North American Journal of Economics and Finance 51 (2020) 101072

Contents lists available at ScienceDirect

North American Journal of Economics and Finance

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

Decomposing the term structures of local currency sovereign bond yields and sovereign credit default swap spreads☆

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ARTICLE INFO

Keywords:
Sovereign credit default swaps
Sovereign bonds
Sovereign credit risk and non-credit risk

JEL:
E43
G01
G12

ABSTRACT

In this study, we analyze the relationship between the term structures of local currency-denominated sovereign bond yields and foreign currency-denominated sovereign credit default swap (CDS) spreads for developed countries. We develop a consistent pricing model between the term structures of local currency-denominated sovereign bond yields and foreign currency-denominated sovereign CDS spreads, which allows us to decompose these term structures into credit risk and non-credit risk (e.g., convenience yield or liquidity risk). In the euro area countries, we show that the credit risk components are mainly related to local equity markets or the proxy of the regulatory incentive of the global dealer banks. In the core countries of the euro area, the non-credit risk component of the bond spread is related to the proxy of the flight to liquidity at all maturities, and function as convenience yield. During the sovereign debt crisis in the developed European market, in the peripheral countries of the euro area, the non-credit risk component of the bond spread is related to the liquidity risk. At the short end of the term structure, this relation is stronger than that at longer maturity. On the other hand, the relationships between the non-credit risk components of CDS spreads and risk factors are weak and the fluctuations of the CDS spread is mainly driven by the credit risk components in both country groups.

1. Introduction

During the European sovereign debt crisis, the sovereign bond yields and credit default swap (CDS) spreads of developed countries fluctuated widely. Concerns over developed country credit risks have grown. Although several studies (e.g., Fontana & Scheicher, 2016 and Klingler & Lando, 2018) have examined the relationship between sovereign bond yields and CDS spreads at a specific maturity for developed countries by assuming a simple arbitrage relationship, research on the term structure relationship has thus far been superficial. During the European sovereign debt crisis, Portuguese bond yield spreads relative to the overnight indexed swap (OIS) and CDS spreads presented high co-movement at 1-year and 10-year maturities. On the other hand, German bond yield spreads and CDS spreads presented different movements at both maturities. German CDS spreads increased, but bond yield spreads did not co-move. These factors indicate that the effect of credit risk on sovereign bond yields is different for each country, and the term structure holds important information.

☆ For their helpful comments on this article, we especially wish to thank Nobuhiro Nakamura, Toshiki Honda, Daisuke Miyakawa, Hidetoshi Nakagawa, Kazuhiko Ohashi, Daisuke Yokouchi, and all participants of the Nippon Finance Association Annual Meeting (2015) and the 46th Japanese Association of Financial Econometrics and Engineering Meeting (2017).

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https://doi.org/10.1016/j.najef.2019.101072
Received 5 January 2019; Received in revised form 11 September 2019; Accepted 16 September 2019
Available online 23 September 2019
1062-9408/

When we study developed countries' CDS spreads, the exchange rate risk should be considered. Many developed countries excluding the United States issue sovereign bonds in denominations other than the U.S. dollars (USD). However, the benchmark sovereign CDS is denominated in U.S. dollars.[1] Therefore, in this study, we develop a consistent pricing model between the term structure of local currency-denominated sovereign bond yields and foreign currency-denominated sovereign CDS spreads, considering the depreciation risk of the exchange rate following a sovereign credit event. The pricing model allows us to decompose these spreads and yields into credit risk and non-credit risk (e.g., convenience yield or liquidity risk).

In our model, an affine term structure model is used. It is important to consider a reduced form approach rather than a simple arbitrage relationship.[2] First, to construct a pricing model of both instruments, we introduce a non-credit risk in addition to the risk-free rate and risk-neutral intensity of the referenced country's credit event in both instruments. This feature allows us to capture any liquidity risk, convenience yield, or other non-credit-related components.[3] In this study, non-credit risk and risk-neutral intensity are treated as hidden processes in the affine term structure model. After estimating the non-credit risk process, we investigate the relationship between the non-credit risk process and these risk factors.

