.080	9.039	1.219	7.139	0.388	6.979	1.100	0.127
	Ireland	− 0.097	16.070	0.000	0.030	0.000	0.017	0.733	16.518	0.000	0.006	1.100	75.366
	Italy	− 0.156	41.799	0.000	0.043	0.000	0.036	0.631	37.923	0.003	0.269	1.100	103.219
	Portugal	− 0.115	22.479	0.000	0.026	0.000	0.030	0.681	25.532	0.004	0.239	1.100	92.452
	Spain	− 0.147	37.034	0.000	0.036	0.000	0.038	0.644	33.837	0.000	0.008	1.100	100.629
	UK	− 0.108	19.972	0.089	10.318	0.132	24.012	1.395	19.636	0.643	18.866	1.100	23.839
Commodity markets	Crude-Oil	− 0.124	26.140	0.000	0.030	0.000	0.028	0.697	23.261	0.000	0.006	1.100	85.884
	Energy	− 0.127	27.806	0.000	0.028	0.000	0.032	0.682	26.087	0.000	0.007	1.100	90.713
	Foodstuffs	− 0.104	18.449	0.000	0.025	0.000	0.031	0.754	14.768	0.000	0.005	1.100	88.713
	Gold	− 0.017	0.509	0.000	0.006	0.000	0.001	0.969	0.187	0.000	0.002	1.100	43.570
	Industrial metals	− 0.018	0.536	0.000	0.006	0.000	0.001	0.968	0.189	0.000	0.002	1.100	43.597
	Natural gas	− 0.038	2.429	0.005	0.047	0.000	0.021	0.929	0.998	0.000	0.002	1.100	63.224
	Nickel	− 0.096	15.796	0.000	0.026	0.000	0.020	0.755	13.882	0.004	0.199	1.100	73.735
	Silver	− 0.070	8.409	0.000	0.019	0.000	0.018	0.841	5.542	0.000	0.003	1.100	70.491
	Stock market	− 0.158	43.135	0.000	0.044	0.000	0.030	0.622	39.801	0.003	0.271	1.100	97.355

Table 17 continued

	UK	Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.132	68.814	0.206	13.175	− 82.307	0.084	0.044	84.332
	Ireland	1.248	174.391	0.333	4.176	239.529	0.214	0.106	208.743
	Italy	1.277	215.517	0.358	5.426	261.014	0.197	0.163	238.346
	Portugal	1.226	157.256	0.305	5.531	199.416	0.169	0.113	100.025
	Spain	1.231	158.390	0.317	5.789	200.909	0.174	0.113	182.404
Sovereign bonds	Greece	1.100	4.017	− 0.078	45.208	15.380	0.003	0.001	12.495
	Ireland	1.100	84.041	− 0.099	14.713	122.097	0.000	0.000	9.136
	Italy	1.100	108.616	− 0.155	22.930	144.527	0.000	0.000	14.152
	Portugal	1.100	87.165	− 0.118	16.810	127.222	0.000	0.000	15.859
	Spain	1.100	99.084	− 0.146	18.711	140.859	0.000	0.000	19.657
	UK	1.100	9.278	− 0.110	16.286	125.671	0.035	0.000	26.259
Commodity markets	Crude-Oil	1.100	90.337	− 0.123	11.926	136.780	0.000	0.000	16.078
	Energy	1.100	90.695	− 0.129	11.823	138.475	0.000	0.000	16.939
	Foodstuffs	1.100	82.855	− 0.104	99.945	118.523	0.000	0.000	10.603
	Gold	1.100	49.742	− 0.016	30.159	52.194	0.000	0.000	3.213
	Industrial metals	1.100	49.650	− 0.016	28.567	52.432	0.000	0.000	3.231
	Natural gas	1.100	44.166	− 0.035	27.375	94.416	0.000	0.000	4.789
	Nickel	1.100	81.875	− 0.096	15.668	121.161	0.000	0.000	9.042
	Silver	1.100	72.306	− 0.069	35.710	99.599	0.000	0.000	11.127
	Stock market	1.100	107.732	− 0.160	9.291	160.406	0.000	0.000	13.491

Table 18 Bivariate copula estimation of Swedish sovereign CDS market and other markets

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.242	102.440	0.301	94.897	0.289	82.662	2.946	155.251	1.755	122.511	1.201	121.020
	Ireland	0.263	122.045	0.308	89.021	0.349	115.742	2.892	172.997	1.903	148.901	1.223	146.747
	Italy	0.256	115.591	0.295	89.171	0.312	97.990	2.428	131.898	1.672	119.376	1.198	123.390
	Portugal	0.256	114.893	0.301	89.716	0.317	98.519	2.596	147.807	1.770	132.390	1.203	125.341
	Spain	0.246	106.054	0.288	84.098	0.294	85.653	2.424	130.561	1.664	118.425	1.191	113.243
Sovereign bonds	Greece	− 0.123	26.001	0.149	27.367	0.130	19.784	1.855	49.650	0.981	39.479	1.102	36.233
	Ireland	− 0.036	2.195	0.000	0.006	0.000	0.004	0.923	1.032	0.000	0.002	1.100	44.917
	Italy	− 0.085	12.449	0.000	0.021	0.000	0.021	0.786	9.758	0.000	0.005	1.100	74.039
	Portugal	− 0.067	7.760	0.000	0.009	0.000	0.017	0.810	7.211	0.000	0.003	1.100	61.171
	Spain	− 0.067	7.648	0.000	0.013	0.000	0.017	0.853	4.243	0.000	0.004	1.100	64.972
	Sweden	− 0.156	41.756	0.177	38.784	0.151	28.353	1.646	42.457	0.943	39.655	1.100	38.087
Commodity markets	Crude-Oil	− 0.089	13.491	0.000	0.028	0.000	0.020	0.772	12.694	0.000	0.006	1.100	78.413
	Energy	− 0.097	16.165	0.000	0.029	0.000	0.023	0.749	15.866	0.000	0.005	1.100	84.707
	Foodstuffs	− 0.075	9.609	0.000	0.022	0.000	0.018	0.816	7.452	0.000	0.004	1.100	72.448
	Gold	− 0.004	0.024	0.004	0.022	0.001	0.002	1.065	0.715	0.122	0.692	1.100	34.911
	Industrial metals	− 0.003	0.019	0.004	0.020	0.001	0.002	1.065	0.712	0.122	0.689	1.100	34.922
	Natural gas	− 0.022	0.834	0.000	0.002	0.000	0.012	0.934	0.869	0.000	0.002	1.100	56.607
	Nickel	− 0.075	9.634	0.000	0.020	0.000	0.019	0.789	9.963	0.000	0.004	1.100	70.374
	Silver	− 0.042	3.066	0.000	0.015	0.000	0.007	0.904	1.758	0.000	0.003	1.100	50.842
	Stock market	− 0.152	39.802	0.000	0.038	0.000	0.039	0.632	38.279	0.000	0.009	1.100	107.346

Table 18 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.193	116.462	0.278	3.977	165.174	0.105	0.104	120.930
	Ireland	1.211	128.383	0.304	5.042	170.243	0.157	0.085	140.064
	Italy	1.189	112.789	0.272	7.445	139.039	0.124	0.088	125.342
	Portugal	1.196	118.799	0.282	6.413	147.378	0.122	0.094	126.593
	Spain	1.185	106.594	0.267	7.501	128.252	0.108	0.089	113.591
Sovereign bonds	Greece	1.100	32.365	− 0.158	4.686	62.518	0.017	0.021	31.657
	Ireland	1.100	48.610	− 0.031	7.975	120.108	0.000	0.000	3.129
	Italy	1.100	69.201	− 0.083	13.906	118.701	0.000	0.000	11.376
	Portugal	1.100	57.426	− 0.065	8.051	126.364	0.000	0.000	5.779
	Spain	1.100	60.368	− 0.059	11.557	116.699	0.000	0.000	6.522
	Sweden	1.101	39.112	− 0.158	13.677	48.184	0.018	0.038	44.360
Commodity markets	Crude-Oil	1.100	85.382	− 0.090	99.995	113.471	0.000	0.000	9.219
	Energy	1.100	88.869	− 0.098	99.775	115.964	0.000	0.000	9.919
	Foodstuffs	1.100	76.826	− 0.075	67.365	109.881	0.000	0.000	7.984
	Gold	1.100	38.849	− 0.007	37.044	51.001	0.000	0.000	1.626
	Industrial metals	1.100	38.753	− 0.007	34.303	51.173	0.000	0.000	1.631
	Natural gas	1.100	51.577	− 0.022	99.994	60.261	0.000	0.000	3.891
	Nickel	1.100	74.299	− 0.078	22.627	112.116	0.000	0.000	11.169
	Silver	1.100	60.241	− 0.039	19.772	66.072	0.000	0.000	4.962
	Stock market	1.100	107.320	− 0.154	27.731	141.676	0.000	0.000	20.099

Table 19 Bivariate copula estimation of American sovereign CDS market and other markets