Second, to study the relationship between different currency-denominated instruments, we derive a pricing formula under a local risk-neutral measure by changing the probability measure. We use the foreign currency-denominated sovereign CDS spreads.[4] Foreign currency-denominated sovereign CDSs are mainly traded.[5] Therefore, foreign currency-denominated CDS spreads are higher than those denominated in the local currency. A pricing formula of foreign currency-denominated CDS spreads is described under a foreign risk-neutral measure. The currency depreciation risk following a sovereign credit event must then be considered. To change the probability measure with depreciation risk, we express the depreciation risk by a jump process, as in Ehlers and Schönbucher (2004). In addition, we show that the larger the depreciation risk priced in CDS spreads, the higher the CDS spread. We show the impact on CDS spreads using a numerical example.

In this study, we apply the model to study the relationship between the euro area countries' term structures for two economic phases, which allows us to specify the intensity process and non-credit risk process as the hidden processes. The sample two phase includes the European sovereign debt crisis and the period of economic expansion after the crisis. We use this specification and decompose the term structures of both instruments into the credit risk components, which consist of the intensity process, and the non-credit risk components. However, based on simulated data, we find that we cannot differentiate between the depreciation ratio and the non-credit risk process using local currency-denominated bonds and foreign currency-denominated CDS. Therefore, before we estimate the model between the local currency-denominated bonds and the foreign currency-denominated CDS, we specify a market-implied depreciation ratio for each country with local currency-denominated CDS spreads and foreign currency-denominated CDS spreads. Furthermore, to study the commonality of the hidden processes in both instruments in euro area countries, we conduct a principal component analysis of the changes in each risk component. Finally, to understand the drivers of each component, we conduct regression analysis with several financial market variables and the proxies of liquidity risk.

To the best of our knowledge, our paper makes two significant contributions to the literature. First, we provide a consistent affine term structure model of local currency-denominated sovereign bond yields and foreign currency-denominated sovereign CDS spreads for developed countries considering currency depreciation risk following a credit event. Second, we provide important insights for practitioners and policy makers regarding the dynamics and drivers in term structures of sovereign bond yields and CDS spreads using a consistent model and considering the credit and non-credit risk components in developed countries. In the crisis period, we find that, on average, the non-credit risk component of the bond spreads is negative in bond spreads at the short end of the term structure. At longer maturities, the non-credit risk component of the bond spreads is less important in bond spreads. In addition, in the peripheral countries, the non-credit risk component of the bond spreads is more volatile than the credit risk components at the short end of the term structure. On the other hand, in CDS spreads, the credit risk component is more important for crisis period. For the expansion period, in the core countries, the levels of CDS spreads are higher than those of theoretical credit risk component, and its difference is constantly earned by seller especially at 5- and 10-years. Following the regression analysis, for the crisis period, the credit risk components in core countries have negative relationship with the local equity market. Further, the bond spreads increase as the local equity market risk decreases even in the core countries for the crisis period unlike Dufour, Stancu, and Varotto (2017). When considering the effect of the risk-free rate term structures, we find that the bond spreads are affected by the local market risk through the credit risk components. Furthermore, the global risk factor is not related to the credit risk components, unlike the findings of Ang and Longstaff (2013) and Longstaff et al. (2011), who study the period before the European sovereign debt crisis for both country groups. In the peripheral countries, the credit risk component is also related to the local equity market for the expansion

[1] Similarly, the United States Treasury does not issue in euros, but the benchmark sovereign CDS is denominated in euros.

[2] Duffie and Liu (2001) and Longstaff, Mithal, and Neis (2005) show that there is a nontrivial difference between a model-free approach and reduced model. A model-free approach can be biased. Longstaff et al. (2005) note that, in general, the effect of the bias is to underestimate the size of the default component in investment-grade bonds, and vice versa for below-investment-grade bonds. Badaoui, Cathcart, and El-Jahel (2013) also indicate the difference.