		Normal		Clayton		Rotated Clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.207	74.348	0.257	72.041	0.236	62.699	2.347	98.415	1.397	80.233	1.159	92.576
	Ireland	0.228	90.561	0.250	66.869	0.303	95.602	2.276	104.242	1.463	90.226	1.187	124.532
	Italy	0.246	105.769	0.282	86.421	0.308	100.717	2.183	101.839	1.461	92.245	1.187	126.680
	Portugal	0.219	83.249	0.260	77.493	0.248	69.254	1.958	76.511	1.267	70.483	1.154	92.719
	Spain	0.233	94.904	0.262	75.447	0.279	85.463	2.124	93.913	1.402	85.164	1.171	107.147
Sovereign bonds	Greece	− 0.121	25.092	0.156	31.331	0.119	17.840	1.705	39.108	0.878	32.264	1.100	31.892
	Ireland	− 0.067	7.716	0.000	0.010	0.000	0.016	0.816	6.635	0.000	0.004	1.100	62.152
	Italy	− 0.097	16.103	0.000	0.022	0.000	0.021	0.734	15.676	0.004	0.201	1.100	76.613
	Portugal	− 0.057	5.596	0.000	0.013	0.000	0.012	0.844	4.762	0.000	0.003	1.100	61.228
	Spain	− 0.107	19.492	0.000	0.024	0.000	0.025	0.725	17.341	0.000	0.006	1.100	81.039
	USA	− 0.096	15.868	0.117	18.393	0.080	8.566	1.356	16.942	0.599	16.560	1.100	8.935
Commodity markets	Crude-Oil	− 0.105	18.912	0.000	0.028	0.000	0.027	0.752	15.338	0.000	0.008	1.100	85.370
	Energy	− 0.107	19.500	0.000	0.026	0.000	0.028	0.745	16.297	0.004	0.215	1.100	86.228
	Foodstuffs	− 0.049	4.037	0.000	0.009	0.000	0.017	0.882	2.878	0.000	0.002	1.100	63.551
	Gold	− 0.028	1.349	0.029	1.261	0.042	2.936	1.086	1.203	0.159	1.152	1.100	18.153
	Industrial metals	− 0.029	1.403	0.030	1.383	0.042	2.942	1.087	1.219	0.160	1.167	1.100	18.031
	Natural gas	− 0.043	3.089	0.000	0.013	0.000	0.013	0.909	1.713	0.000	0.003	1.100	56.918
	Nickel	− 0.101	17.351	0.000	0.024	0.000	0.026	0.761	13.330	0.004	0.198	1.100	76.998
	Silver	− 0.025	1.071	0.000	0.007	0.005	0.057	0.935	0.778	0.000	0.001	1.100	43.696
	Stock market	− 0.098	16.348	0.000	0.021	0.000	0.025	0.764	12.701	0.004	0.193	1.100	77.431

Table 19 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.161	91.419	0.229	4.427	127.128	0.072	0.087	97.827
	Ireland	1.167	95.218	0.245	4.666	141.824	0.143	0.052	120.727
	Italy	1.176	111.521	0.247	5.677	148.169	0.128	0.083	135.151
	Portugal	1.156	94.458	0.218	6.580	114.505	0.076	0.088	106.750
	Spain	1.164	96.832	0.235	6.788	120.462	0.104	0.076	114.391
Sovereign bonds	Greece	1.100	32.521	− 0.139	5.510	59.469	0.007	0.033	34.222
	Ireland	1.100	60.206	− 0.066	7.965	126.401	0.000	0.000	5.836
	Italy	1.100	73.365	− 0.097	9.085	130.877	0.000	0.000	12.271
	Portugal	1.100	60.228	− 0.057	10.566	116.351	0.000	0.000	8.080
	Spain	1.100	79.397	− 0.104	10.390	130.745	0.000	0.000	13.729
	USA	1.100	8.205	− 0.100	16.413	122.170	0.001	0.012	18.406
Commodity markets	Crude-Oil	1.100	89.302	− 0.105	40.943	119.884	0.000	0.000	13.464
	Energy	1.100	88.746	− 0.107	30.956	121.225	0.000	0.000	15.379
	Foodstuffs	1.100	58.074	− 0.047	28.480	105.910	0.000	0.000	5.657
	Gold	1.100	27.282	− 0.028	13.384	39.585	0.000	0.000	3.194
	Industrial metals	1.100	27.081	− 0.028	13.317	39.763	0.000	0.000	3.268
	Natural gas	1.100	61.940	− 0.042	99.948	103.174	0.000	0.000	7.832
	Nickel	1.100	82.490	− 0.097	15.497	123.192	0.000	0.000	13.512
	Silver	1.100	51.430	− 0.024	13.781	108.340	0.000	0.000	2.884
	Stock market	1.100	76.910	− 0.095	11.352	127.761	0.000	0.000	8.659

Table 20 Bivariate copula estimation of Chinese sovereign CDS market and other markets

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.223	38.140	0.169	40.232	0.159	36.130	1.391	18.907	0.627	17.788	1.100	42.096
	Ireland	0.229	91.259	0.259	72.958	0.285	88.326	2.157	99.464	1.450	91.195	1.172	106.836
	Italy	0.319	182.345	0.381	139.161	0.396	156.243	2.829	189.405	2.037	177.019	1.242	179.001
	Portugal	0.267	125.727	0.292	90.622	0.334	118.666	2.286	120.798	1.613	114.195	1.195	136.180
	Spain	0.291	150.609	0.334	111.998	0.361	131.058	2.601	159.672	1.863	149.477	1.220	153.528
Sovereign bonds	Greece	− 0.076	9.777	0.079	9.846	0.099	14.943	1.191	5.165	0.327	4.819	1.100	6.505
	Ireland	− 0.084	12.032	0.000	0.017	0.000	0.013	0.766	11.971	0.004	0.186	1.100	62.007
	Italy	− 0.135	31.173	0.000	0.034	0.000	0.025	0.636	34.354	0.000	0.009	1.100	87.372
	Portugal	− 0.127	27.829	0.000	0.028	0.000	0.031	0.663	28.757	0.000	0.007	1.100	88.633
	Spain	− 0.118	23.654	0.000	0.023	0.000	0.030	0.696	22.876	0.000	0.007	1.100	88.780
	China	− 0.013	0.2916	0.000	0.023	0.084	11.676	1.032	0.198	0.065	0.202	1.100	13.671
Commodity markets	Crude-Oil	− 0.122	25.368	0.000	0.026	0.000	0.029	0.704	21.243	0.000	0.006	1.100	83.532
	Energy	− 0.123	26.014	0.000	0.023	0.000	0.030	0.703	21.281	0.004	0.226	1.100	83.859
	Foodstuffs	− 0.060	6.081	0.000	0.006	0.000	0.018	0.853	4.353	0.000	0.004	1.100	63.012
	Gold	− 0.015	0.397	0.036	2.206	0.039	2.409	1.099	1.487	0.175	1.379	1.100	12.502
	Industrial metals	− 0.015	0.401	0.037	2.317	0.039	2.409	1.099	1.496	0.176	1.387	1.100	12.419
	Natural gas	− 0.022	0.812	0.005	0.042	0.000	0.010	0.962	0.276	0.000	0.001	1.100	51.036
	Nickel	− 0.166	47.296	0.000	0.040	0.000	0.032	0.603	43.774	0.003	0.275	1.100	92.289
	Silver	− 0.061	6.416	0.000	0.011	0.000	0.010	0.870	3.292	0.000	0.003	1.100	48.673
	Stock market	− 0.257	115.950	0.000	0.060	0.000	0.063	0.443	118.347	0.002	0.348	1.100	143.502

Table 20 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.100	50.408	0.121	7.287	62.185	0.025	0.044	57.758
	Ireland	1.165	96.729	0.237	5.771	135.202	0.107	0.069	112.935
	Italy	1.243	178.272	0.325	7.647	208.361	0.158	0.139	197.170
	Portugal	1.185	117.872	0.267	7.945	148.994	0.139	0.077	145.926
	Spain	1.212	142.747	0.299	8.148	172.322	0.148	0.105	163.271
Sovereign bonds	Greece	1.100	5.062	− 0.063	7.920	31.986	0.009	0.001	18.201
	Ireland	1.100	65.665	− 0.085	7.312	138.518	0.000	0.000	6.392
	Italy	1.100	91.031	− 0.141	7.689	154.292	0.000	0.000	11.037
	Portugal	1.100	88.706	− 0.130	9.771	141.679	0.000	0.000	16.474
	Spain	1.100	76.667	− 0.118	9.612	139.813	0.000	0.000	10.057
	China	1.100	61.529	− 0.013	99.936	80.231	0.001	0.000	5.287
Commodity markets	Crude-Oil	1.100	80.513	− 0.116	8.211	146.804	0.000	0.000	10.086
	Energy	1.100	77.834	− 0.117	7.523	151.991	0.000	0.000	10.040
	Foodstuffs	1.100	51.792	− 0.055	9.673	121.333	0.000	0.000	5.505
	Gold	1.100	13.190	− 0.028	5.746	143.813	0.000	0.000	3.555
	Industrial metals	1.100	12.850	− 0.028	5.701	144.854	0.000	0.000	3.636
	Natural gas	1.100	40.155	− 0.019	19.700	64.476	0.000	0.000	3.001
	Nickel	1.100	101.394	− 0.163	6.608	180.663	0.000	0.000	12.983
	Silver	1.100	53.565	− 0.047	6.903	134.98	0.000	0.000	4.905
	Stock market	1.100	140.619	− 0.262	8.940	235.27	0.000	0.000	30.916

Table 21 Bivariate copula estimation of Japanese sovereign CDS market and other markets

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.102	17.943	0.120	20.123	0.116	19.354	1.354	16.137	0.582	15.406	1.100	21.626
	Ireland	0.113	21.789	0.095	11.741	0.150	29.165	1.467	24.198	0.707	22.205	1.100	34.594
	Italy	0.121	24.933	0.117	17.298	0.147	29.394	1.464	24.755	0.718	23.155	1.100	35.113
	Portugal	0.144	35.729	0.147	26.291	0.172	37.123	1.615	38.927	0.902	36.270	1.101	44.857
	Spain	0.119	24.108	0.126	20.558	0.127	21.425	1.469	25.555	0.731	24.119	1.100	25.103
Sovereign bonds	Greece	− 0.020	0.692	0.051	4.507	0.052	4.628	1.055	0.485	0.100	0.451	1.100	11.572
	Ireland	− 0.046	3.670	0.000	0.005	0.001	0.001	0.852	4.301	0.000	0.004	1.100	39.850
	Italy	− 0.023	0.864	0.000	0.013	0.007	0.090	0.936	0.788	0.000	0.002	1.100	46.678
	Portugal	− 0.060	6.046	0.000	0.011	0.000	0.009	0.820	6.573	0.000	0.004	1.100	55.870
	Spain	− 0.033	1.903	0.000	0.006	0.000	0.006	0.913	1.448	0.000	0.002	1.100	50.323
	Japan	− 0.062	6.548	0.052	3.714	0.074	7.785	1.262	9.706	0.452	9.399	1.100	0.387
Commodity markets	Crude-Oil	− 0.021	0.723	0.000	0.008	0.000	0.003	0.948	0.550	0.000	0.002	1.100	47.639
	Energy	− 0.029	1.408	0.000	0.008	0.000	0.005	0.918	1.387	0.000	0.003	1.100	51.039
	Foodstuffs	− 0.021	0.750	0.000	0.002	0.006	0.064	0.936	0.769	0.000	0.001	1.100	36.168
	Gold	− 0.015	0.386	0.005	0.043	0.030	1.483	1.036	0.235	0.070	0.232	1.100	28.785
	Industrial metals	− 0.015	0.391	0.006	0.055	0.030	1.483	1.037	0.238	0.071	0.235	1.100	28.721
	Natural gas	− 0.007	0.079	0.014	0.361	0.003	0.012	1.008	0.012	0.016	0.012	1.100	36.096
	Nickel	− 0.020	0.687	0.000	0.006	0.007	0.085	0.913	1.531	0.000	0.003	1.100	40.736
	Silver	− 0.019	0.633	0.000	0.007	0.014	0.378	0.935	0.816	0.000	0.001	1.100	36.737
	Stock market	− 0.228	91.038	0.000	0.059	0.000	0.054	0.483	97.709	0.003	0.342	1.100	135.218