[3] The convenience yield is lost to an investor wishing to receive fixed-rate payments instead of holding an instrument. Duffie and Singleton (1997) and Grinblatt (2001) use this factor for the study of spreads between government bond yields and interest rate swaps.

[4] Ang and Longstaff (2013), Klingler and Lando (2018), Longstaff, Pan, Pedersen, and Singleton (2011), Pelizzon, Subrahmanyam, Tomio, and Uno (2016) also use foreign currency-denominated sovereign CDSs referencing developed countries.

[5] De Santis (2015), Fontana and Scheicher (2016) and O'Kane (2012) make this point. De Santis (2015) mention that local currency sovereign CDSs might have higher liquidity risk. In addition, De Santis (2015), Jarrow et al. (2016), and Fontana and Scheicher (2016) mention that foreign currency-denominated sovereign CDSs have exchange rate and depreciation risks, following sovereign credit events.

period. These results in peripheral countries are in line with Dufour et al. (2017). The credit risk component is also related to the proxy for global dealer banks' regulatory incentives for both periods in both country groups. This supports the results of Klingler and Lando (2018). We can infer that this relationship is priced in the credit risk component. In the core countries, the non-credit risk component of the bond yield is mainly related to flight to liquidity effect, for which the KfW spread is the proxy, and function as convenience yield. In the peripheral countries, for the crisis period, the non-credit risk component of the bond spread is also mainly related to market liquidity, for which the bid–ask spread is the proxy. Especially, at 1-year maturity, it is also related to the KfW spreads. On the whole, the relationships between CDSs' non-credit risk components and risk factors are weak and these fluctuations have little effect on the fluctuation of CDS spreads in both country groups unlike the findings of Badaoui et al. (2013).

2. Related literature

Several studies have examined the relationship between sovereign bond yields and CDS spreads at a specific maturity for developed countries by assuming a simple arbitrage relationship. Fontana and Scheicher (2016) study the CDS-bond basis of European sovereigns. They assume a simple arbitrage relationship and find that the flight-to-quality/liquidity phenomenon in bond markets is a key driver of the large positive basis of better-rated countries. Klingler and Lando (2018) investigate the sovereign credit spread of local currency-denominated bonds and foreign currency-denominated CDS. They develop a model in which a derivatives-dealing bank faces capital charges from uncollateralized swap positions with sovereigns, and use regression analysis to argue that CDS spreads for safe sovereigns are primarily driven by regulatory incentive of global dealer banks. CDS can be used to reduce the capital requirements of dealer banks that have uncollateralized derivatives positions with sovereigns. In these studies, a simple arbitrage relationship is assumed.

Dufour et al. (2017) study the determinants of European sovereign bond returns during the calm and crisis periods. They show that the sign of covariance between the returns of sovereign bond and local equity index is switched from negative to positive as the level of credit risk increases.[6]

Some studies investigate the non-credit risks in sovereign bond yields with a particular focus on the liquidity risk effect. Beber, Brandt, and Kavajecz (2009) study the liquidity effect in sovereign bond yields for European sovereigns using the CDS spreads between April 2003 and December 2004. They show that liquidity plays a nontrivial role in the dynamics of sovereign bond yields, especially for low credit risk countries and during times of heightened market uncertainty. Monfort and Renne (2014) use the Kreditanstalt für Wiederaufbau (KfW) spread as the liquidity factor, and find that a sizable share of variations in euro area sovereign bond spreads during the European sovereign debt crisis is liquidity driven.

Further, a non-credit risk is used in an affine model for corporate bonds in Longstaff et al. (2005) and for LIBOR and LIBOR swaps in Filipović and Trolle (2013).[7] In these studies, the authors assume that non-credit risk represents liquidity risk and that liquidity risk is priced into corporate bonds or corporate loans, and that non-credit risk is not used in CDS pricing. After estimating the non-credit risk process, they confirm that the non-credit risk process is related to the proxy of the liquidity risk.