Table 21 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.100	23.576	0.100	6.982	49.216	0.010	0.016	28.890
	Ireland	1.100	15.669	0.119	8.611	37.524	0.058	0.000	32.151
	Italy	1.100	25.806	0.124	8.649	43.018	0.036	0.004	34.969
	Portugal	1.100	37.993	0.151	8.496	55.223	0.044	0.016	45.816
	Spain	1.100	24.384	0.123	10.607	36.196	0.014	0.013	29.322
Sovereign bonds	Greece	1.100	6.901	− 0.014	4.953	62.647	0.000	0.001	7.177
	Ireland	1.100	43.488	− 0.050	5.769	46.102	0.000	0.000	2.681
	Italy	1.100	54.671	− 0.023	41.095	101.752	0.000	0.000	3.230
	Portugal	1.100	58.425	− 0.062	8.078	125.780	0.000	0.000	4.755
	Spain	1.100	48.413	− 0.032	13.868	59.043	0.000	0.000	4.532
	Japan	1.100	11.949	− 0.068	15.796	12.699	0.011	0.000	9.386
Commodity markets	Crude-Oil	1.100	53.771	− 0.021	99.955	70.820	0.000	0.000	3.242
	Energy	1.100	56.426	− 0.029	68.261	71.799	0.000	0.000	3.715
	Foodstuffs	1.100	44.559	− 0.022	10.760	113.496	0.000	0.000	1.878
	Gold	1.100	35.436	− 0.015	36.255	51.524	0.000	0.000	0.691
	Industrial metals	1.100	35.246	− 0.015	34.340	51.672	0.000	0.000	0.807
	Natural gas	1.100	41.030	− 0.006	99.934	70.184	0.000	0.000	1.011
	Nickel	1.100	50.133	− 0.024	23.719	63.813	0.000	0.000	2.278
	Silver	1.100	47.220	− 0.021	15.087	57.278	0.000	0.000	1.274
	Stock market	1.100	141.624	− 0.236	16.286	197.704	0.000	0.000	29.552

Table 22 Bivariate copula estimation of Danish sovereign CDS market and other markets

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.242	102.252	0.293	88.998	0.266	73.816	2.445	126.766	1.635	114.369	1.177	101.922
	Ireland	0.265	123.671	0.325	102.668	0.330	106.918	2.794	161.311	1.833	139.093	1.216	142.830
	Italy	0.272	130.973	0.319	102.904	0.330	109.905	2.523	144.486	1.755	131.706	1.209	137.612
	Portugal	0.229	91.222	0.267	77.527	0.262	75.367	2.156	96.938	1.425	87.829	1.167	99.447
	Spain	0.256	114.862	0.312	97.423	0.306	93.337	2.516	139.461	1.718	125.618	1.199	125.870
Sovereign bonds	Greece	− 0.131	29.547	0.147	26.376	0.119	18.075	1.629	38.989	0.901	35.962	1.100	26.396
	Ireland	− 0.063	6.721	0.000	0.016	0.000	0.014	0.854	4.121	0.000	0.004	1.100	58.525
	Italy	− 0.109	20.344	0.000	0.028	0.000	0.026	0.734	15.594	0.000	0.006	1.100	80.062
	Portugal	− 0.089	13.477	0.000	0.020	0.000	0.022	0.765	11.756	0.004	0.183	1.100	71.631
	Spain	− 0.109	20.459	0.000	0.025	0.000	0.031	0.746	14.716	0.000	0.005	1.100	83.225
Commodity markets	Denmark	0.168	48.389	0.171	34.589	0.189	41.445	1.743	54.109	1.070	51.434	1.116	53.454
	Crude-Oil	− 0.074	9.222	0.000	0.013	0.000	0.020	0.794	9.496	0.000	0.005	1.100	69.885
	Energy	− 0.072	8.921	0.000	0.012	0.000	0.020	0.801	8.856	0.000	0.004	1.100	71.442
	Foodstuffs	− 0.067	7.640	0.000	0.016	0.000	0.020	0.822	6.855	0.000	0.004	1.100	71.913
	Gold	0.000	0.000	0.007	0.084	0.000	0.005	1.053	0.491	0.102	0.484	1.100	40.743
	Industrial metals	0.000	0.000	0.009	0.117	0.000	0.004	1.054	0.499	0.103	0.492	1.100	40.636
	Natural gas	− 0.029	1.417	0.000	0.002	0.000	0.017	0.938	0.788	0.000	0.002	1.100	57.844
	Nickel	− 0.062	6.442	0.000	0.009	0.000	0.019	0.850	4.680	0.000	0.004	1.100	65.873
	Silver	− 0.041	2.900	0.000	0.011	0.000	0.011	0.913	1.493	0.000	0.003	1.100	57.837
	Stock market	− 0.069	8.107	0.000	0.019	0.000	0.018	0.837	5.745	0.000	0.004	1.100	70.112

Table 22 continued

		Rotated gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.178	103.425	0.257	8.617	119.189	0.076	0.102	109.742
	Ireland	1.213	137.968	0.296	4.795	172.927	0.127	0.118	145.713
	Italy	1.203	129.902	0.284	7.285	155.658	0.128	0.106	143.488
	Portugal	1.166	97.047	0.236	6.912	115.854	0.085	0.087	107.422
	Spain	1.199	124.350	0.278	6.117	149.363	0.107	0.113	131.036
Sovereign bonds	Greece	1.100	25.687	− 0.136	21.923	31.928	0.009	0.022	29.833
	Ireland	1.100	64.622	− 0.058	13.727	112.683	0.000	0.000	6.246
	Italy	1.100	82.620	− 0.104	14.465	125.154	0.000	0.000	14.913
	Portugal	1.100	72.250	− 0.086	11.653	121.496	0.000	0.000	12.021
	Spain	1.100	80.820	− 0.104	18.327	123.735	0.000	0.000	10.504
Commodity markets	Denmark	1.103	39.558	− 0.174	13.597	155.588	0.057	0.016	52.715
	Crude-Oil	1.100	65.754	− 0.075	15.218	115.873	0.000	0.000	6.721
	Energy	1.100	64.476	− 0.074	16.732	114.343	0.000	0.000	6.859
	Foodstuffs	1.100	68.715	− 0.067	41.629	88.393	0.000	0.000	7.238
	Gold	1.100	39.888	− 0.002	57.727	50.430	0.000	0.000	2.197
	Industrial metals	1.100	39.731	− 0.003	55.772	50.464	0.000	0.000	2.122
	Natural gas	1.100	51.242	− 0.028	99.984	61.305	0.000	0.000	4.455
	Nickel	1.100	61.295	− 0.059	14.049	113.445	0.000	0.000	6.117
	Silver	1.100	61.299	− 0.040	51.392	73.417	0.000	0.000	7.427
	Stock market	1.100	69.766	− 0.068	33.204	109.415	0.000	0.000	10.713

Table 23 Bivariate copula estimation of South-African sovereign CDS market and other markets

		Normal		Clayton		Rotated clayton		Placket		Frank		Gumbel	
		ρ	LL	θ	LL	θ	LL	ρ	LL	θ	LL	θ	LL
Sovereign CDS	Greece	0.197	67.464	0.225	64.128	0.208	55.071	1.638	44.699	0.975	43.493	1.121	67.494
	Ireland	0.273	131.517	0.323	107.655	0.361	132.402	2.481	132.860	1.666	117.000	1.217	164.348
	Italy	0.401	298.329	0.518	233.155	0.558	267.595	3.677	297.671	2.582	273.879	1.344	316.565
	Portugal	0.332	198.910	0.396	155.857	0.428	174.388	2.862	190.182	2.029	174.707	1.262	210.533
	Spain	0.360	235.795	0.443	179.918	0.487	215.457	3.201	237.332	2.288	219.208	1.296	255.070
Sovereign bonds	Greece	− 0.063	6.733	0.064	6.671	0.090	12.568	1.159	3.835	0.283	3.676	1.100	3.981
	Ireland	− 0.066	7.314	0.000	0.012	0.000	0.010	0.821	6.493	0.000	0.003	1.100	56.520
	Italy	− 0.202	70.971	0.000	0.048	0.000	0.046	0.528	69.523	0.003	0.307	1.100	115.733
	Portugal	− 0.110	20.621	0.000	0.023	0.000	0.027	0.706	20.987	0.004	0.225	1.100	82.989
	Spain	− 0.154	40.661	0.000	0.032	0.000	0.035	0.636	34.636	0.000	0.009	1.100	94.637
	South Africa	− 0.004	0.022	0.000	0.002	0.015	0.353	0.992	0.012	0.001	0.001	1.100	35.236
Commodity markets	Crude-Oil	− 0.255	114.444	0.000	0.061	0.000	0.060	0.454	108.987	0.003	0.340	1.100	137.045
	Energy	− 0.264	122.673	0.000	0.061	0.000	0.061	0.435	120.765	0.002	0.345	1.100	139.768
	Foodstuffs	− 0.142	34.619	0.000	0.026	0.000	0.040	0.657	30.730	0.003	0.252	1.100	98.357
	Gold	− 0.087	13.041	0.000	0.012	0.000	0.010	0.738	14.745	0.000	0.005	1.100	54.663
	Industrial metals	− 0.087	12.878	0.000	0.012	0.000	0.010	0.738	14.692	0.000	0.006	1.100	54.532
	Natural gas	− 0.035	2.134	0.002	0.007	0.000	0.019	0.940	0.672	0.000	0.002	1.100	59.868
	Nickel	− 0.274	132.197	0.000	0.063	0.000	0.062	0.426	128.004	0.000	0.015	1.100	139.960
	Silver	− 0.188	61.148	0.000	0.042	0.000	0.040	0.548	60.283	0.000	0.010	1.100	102.193
	Stock market	− 0.385	272.435	0.000	0.109	0.000	0.105	0.315	241.416	0.002	0.389	1.100	182.477

Table 23 continued

		Rotated Gumbel		Student's t		Symmetrized Joe-Clayton			
		θ	LL	ρ	N	LL	τ_U	τ_L	LL
Sovereign CDS	Greece	1.126	74.354	0.182	9.410	183.873	0.049	0.071	87.749
	Ireland	1.208	145.581	0.272	4.146	202.569	0.159	0.107	175.398
	Italy	1.333	295.604	0.403	5.273	351.780	0.257	0.202	341.117
	Portugal	1.249	193.401	0.330	6.321	231.159	0.191	0.141	228.649
	Spain	1.286	230.363	0.364	5.698	281.971	0.221	0.163	270.158
Sovereign bonds	Greece	1.100	0.012	− 0.055	8.366	28.538	0.010	0.000	15.168
	Ireland	1.100	57.181	− 0.064	7.418	131.713	0.000	0.000	7.801
	Italy	1.100	116.335	− 0.202	7.346	196.876	0.000	0.000	23.964
	Portugal	1.100	79.694	− 0.112	10.388	133.692	0.000	0.000	9.485
	Spain	1.100	87.359	− 0.145	6.589	173.437	0.000	0.000	18.722
	South Africa	1.100	45.026	− 0.003	99.967	120.043	0.000	0.000	0.823
Commodity markets	Crude-Oil	1.100	139.428	− 0.255	7.468	141.120	0.000	0.000	29.368
	Energy	1.100	140.845	− 0.267	6.500	158.476	0.000	0.000	12.274
	Foodstuffs	1.100	90.764	− 0.140	9.304	151.245	0.000	0.000	7.907
	Gold	1.100	56.712	− 0.092	4.547	77.892	0.000	0.000	7.550
	Industrial metals	1.100	56.364	− 0.092	4.531	78.560	0.000	0.000	4.607
	Natural gas	1.100	44.732	− 0.031	23.395	64.480	0.000	0.000	27.662
	Nickel	1.100	142.430	− 0.274	6.424	170.660	0.000	0.000	19.820
	Silver	1.100	106.391	− 0.187	5.506	155.145	0.000	0.000	45.686
	Stock market	1.100	191.656	− 0.377	6.378	306.637	0.000	0.000	102.124

Appendix 3: Results of Estimations of GARCH models

See Tables 24, 25.

Table 24 Estimations of Garch models of changes of sovereign CDS and bonds series

		GARCH (1.1)				EGARCH (1.1)					GJR-GARCH (1.1)				
		C	α	β	LogL	C	α	β	λ	LogL	C	α	β	λ	LogL
Sovereign cds	Greece	0.0001	0.66	0.16	6485.125	− 0.22	0.95	0.24	0.05	6452.783	0.0001	0.80	0.20	− 0.08	6652.456
	Ireland	0.0001	0.79	0.19	7233.180	− 0.34	0.94	0.26	0.06	7233.180	0.0001	0.80	0.23	− 0.09	7241.248
	Italy	0.0001	0.82	0.17	6405.428	− 0.27	0.95	0.29	0.05	6403.681	0.0001	0.82	0.20	− 0.07	6412.191
	Portugal	0.0001	0.80	0.17	6592.155	− 0.60	0.90	0.31	0.03	6563.137	0.0001	0.80	0.19	− 0.04	6594.329
	Spain	0.0001	0.80	0.16	6012.353	− 0.31	0.94	0.29	0.01	6016.890	0.0001	0.80	0.17	− 0.01	6018.519
	Belgium	0.0002	0.72	0.20	5860.386	− 1.13	0.80	0.36	0.06	5834.398	0.0003	0.72	0.23	− 0.07	5863.756
	Denmark	0.0001	0.93	0.06	5241.993	− 0.12	0.97	0.15	0.04	5132.799	0.0001	0.93	0.07	− 0.01	5243.218
	France	0.0002	0.77	0.20	5647.940	− 0.65	0.88	0.34	0.05	5629.189	0.0002	0.77	0.25	− 0.08	5653.595
	Germany	0.0005	0.91	0.09	5317.131	− 10.00	− 0.99	0.06	− 0.01	4459.132	0.0000	0.91	0.10	0.03	5320.846
	Netherland	0.0001	0.81	0.18	7336.376	− 0.54	0.91	0.30	0.10	7309.596	0.0001	0.80	0.26	− 0.14	7358.991
	Poland	0.0002	0.72	0.12	6934.090	− 1.10	0.83	0.12	0.13	6869.806	0.0002	0.75	0.16	− 0.12	6946.100
	Sweden	0.0001	0.93	0.06	4326.214	− 0.63	0.86	0.25	0.09	4226.175	0.0001	0.93	0.07	− 0.04	4335.926
	UK	0.0002	0.79	0.14	5732.259	− 1.65	0.72	0.38	− 0.04	5685.424	0.0002	0.79	0.11	0.04	5734.111
	USA	0.0004	0.63	0.16	6488.313	− 2.99	0.84	0.20	− 0.05	6489.425	0.0003	0.63	0.21	− 0.12	6498.408
	China	0.0001	0.85	0.11	6925.724	− 0.30	0.95	0.22	0.02	6910.480	0.0000	0.85	0.11	0.00	6925.736
	Japan	0.0003	0.83	0.10	5212.497	− 0.98	0.82	0.19	0.11	5038.984	0.0003	0.82	0.16	− 0.12	5229.471
	South Africa	0.0001	0.78	0.10	7039.396	− 0.97	0.86	0.15	0.09	6947.268	0.0001	0.79	0.13	− 0.07	7047.100
Sovereign bonds	Greece	0.0002	0.49	0.51	18,346.08	− 1.40	1.00	0.96	0.16	27,510.15	0.0002	0.48	0.70	− 0.37	18,418.85
	Ireland	0.0002	0.79	0.21	16,115.17	0.03	1.00	0.24	0.02	16,296.27	0.0002	0.78	0.29	− 0.14	16,149.06

Table 24 continued

	GARCH (1.1)				EGARCH (1.1)					GJR-GARCH (1.1)				
	C	α	β	LogL	C	α	β	λ	LogL	C	α	β	λ	LogL
Italy	0.0002	0.83	0.17	15,357.49	− 0.22	0.98	0.23	− 0.11	15,408.37	0.0002	0.85	0.06	0.18	15,405.72
Portugal	0.0002	0.84	0.16	14,654.81	0.02	1.00	0.20	− 0.05	14,764.14	0.0002	0.84	0.14	0.04	14,658.54
Spain	0.0002	0.82	0.17	15,995.70	− 0.09	0.99	0.19	− 0.07	16,078.08	0.0002	0.83	0.06	0.18	16,032.01
Belgium	0.0002	0.74	0.21	17,276.15	− 0.29	0.98	0.24	− 0.04	17,300.30	0.0002	0.74	0.18	0.05	17,278.28
Denmark	0.0002	0.88	0.08	16,760.21	0.01	1.00	0.09	0.00	16,812.64	0.0002	0.88	0.09	− 0.03	16,762.54
France	0.0002	0.77	0.16	17,229.65	− 0.20	0.98	0.16	− 0.01	17,267.13	0.0002	0.77	0.17	− 0.01	17,229.81
Germany	0.0002	0.80	0.13	17,138.16	− 0.11	0.99	0.10	0.00	17,191.74	0.0002	0.80	0.13	0.00	17,138.17
Netherlands	0.0002	0.77	0.16	17,287.19	− 0.15	0.99	0.13	0.00	17,335.33	0.0002	0.78	0.15	0.00	17,288.28
Poland	0.0002	0.85	0.12	16,298.04	− 0.82	0.93	0.17	− 0.02	16,169.24	0.0002	0.85	0.10	0.04	16,300.97
Sweden	0.0002	0.79	0.15	17,222.97	− 0.22	0.98	0.18	0.01	17,272.95	0.0002	0.79	0.17	− 0.04	17,224.29
UK	0.0002	0.84	0.11	16,520.10	− 0.16	0.99	0.14	− 0.02	16,536.27	0.0002	0.83	0.09	0.03	16,515.40
US	0.0002	0.86	0.11	15,936.31	− 0.17	0.99	0.16	0.00	15,955.72	0.0002	0.86	0.11	− 0.01	15,936.48
China	0.0002	0.41	0.33	15,835.19	− 0.34	0.97	0.29	− 0.03	16,034.98	0.0002	0.41	0.33	0.00	15,835.19
Japan	0.0002	0.26	0.50	20,253.31	− 0.45	0.97	0.30	− 0.03	20,631.07	0.0002	0.26	0.44	0.12	20,254.55
South Africa	0.0008	0.62	0.34	15,484.13	− 0.64	0.94	0.25	0.08	15,581.79	0.0001	0.62	0.19	0.31	15,529.59

All parameters are significant at 5% level of significance

Table 25 Estimations of GARCH models of stock market and commodities returns series

		GARCH (1.1)				EGARCH (1.1)					GJR-GARCH (1.1)				
		C	α	β	LogL	C	α	β	λ	LogL	C	α	β	λ	LogL
Commodity markets	Crude_Oil	0.0002	0.94	0.06	8746.49	− 0.07	0.99	0.10	− 0.07	8799.77	0.0002	0.95	0.01	0.07	8782.57
	Energy	0.0002	0.93	0.07	8914.15	− 0.07	0.99	0.09	− 0.07	8969.53	0.0002	0.94	0.01	0.08	8955.51
	Foodstuffs	0.0002	0.92	0.08	12,489.16	− 0.05	1.00	1.00	− 0.03	14,921.40	0.0002	0.92	0.09	− 0.01	12,489.80
	Gold	0.0001	0.95	0.04	10,758.16	− 0.09	0.99	0.11	0.01	10,760.72	0.0001	0.95	0.04	− 0.01	10,758.59
	Indusmetals	0.0001	0.96	0.04	10,773.31	− 0.08	0.99	0.10	0.01	10,776.86	0.0001	0.95	0.04	− 0.01	10,774.50
	Naturalgas	0.0009	0.92	0.07	7774.57	− 0.11	0.98	0.15	0.02	7785.88	0.0009	0.92	0.08	− 0.02	7776.28
	Nickel	0.0082	0.61	0.21	8506.94	− 0.06	0.99	0.09	0.00	8557.35	0.0082	0.61	0.21	0.00	8506.94
	Silver	0.0003	0.95	0.05	8739.65	− 0.09	0.99	0.13	0.00	8740.68	0.0003	0.95	0.05	− 0.01	8740.13
Stock markets	Greece	0.0007	0.87	0.12	8456.72	− 0.17	0.98	0.21	− 0.07	8498.20	0.0007	0.88	0.07	0.09	8477.04
	Ireland	0.0004	0.88	0.11	9693.93	− 0.16	0.98	0.20	− 0.06	9712,26	0.0004	0.88	0.07	0.08	9707.34
	Italy	0.0004	0.89	0.10	9591.30	− 0.21	0.97	0.14	− 0.12	9666.12	0.0006	0.89	0.01	0.15	9649.35
	Portugal	0.0004	0.85	0.13	8736.64	− 0.31	0.96	0.19	− 0.09	8767.39	0.0004	0.87	0.05	0.11	8759.00
	Spain	0.0004	0.88	0.11	9941.69	− 0.17	0.98	0.14	− 0.11	9999.13	0.0003	0.89	0.02	0.14	9986.47
	Belgium	0.0002	0.88	0.11	10,587.88	− 0.23	0.97	0.16	− 0.13	10,660.46	0.0003	0.89	0.01	0.17	10,650.93
	Danmark	0.0007	0.81	0.16	10,465.57	− 0.37	0.96	0.18	− 0.08	10,594.03	0.0007	0.85	0.04	0.13	10,502.95
	France	0.0002	0.87	0.13	10,272.72	− 0.21	0.98	0.13	− 0.16	10,387.00	0.0003	0.88	0.00	0.21	10,355.29
	Germany	0.0003	0.90	0.09	10,273.15	− 0.20	0.98	0.12	− 0.12	10,360.39	0.0003	0.91	0.00	0.14	10,344.63
	Netherlands	0.0002	0.88	0.11	10,660.17	− 0.18	0.98	0.13	− 0.15	10,759.64	0.0002	0.90	0.00	0.18	10,741.22
	Poland	0.0002	0.92	0.07	10,158.89	− 0.12	0.99	0.12	− 0.08	10,198.99	0.0002	0.93	0.02	0.08	10,190.56
	Sweden	0.0002	0.90	0.09	10,489.48	− 0.16	0.98	0.13	− 0.12	10,555.04	0.0002	0.91	0.00	0.16	10,561.43
	UK	0.0002	0.86	0.13	11,005.41	− 0.18	0.98	0.14	− 0.12	11,084.26	0.0002	0.89	0.00	0.18	11,076.04
	USA	0.0003	0.83	0.15	11,109.82	− 0.31	0.96	0.21	− 0.15	11,179.96	0.0003	0.84	0.05	0.18	11,170.82
	China	0.0001	0.93	0.07	9745.20	− 0.07	0.99	0.15	0.00	9749.44	0.0001	0.93	0.07	0.01	9745.41

Table 25 continued

	GARCH (1.1)				EGARCH (1.1)					GJR-GARCH (1.1)				
	C	α	β	LogL	C	α	β	λ	LogL	C	α	β	λ	LogL
Japan	0.0006	0.84	0.14	10,160.43	− 0.35	0.96	0.22	− 0.11	**10,218.84**	0.0006	0.85	0.05	0.16	10,205.59
South Africa	0.0003	0.86	0.13	10,534.71	− 0.22	0.98	0.15	− 0.13	10,602.65	0.0003	0.89	0.00	0.19	10,598.55

All parameters are significant at 5% level of significance

Appendix 4: Results of switching regime ARMA of time series of daily Kendall's tau correlations

See Tables 26, 27, 28, 29, 30, 31, 32, 33.

Table 26 Results of switching regime ARMA of Kendall's tau correlations of Greek and Irish sovereign CDS indexes with other financial indexes

		CDS Greece						
		α_1	α_2	σ_1	σ_2	P_{11}	P_{22}	Loglikelhood
Sovereign Bonds	Greece	0.2681	− 0.0173	0.00141	0.00518	0.99	0.99	2715.6896
	Ireland	0.35	− 0.0174	0.00123	0.00258	0.99	0.99	3515.78
	Italy	0.36	− 0.0175	0.001114	0.00232	0.99	0.99	2895.7896
	Portugal	0.37	− 0.0176	0.0005	0.0036	0.99	0.99	4715.687
	Spain	0.38	− 0.0177	0.00024	0.00128	0.99	0.99	2915.781
Sovereign CDS	Greece							
	Ireland	0.3097	0.0344	0.012	0.015892	0.99	0.99	7645.0851
	Italy	0.2728	0.0381	0.000034	0.021585	0.99	0.99	6927.745
	Portugal	0.2784	0.0482	0.000037	0.023041	0.99	0.99	7484.7711
	Spain	0.1600	− 0.2060	0.012509	0.019971	0.99	0.99	2622.3032
Commodities	Crude oil	− 0.0203	− 0.0419	0.00003	0.005436	0.47	0.99	11,600.0122
	Energy	− 0.0196	− 0.0451	0.00003	0.004901	0.48	0.99	11,744.1006
	Foostuffs	0.0942	0.0932	0.00003	0.005	0.97	0.98	2437.612
	Gold	0.0023	− 0.0028	0.00001	0.001326	0.48	0.99	16,685.5346
	Industrial metals	0.0024	− 0.0028	0.00004	0.001321	0.98	0.99	16,678.673
	Natural gas	− 0.0269	0.0120	0.000525	0.00135	0.47	0.99	8249.6374
	Nickel	− 0.0290	− 0.0414	0.00001	0.001869	0.98	0.99	12,991.9875
	Silver	− 0.0106	− 0.0289	0.00001	0.003301	0.96	0.99	13,207.293
	Stock Market	− 0.1395	0.135	0.013933	0.000003	0.98	0.99	9278.7563

Table 26 continued

		CDS Ireland										
		α_1	α_2	$AR_1(1)$	$AR_2(1)$	$MA_1(1)$	$MA_2(1)$	σ_1	σ_2	P_{11}	P_{22}	Loglikelhood
Sovereign bonds	Greece	− 0.0018	− 0.0031	1.0108	0.9723			0.000006	0.011299	0.99	0.98	2788.123
	Ireland	− 0.2456	− 0.0410					0.001648	0.003912	0.99	0.99	5400.7198
	Italy	− 0.2411	− 0.0929					0.02206	0.002408	0.99	0.99	5461.5519
	Portugal	− 0.2425	− 0.0987					0.001831	0.002669	0.99	0.99	5398.8959
	Spain	− 0.2468	− 0.0789					0.002070	0.002589	0.99	0.99	7645.0851
Sovereign CDS	Greece	0.3097	0.0344					0.000122	0.015892	0.99	0.99	7645.0851
	Ireland											
	Italy	0.3995	0.1897					0.0037	0.00544	0.99	0.99	4393.4505
	Portugal	0.4191	0.2207					0.005163	0.005584	0.99	0.99	8506.5815
	Spain	0.4061	0.2308					0.002239	0.006396	0.99	0.99	7860.2438
Commodities	Crude oil	− 0.0759	− 0.0288					0.000346	0.00385	0.97	0.98	7891.325
	Energy	− 0.0541	− 0.0597					0.000127	0.001999	0.97	0.98	4432.89
	Foostuffs											
	Gold	0.0071	0.0028					0.000496	0.007400	0.97	0.97	5582.5103
	Industrial metals	0.0065	0.0014					0.000469	0.007197	0.97	0.98	9173.8634
	Natural gas											
	Nickel	− 0.0868	− 0.0483					0.000243	0.000227	0.98	0.99	6861.3543
	Silver	− 0.0901	− 0.0178					0.000636	0.000679	0.98	0.99	6878.159
	Stock Market	− 0.1467	− 0.0734					0.000731	0.001436	0.98	0.99	7892.230

All parameters are significant at 5% level of significance

Table 27 Results of switching regime ARMA of Kendall's tau correlations of Italian and Portuguese sovereign CDS indexes with other financial indexes

		CDS Italy										
		α_1	α_2	$AR_1(1)$	$AR_2(1)$	$MA_1(1)$	$MA_2(1)$	σ_1	σ_2	P_{11}	P_{22}	Log likelihood
Sovereign bonds	Greece	0.2067	0.1204					0.0001	0.0017	0.99	0.99	2132.6814
	Ireland	− 0.1726	− 0.0283					0.0016	0.0036	0.99	1.00	5384.0461
	Italy	− 0.4364	− 0.2061					0.00347	0.001	0.99	0.99	3724.514
	Portugal	− 0.2580	− 0.0881					0.0032	0.005	0.99	1.00	4639.6859
	Spain	− 0.3749	− 0.1378					0.004	0.008	0.99	1.00	888.2656
Sovereign CDS	Greece	0.2728	0.0381					0.000034	0.0216	0.99	0.99	6927.745
	Ireland	0.3995	0.1897					0.0037	0.00544	0.99	0.99	4393.4505
	Italy											
	Portugal	0.6186	0.6009	1.0241	0.2004	1.0241	0.2004	0.000062	0.0555	0.99	0.98	9477.9265
	Spain	0.5415	− 0.3021			1.002	7.212	0.000012	0.3823	0.98	0.99	12,834.9393
Commodities	Crude oil	− 0.1140	− 0.0371					0.0005	0.0008	0.99	0.99	7685.5825
	Energy	− 0.1224	− 0.0357					0.00051	0.009	0.99	0.99	7468.7974
	Foostuffs	− 0.0606	− 0.0742					0.00025	0.005	0.95	0.97	12,603.7307
	Gold	0.0365	− 0.0042					0.0005	0.005	0.97	0.98	6240.5327
	Industrial metals	0.0363	− 0.0042					0.0004	0.005	0.97	0.97	2144.6814
	Natural gas	− 0.0297	− 0.0306					0.0002	0.002	0.48	0.5	8692.785
	Nickel	− 0.1195	− 0.0742					0.0003	0.0033	0.97	0.98	8689.5057
	Silver	− 0.0810	− 0.0165					0.0005	0.0083	0.96	0.98	7626.6452
	Stock market	− 0.0009	− 0.0005					0.00012	0.00192	0.88	0.89	8130.2947

Table 27 continued

		CDS Portugal										
		α_1	α_2	$AR_1(1)$	$AR_2(1)$	$MA_1(1)$	$MA_2(1)$	σ_1	σ_2	P_{11}	P_{22}	Log likelihood
Sovereign bonds	Greece	0.3531	0.2504					0.001	0.0213	0.98	0.98	1256.6211
	Ireland	− 0.3708	− 0.1540					0.004	0.0065	0.99	0.99	4086.6915
	Italy	− 0.3922	− 0.1366					0.0066	0.0110	1	0.99	3325.7133
	Portugal	− 0.5138	− 0.1914					0.010193	0.01715	0.99	0.99	2481.3736
	Spain	− 0.4020	− 0.1021					0.006764	0.01371	1.00	1.00	3181.9397
Sovereign CDS	Greece	0.2784	0.0482					0.000037	0.023041	0.99	1.00	7484.7711
	Ireland	0.4191	0.2207					0.005163	0.005584	0.99	0.99	8506.5815
	Italy	0.6186	0.6009	1.0241	0.2004	1.0241	0.2004	0.000062	0.0555	0.99	0.99	9477.9265
	Portugal											
	Spain	0.7025	0.5264					0.002674	0.00734	0.99	0.99	4222.8786
Commodities	Crude oil	− 0.1491	− 0.0869					0.000517	0.00085	0.98	0.97	7308.2251
	Energy	− 0.1265	− 0.0596					0.000678	0.0012	0.97	0.97	7047.9425
	Foostuffs	− 0.0589	− 0.0685					0.000145	0.00228	0.95	0.97	8200.4438
	Gold	0.0700	− 0.0233					0.001905	0.0021	0.97	0.98	8856.742
	Industrial metals											
	Natural gas	− 0.0193	− 0.0188					0.000001	0.00047	0.53	0.63	13,203.3759
	Nickel	− 0.1245	− 0.1264					0.000006	0.00324	0.51	0.61	7903.853
	Silver	− 0.0921	0.0001					0.001996	0.00145	0.96	0.98	5875.4995
	Stock market	− 0.0247	− 0.0226					0.00003	0.0016	0.88	0.89	8747.4813

Table 28 Results of switching regime ARMA of Kendall's tau correlations of Spanish sovereign CDS index with other financial indexes

	CDS Spain										
		α_1	α_1	$AR_1(1)$	$AR_2(1)$	$MA_1(1)$	$MA_2(1)$	α_1	α_1	P_{11}	P_{22}	Loglikelihood
Sovereign bonds	Greece	0.1897	0.118					0.0001	0.0039	0.99	0.99	3356.55
	Ireland	− 0.1989	− 0.028					0.0010	0.0056	0.99	0.99	4987.87
	Italy	− 0.3468	− 0.124					0.0049	0.0065	0.99	0.99	3960.79
	Portugal	− 0.2645	− 0.066					0.0033	0.0057	0.99	0.99	4493.80
	Spain	− 0.3829	− 0.105					0.0059	0.0097	0.99	0.99	3396.38
Sovereign CDS	Greece	0.1600	− 0.2060					0.0125	0.02	0.99	0.99	2622.3032
	Ireland	0.4061	0.2308					0.0022	0.0064	0.99	0.99	7860.2438
	Italy	0.5415	− 0.3021			1.002	7.212	0.000012	0.3823	0.99	0.99	12,834.94
	Portugal	0.7025	0.5264					0.0027	0.00734	0.99	0.99	4222.8786
	Spain											
Commodities	Crude oil	− 0.1126	− 0.042					0.0008	0.0006	0.97	0.98	7399.36
	Energy	− 0.1232	− 0.039					0.0010	0.0009	0.97	0.98	6870.83
	Foostuffs											
	Gold	0.0386	0.010					0.0003	0.0042	0.97	0.98	7014.68
	Industrial metals	0.0385	0.008					0.0003	0.0041	0.97	0.97	6992.60
	Natural gas											
	Nickel	− 0.1278	− 0.066					0.0008	0.0006	0.97	0.97	7407.44
	Silver	− 0.0661	− 0.012					0.0002	0.0006	0.98	0.98	8639.04
	Stock market	− 0.0030	0.001					0.0001	0.001	0.98	0.99	14,660.60

Table 29 Results of Switching regime ARMA of Kendall's tau correlations of Belgian and Danish sovereign CDS indexes with other financial indexes

		CDS Belgium						
		α_1	α_2	σ_1	σ_2	P_{11}	P_{22}	Loglikelhood
Sovereign bonds	Greece	0.1625	− 0.3631	0.0020	0.0042	0.99	0.99	1844.6862
	Ireland	− 0.1248	− 0.0082	0.0012	0.0022	0.99	0.99	6009.5851
	Italy	− 0.1913	− 0.0382	0.0045	0.0045	0.99	0.99	4709.0753
	Portugal	− 0.1354	− 0.0368	0.0018	0.0012	0.99	0.99	6160.0598
	Spain	− 0.1748	− 0.0204	0.0043	0.0020	0.99	0.99	5092.346
	Sov-bonds	− 0.1534	0.0207	0.0053	0.0025	0.99	0.99	4884.0824
Sovereign CDS	Greece	0.2811	0.0246	0.0083	0.0006	0.99	0.99	5448.8879
	Ireland	0.3537	0.1100	0.0079	0.0050	0.99	0.99	3632.1978
	Italy	0.4748	0.1463	0.0087	0.0118	0.99	0.99	2827.1008
	Portugal	0.3688	0.1346	0.0059	0.0051	0.99	0.99	3899.9154
	Spain	0.4161	0.1326	0.0126	0.0104	0.98	0.99	2622.5035
Commodities	Crude oil	− 0.1110	− 0.0408	0.0004	0.0005	0.99	0.99	8242.634
	Energy	− 0.1171	− 0.0377	0.0005	0.0003	0.99	0.99	8572.8793
	Foostuffs							
	Gold	0.0167	0.0005	0.0003	0.0054	0.96	0.95	6542.6697
	Industrial metals grah	0.0156	0.0010	0.0003	0.0053	0.96	0.95	6571.3269
	Natural gas	− 0.0375	− 0.0153	0.0001	0.0000	0.99	0.99	12,322.2249
	Nickel	− 0.0663	0.0916	0.0010	0.0003	1	0.00	6858.0291
	Silver	− 0.0347	− 0.0144	0.0062	0.0004	0.97	0.98	6287.7425
	Stock market	− 0.2351	− 0.1041	0.0036	0.0025	0.98	0.97	4976.4864

Table 29 continued

		CDS Denmark						
		α_1	α_2	σ_1	σ_2	P_{11}	P_{22}	Loglikelihood
Sovereign bonds	Greece	0.1124	− 0.0138	0.0001	0.0014	0.99	0.99	2495.7232
	Ireland	− 0.0496	− 0.0397	0.0001	0.0008	0.47	0.91	10,782.9598
	Italy	− 0.1092	− 0.0167	0.0003	0.0022	0.99	0.99	7409.5575
	Portugal	− 0.0532	− 0.0493	0.0001	0.0045	0.57	0.92	19,583.0412
	Spain	− 0.1247	− 0.0206	0.0005	0.0025	0.99	0.99	7303.4017
	Sov-bonds	0.1154	0.0255	0.0002	0.0045	0.99	0.99	7108.608
Sovereign CDS	Greece	0.1016	0.2871	0.0041	0.0256	0.98	0.99	4242.2059
	Ireland	0.2647	0.066	0.0031	0.0040	0.99	0.99	4614.7132
	Italy	0.2871	0.0528	0.0030	0.0080	0.99	0.99	4307.9027
	Portugal	0.2025	0.0646	0.0048	0.0010	0.99	0.99	5643.2238
	Spain	0.3028	0.062	0.0035	0.0039	0.99	0.99	4645.9959
Commodities	Crude oil	− 0.0671	− 0.006	0.0006	0.0008	0.97	0.98	7074.801
	Energy	− 0.0644	− 0.0037	0.0007	0.0008	0.91	0.95	7142.9513
	Foostuffs	− 0.0741	− 0.0423	0.0002	0.0004	0.98	0.99	10,516.5291
	Gold	− 0.0109	− 0.0048	0.0001	0.0007	0.88	0.94	12,132.2297
	Industrial metals	− 0.0105	− 0.0084	0.0001	0.0005	0.93	0.91	12,160.1617
	Natural gas							
	Nickel	− 0.0936	0.0091	0.0007	0.0005	1	0.00	7909.4185
	Silver	− 0.0251	− 0.0271	0.0001	0.0010	0.93	0.95	9780.585
	Stock market	− 0.031	− 0.0287	0.0001	0.0002	0.71	0.79	14,766.3175

Table 30 Results of switching regime arma of Kendall's tau correlations of French and Deutsch sovereign CDS indexes with other financial indexes

		CDS France						
		α_1	α_2	σ_1	σ_2	P_{11}	P_{22}	Loglikelihood
Sovereign bonds	Greece	0.1425	0.1540	0.0001	0.0020	0.98	0.97	2786.5954
	Ireland	− 0.1181	− 0.0318	0.0005	0.0012	0.99	0.99	7231.7324
	Italy	− 0.1671	− 0.0123	0.0013	0.0018	0.99	0.99	1999.6065
	Portugal	− 0.0621	− 0.0914	0.0002	0.0024	0.99	0.99	7503.3783
	Spain	− 0.1673	0.0114	0.0007	0.0024	0.98	0.99	4942.6468
	Sov-bonds	− 0.0057	− 0.0003	0.0005	0.0102	0.98	0.99	2103.5486
Sovereign CDS	Greece	0.2508	0.0537	0.0040	0.0007	0.97	0.98	6059.4231
	Ireland	0.3170	0.1363	0.0049	0.0051	0.99	0.99	4048.6980
	Italy	0.3453	0.1874	0.0030	0.0026	0.99	0.99	5117.3330
	Portugal	0.3439	0.1503	0.0029	0.0029	0.99	0.99	5060.7810
	Spain	0.3552	0.1549	0.0048	0.0046	0.99	0.99	4227.2415
Commodities	Crude oil	− 0.0924	− 0.0184	0.0012	0.0011	0.96	0.97	6515.2284
	Energy	− 0.0946	− 0.0109	0.0015	0.0013	0.91	0.95	6110.6278
	Foostuffs	− 0.0765	− 0.0366	0.0004	0.0002	0.45	0.91	6120.7000
	Gold	− 0.0065	− 0.0135	0.0000	0.0006	0.97	0.97	10,702.3164
	Industrial metals	− 0.0064	− 0.0123	0.0000	0.0005	0.97	0.96	5546.7830
	Natural gas	− 0.0038	− 0.0012	0.0001	0.0013	0.91	0.95	9104.3247
	Nickel	− 0.0843	− 0.0210	0.0006	0.0004	0.99	0.98	8024.1491
	Silver	− 0.0239	− 0.0445	0.0001	0.0013	0.93	0.91	9215.5509
	Stock market	− 0.1981	− 0.0648	0.0045	0.0012	0.99	0.97	5533.4642

Table 30 continued

		CDS Germany										
		α_1	α_2	$AR_1(1)$	$AR_2(1)$	$MA_1(1)$	$MA_2(1)$	σ_1	σ_2	P_{11}	P_{22}	Loglikelhood
Sovereign bonds	Greece	0.122	0.068					0.001	0.003	0.99	0.99	3707.599
	Ireland	− 0.065	− 0.036					0.002	0.004	0.99	0.99	6785.093
	Italy	− 0.082	− 0.112					0.001	0.008	0.95	0.97	6157.270
	Portugal	− 0.114	− 0.044					0.001	0.001	0.99	0.99	6950.936
	Spain	0.098	0.051					0.007	0.000	0.95	0.96	6189.351
	Sov-bonds	− 0.133	− 0.046					0.002	0.001	0.97	0.98	5690.159
Sovereign CDS	Greece	0.000	0.000	0.999	1.002	0.001	− 0.001	0.001	0.003	0.41	0.93	18,846.362
	Ireland	0.258	0.088					0.006	0.001	0.99	0.98	5099.034
	Italy	0.001	− 0.001	0.997	0.749			0.000	0.043	0.41	0.93	13,912.360
	Portugal	0.283	0.077					0.008	0.002	0.98	0.99	4964.798
	Spain	0.321	0.117					0.004	0.003	0.98	0.99	4977.450
Commodities	Crude oil	− 0.073	− 0.033					0.001	0.004	0.96	0.97	5541.257
	Energy	− 0.081	− 0.032					0.003	0.006	0.99	0.98	9016.079
	Foostuffs	− 0.021	− 0.023					0.003	0.009	0.55	0.89	10,070.521
	Gold	− 0.007	0.005					0.003	0.005	0.79	0.82	12,187.334
	Industrial metals	− 0.008	− 0.004					0.002	0.003	0.51	0.86	12,112.941
	Natural gas											
	Nickel	− 0.056	− 0.058					0.002	0.041	0.94	0.95	11,179.776
	Silver	− 0.037	− 0.042					0.001	0.013	0.41	0.94	8758.669
	Stock market	− 0.170	− 0.081					0.001	0.002	0.98	0.99	6981.583

Table 31 Results of Switching regime ARMA of Kendall's tau correlations of Dutch and Polish sovereign CDS indexes with other financial indexes

	CDS Netherlands										
	α_1	α_2	$AR_1(1)$	$AR_2(1)$	$MA_1(1)$	$MA_2(1)$	σ_1	σ_2	P_{11}	P_{22}	Log likelihood
Greece	0.131	− 0.005					0.0004	0.0013	0.99	0.99	2269.082
Ireland	− 0.090	− 0.026					0.0003	0.0006	0.99	0.99	8495.263
Italy	− 0.139	− 0.065					0.0003	0.0054	0.99	0.99	6297.880
Portugal	− 0.090	− 0.026					0.0003	0.0006	0.99	0.99	8495.263
Spain	− 0.164	− 0.051					0.0014	0.0026	0.99	0.99	5930.880
Sov-bonds	0.076	0.051					0.0001	0.0027	0.98	0.97	7302.919
Greece	0.216	0.045					0.0002	0.0073	0.99	0.99	7148.129
Ireland	0.346	0.149					0.0038	0.0041	0.99	0.99	4504.608
Italy	0.420	0.170					0.0040	0.0045	0.99	0.99	4390.802
Portugal	0.003	− 0.002	0.990	0.991	0.000	0.006	0.0006	0.0005	0.97	0.96	13,207.922
Spain	0.349	0.172					0.0031	0.0044	0.99	0.99	4585.926
Crude oil	− 0.084	− 0.037					0.0002	0.0003	0.99	0.99	9166.580
Energy	− 0.085	− 0.029					0.0003	0.0004	0.99	0.99	8619.036
Foostuffs											
Gold	0.002	0.005					0.0004	0.0087	0.95	0.94	5742.810
Industrial metals	0.002	0.004					0.0004	0.0084	0.93	0.91	5774.571
Natural gas											
Nickel	− 0.099	− 0.044					0.0003	0.0004	0.99	0.97	8457.155
Silver	− 0.074	− 0.017					0.0007	0.0010	0.97	0.98	7068.872
Stock market	− 0.139	0.263					0.0031	0.0042	1.00	0.00	5011.039

Table 31 continued

	CDS Poland										
	α_1	α_2	$AR_1(1)$	$AR_2(1)$	$MA_1(1)$	$MA_2(1)$	σ_1	σ_2	P_{11}	P_{22}	Log likelihood
Greece	0.083	0.057					0.0003	0.0076	0.99	0.99	2188.346
Ireland	− 0.039	− 0.068					0.0001	0.0072	0.99	0.99	7117.788
Italy	− 0.144	− 0.044					0.0003	0.0109	0.97	0.99	6305.668
Portugal	− 0.053	0.061					0.0016	0.0023	0.99	0.97	6101.459
Spain	− 0.167	− 0.020					0.0024	0.0027	0.99	0.99	5575.188
Sov-bonds	− 0.121	− 0.026					0.0007	0.0150	0.97	0.98	5542.167
Greece	0.210	0.046					0.0001	0.0140	0.99	0.99	7280.794
Ireland	0.246	0.064					0.0015	0.0045	0.99	0.99	281.412
Italy	0.269	0.050					0.0011	0.0092	0.99	0.99	4880.832
Portugal	0.220	0.057					0.0010	0.0044	0.99	0.99	5909.362
Spain	0.002	− 0.003	0.995	0.997			0.0001	0.0007	0.47	0.95	13,431.601
Crude oil	− 0.176	− 0.035					0.0012	0.0036	0.99	0.99	5868.401
Energy	− 0.176	− 0.031					0.0011	0.0043	0.99	0.99	5782.918
Foostuffs											
Gold	− 0.006	− 0.010					0.0001	0.0019	0.99	0.99	8562.197
Industrial metals	− 0.007	− 0.011					0.0001	0.0019	0.93	0.91	8611.252
Natural gas											
Nickel	− 0.159	− 0.013					0.0004	0.0043	0.00	1.00	6228.013
Silver	− 0.125	− 0.010					0.0020	0.0006	0.99	0.99	7146.151
Stock market	− 0.271	− 0.049					0.0019	0.0053	0.99	0.99	5034.663

Table 32 Results of switching regime ARMA of Kendall's tau correlations of UK, USA and Swedish sovereign CDS indexes with other financial indexes

		CDS UK							CDS USA						
		α_1	α_2	$\sigma 1$	$\sigma 2$	P_{11}	P_{22}	Log likelihood	α_1	α_2	$\sigma 1$	$\sigma 2$	P_{11}	P_{22}	Log likelihood
Sovereign bonds	Greece	0.0876	0.1916	0.0009	0.0033	0.97	0.96	1906.0828	0.1566	0.0481	0.0005	0.0017	0.99	0.99	2085.0084
	Ireland	− 0.0922	− 0.0014	0.0006	0.0022	0.99	0.99	6756.4541							
	Italy	− 0.1369	− 0.0448	0.0006	0.0013	0.99	0.99	7087.5143	− 0.0663	− 0.0182	0.0002	0.0003	0.99	0.99	9286.2391
	Portugal	− 0.1344	− 0.0413	0.0009	0.0016	0.99	0.99	6728.8943	− 0.0663	− 0.0182	0.0002	0.0003	0.99	0.99	9286.2391
	Spain	− 0.1693	− 0.0412	0.0013	0.0017	0.99	0.99	6336.3994	− 0.0703	− 0.0033	0.0002	0.0007	0.99	0.99	8382.2579
	Sov-bonds	0.1169	0.0143	0.0017	0.0018	0.99	0.99	5858.0540	0.1466	0.0325	0.0001	0.0170	0.99	0.99	8331.6699
Sovereign CDS	Greece	0.1349	0.0031	0.0001	0.0431	0.98	0.98	8841.3305	− 0.0672	− 0.0150	0.0002	0.0003	0.99	0.99	9348.1735
	Ireland	0.2882	0.0916	0.0016	0.0073	0.99	0.99	5042.4504	0.1270	− 0.0063	0.0001	0.0038	0.99	0.99	4750.8070
	Italy	0.3761	0.0894	0.0039	0.0056	0.99	0.99	4386.2974	0.1280	0.0554	0.0004	0.0088	0.99	0.99	5955.8071
	Portugal	0.3353	0.1039	0.0022	0.0037	0.99	0.99	5321.0500							
	Spain	0.3554	0.1053	0.0050	0.0017	0.99	0.99	4625.7449	− 0.0703	− 0.0033	0.0005	0.007	0.23	0.99	4425.985
Commodities	Crude oil	− 0.0490	− 0.1069	0.0003	0.0006	0.99	0.99	8248.5588	0.0530	− 0.0042	0.0007	0.0011	0.47	0.91	6235.1692
	Energy	− 0.0838	− 0.0644	0.0001	0.0020	0.99	0.99	7554.4925	0.1688	0.0508	0.0006	0.0149	0.99	0.99	5075.5972
	Foostuffs	− 0.0841	− 0.0450	0.0002	0.0023	0.99	0.99	9501.2058	0.1781	0.0554	0.0006	0.0036	0.99	0.99	6233.7289
	Gold	− 0.0201	− 0.0306	0.0002	0.0007	0.96	0.97	10,117.5973	0.1691	− 0.4156	0.0021	0.0038	0.00	1.00	5693.2166
	Industrial metals	− 0.0238	− 0.0272	0.0003	0.0088	0.93	0.90	10,011.1090	0.3036	0.1008	0.0045	0.0079	0.98	0.98	3821.4688
	Natural gas	− 0.0281	− 0.0099	0.0005	0.0007	0.93	0.90	11,657.6490	0.1181	0.0686	0.0002	0.0005	0.97	0.95	8154.1026
	Nickel	− 0.0886	− 0.0308	0.0004	0.0002	0.99	0.99	9359.9128	− 0.2845	− 0.1523	0.0026	0.0050	0.98	0.97	4654.8361

Table 32 continued

		CDS UK							CDS USA						
		α_1	α_2	$\sigma 1$	$\sigma 2$	P_{11}	P_{22}	Log likelihood	α_1	α_2	$\sigma 1$	$\sigma 2$	P_{11}	P_{22}	Log likelihood
	Silver	− 0.0474	− 0.0493	0.0001	0.0015	0.98	0.97	8410.8817	− 0.0925	0.1072	0.0053	0.0059	0.99	0.98	3817.9767
	Stock market	− 0.1272	− 0.0390	0.0006	0.0012	0.99	0.99	7196.6297	− 0.1245	− 0.0527	0.0002	0.0005	0.96	0.97	3544.1238

		CDS Sweden						
		α_1	α_2	$\sigma 1$	$\sigma 2$	P_{11}	P_{22}	Log likelihood
Sovereign bonds	Greece	0.0816	− 0.0384	0.0001	0.0008	0.99	0.99	2638.8679
	Ireland							
	Italy	− 0.1645	− 0.0612	0.0025	0.0026	0.97	0.97	5076.4016
	Portugal	− 0.0537	− 0.0105	0.0002	0.0003	0.99	0.99	9378.5886
	Spain	− 0.0374	− 0.0031	0.0003	0.0017	0.99	0.99	8115.7333
	sov-bonds	0.1083	0.0246	0.0002	0.0011	0.99	0.99	7964.2463
Sovereign CDS	Greece	0.1817	0.0208	0.0001	0.0195	0.99	0.98	8173.0061
	Ireland	0.247	0.0532	0.0017	0.0054	0.99	0.99	5276.6087
	Italy	0.2666	0.0485	0.0016	0.008	0.99	0.99	5047.5826
	Portugal	0.2199	0.0545	0.0008	0.012	0.99	0.99	5408.7736
	Spain	0.2588	0.0498	0.0017	0.0057	0.99	0.99	5891.326
Commodities	Crude oil	− 0.0689	− 0.0035	0.0008	0.0072	0.99	0.99	7286.5673
	Energy	− 0.0781	− 0.0116	0.0007	0.0008	0.99	0.99	7289.6447
	Foostuffs	− 0.0551	− 0.0142	0.0002	0.0003	0.99	0.99	9854.8183
	Gold	− 0.0303	0.0074	0.0001	0.0002	0.99	0.99	9976.9816

Table 32 continued

	CDS Sweden						
	α_1	α_2	$\sigma 1$	$\sigma 2$	P_{11}	P_{22}	Log likelihood
Industrial metals	− 0.0308	0.0075	0.0001	0.0002	0.99	0.99	9924.1269
Natural gas							
Nickel	− 0.0372	− 0.0137	0.0003	0.0005	0.94	0.95	10,633.2001
Silver	− 0.0339	− 0.0158	0.0002	0.0024	0.95	0.96	7489.3377
Stock market	− 0.0708	− 0.0038	0.0002	0.0052	0.98	0.97	6274.2791

Table 33 Results of switching regime ARMA of Kendall's tau correlations of Chinese, Japanese and South-African sovereign CDS indexes with other

		CDS China							CDS Japan						
		α1	α2	α1	α2	P11	P22	Log likelihood	α1	α2	α1	α2	P11	P22	Log likelihood
Sovereign bonds	Greece	− 0.0767	− 0.0497	0.0005	0.0090	0.99	0.97	5659.82	0.06	0.01	0.0003	0.0043	0.99	0.99	4675.984
	Ireland	− 0.0875	0.0173	0.0029	0.0031	0.97	0.96	4898.44	− 0.012	0.02	0.0003	0.0039	0.98	0.99	13025.05
	Italy	− 0.0851	− 0.0786	0.0003	0.0071	0.97	0.95	6944.10							
	Portugal	− 0.0662	− 0.0731	0.0006	0.0100	0.97	0.95	5705.1							
	Spain	− 0.0767	− 0.0497	0.0005	0.0090	0.97	0.96	5659.82	− 0.006	0.04	0.0001	0.0056	0.97	0.99	9731.22
	sov-bonds	0.088	0.056	0.0005	0.001	0.97	0.96	5489.2	0.02	0.02	0.0001	0.0010	0.98	0.98	20746.38
Sovereign CDS	Greece	0.1926	0.0138	0.0053	0.0002	0.99	0.99	7503.42	0.067	0.005	0.0001	0.0049	0.99	0.96	12389.12
	Ireland	0.1484	− 0.4190	0.0015	0.0019	1.00	0.00	6259.53	0.114	0.009	0.0020	0.0042	0.99	0.99	5091.79
	Italy	0.2276	0.1877	0.0002	0.0002	0.97	0.95	9284.04	0.061	0.07	0.0001	0.0020	0.84	0.46	8672.3
	Portugal	0.1631	− 0.3166	0.0011	0.0016	1.00	0.00	6791.8	0.084	0.06	0.0002	0.0061	0.84	0.45	6817.81
	Spain	0.1657	0.2225	0.0003	0.0008	0.96	0.97	8190.72	0.075	0.04	0.0001	0.0038	0.82	0.48	8125.63
Commodities	Crude oil	0.0025	0.002	0.0001	0.0005	0.48	0.84	8562.12							
	Energy	− 0.0709	− 0.0757	0.0001	0.0010	0.92	0.95	9262.58							
	Foostuffs								0.008	0.006	0.0001	0.0013	0.45	0.91	9916.73
	Gold								0.024	− 0.005	0.0001	0.0023	0.97	0.98	8572.81
	Industrial metals	0.0087	0.0085	0.0002	0.0013	0.48	0.82	14363	0.023	− 0.005	0.0001	0.0023	0.98	0.96	8640.67
	Natural gas	0.0016	− 0.0127	0.0001	0.0013	0.91	0.95	8257.26							
	Nickel	− 0.1253	− 0.0889	0.0001	0.0003	0.94	0.95	9382.7	0.01	0.012	0.0002	0.0008	0.94	0.95	12036
	Silver	− 0.0472	− 0.0474	0.0005	0.0047	0.39	0.64	11878.21	0.022	− 0.008	0.0002	0.0003	0.97	0.97	9165.53
	Stock market	− 0.0003	0.0003	0.0001	0.0020	0.00	1.00	17050.64	− 0.18	− 0.05	0.0018	0.0024	0.98	0.97	5552.9

Table 33 continued

		CDS South Africa						
		α1	α2	α1		P11	P22	Log likelihood
Sovereign bonds	Greece	0.076	− 0.028	0.0007	0.0143	0.99	0.99	2044.8
	Ireland	− 0.017	− 0.061	0.0005	0.0124	0.98	0.98	5717.7
	Italy	− 0.165	− 0.061	0.0025	0.0026	0.97	0.95	5076.4
	Portugal	− 0.1	0.005	0.0010	0.0069	0.98	0.98	5461.6
	Spain	− 0.146	− 0.004	0.0042	0.0043	0.95	0.94	4211
	Sov-bonds	0.002	0.005	0.0001	0.0005	0.5	0.95	10548.8
Sovereign CDS	Greece	0.151	0.007	0.0001	0.0067	0.99	0.99	7877.7
	Ireland	0.211	0.13	0.0003	0.0041	0.97	0.98	6831.5
	Italy	0.22	− 0.33	0.0069	0.0033	0	1	3624.2
	Portugal	0.174	− 0.3	0.0036	0.0041	0	1	4747.7
	Spain	0.214	− 0.16	0.0041	0.0096	0	1	4506.4
Commodities	Crude oil	− 0.203	− 0.1	0.0014	0.0017	0.98	0.98	6295.12
	Energy	− 0.207	− 0.103	0.0014	0.0018	0.98	0.98	6484.86
	Foostuffs							
	Gold	− 0.074	− 0.017	0.0007	0.0008	0.96	0.97	7249.6
	Industrial metals	− 0.074	− 0.018	0.0007	0.0008	0.98	0.97	7273.32
	Natural gas	− 0.027	− 0.012	0.0004	0.0014	0.98	0.98	11310.5
	Nickel	− 0.17	0.37	0.0021	0.0028	0	1	5640.35
	Silver	− 0.121	− 0.09	0.0001	0.0022	0.97	0.97	7417.9
	Stock market	− 0.28	− 0.14	0.0020	0.0023	0.99	0.99	5509

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