The drivers of sovereign CDS spreads have been investigated in some studies. Longstaff et al. (2011) and Pan and Singleton (2008) use the sovereign CDS term structure to estimate the risk premium component, and find that it is related to global risk factors. Ang and Longstaff (2013) study the systemic risk component in U.S. sovereigns and Eurozone sovereigns, and find that the systemic risk component is related to global risk factors. On the other hand, the liquidity effects in corporate CDS markets have been investigated in some studies (e.g., Bongaerts, Jong, & Driessen, 2011, Qiu and Yu, 2012).

Badaoui et al. (2013) and Badaoui, Cathcart, and El-Jahel (2016) study the relationship between sovereign bond yields and CDS spreads of emerging countries. They construct an affine term structure model between these term structures, considering liquidity risk for both, and find that liquidity risk plays an important role in sovereign CDS. However, although Badaoui et al. (2013) treat a hidden process other than the credit risk process as liquidity risk,[8] little attention has been paid to investigating whether an estimated risk process is related to the alternative variables of liquidity risk or other risk factors. In contrast Filipović and Trolle (2013) and Longstaff et al. (2005) confirm that the non-credit risk process is related to the liquidity factor proxy after estimating the non-credit risk process. Furthermore, Badaoui et al. (2013) and Badaoui et al. (2016) focus on foreign currency-denominated bonds in emerging market countries to avoid any currency mismatch between a sovereign bond currency and a sovereign CDS currency. Foreign currency-denominated CDSs are mainly traded in the sovereign CDS market.[9] Badaoui et al. (2016) mention that a study on developed countries is an issue for future research.

Credit risk pricing in local currency-denominated sovereign bonds of emerging countries is studied in Du and Schreger (2016). They use cross-currency swap and local currency-denominated sovereign bond yields for emerging countries. The results show that local currency credit spreads have lower means, lower cross-country correlations, and lower sensitivity to global risk factors than

[6] Note that Dufour et al. (2017) use bond returns instead of bond yield changes which are used in this study. Therefore, their signs should be interpreted in reverse when comparing with our results.

[7] Longstaff et al. (2005) use non-credit risk to construct the pricing formula of corporate bonds to study how financial markets value corporate debt. Filipović and Trolle (2013) also use this risk to construct the pricing formula for LIBOR and LIBOR swaps to infer a term structure of interbank risk from spreads between rates on interest rate swaps indexed to the LIBOR and OISs.

[8] Badaoui et al. (2016) assume that the difference between the mid and ask quotes provides an upper bound estimate of liquidity risk following Chen, Fabozzi, and Sverdlove (2010).

[9] Jarrow et al. (2016) mention that liquidity of CDS contracts is a concern, especially across currencies of a particular denomination.

credit spreads on foreign currency-denominated bonds.

The depreciation risk priced in sovereign CDS has been investigated in some studies. De Santis (2015) and Jarrow et al. (2016) estimate the depreciation rate using CDS spread data. However, these studies do not consider a probability measure change[10] following the depreciation risk and the liquidity risk. In addition, De Santis (2015), Fontana and Scheicher (2016), and Jarrow et al. (2016) note that foreign currency-denominated sovereign CDSs have exchange rate and depreciation risks following sovereign credit events. Ehlers and Schönbucher (2004) propose the approach of linking foreign exchange rate and the intensity process by considering an affine jump-diffusion model for the FX process where the jump happens at the credit event. The currency depreciation risk following a sovereign credit event has to be considered.

3. The pricing model

In this section, we present a pricing model for a local currency-denominated sovereign bond and foreign currency-denominated sovereign CDS, referencing the same country under the same probability measure for the analysis of the relationship with these instruments. For example, an investor invests in euro-denominated sovereign German bonds and U.S. dollar-denominated sovereign CDSs referencing Germany. For this model, we must consider the impact of the exchange rate and the relationship between the domestic and foreign risk-neutral measures. Ehlers and Schönbucher (2004) describe the influence of the exchange rate on credit spreads.

3.1. The fundamental setting

A complete filtered probability space $(\Omega, \mathscr{G}, (\mathscr{G}_t), \mathbb{Q})$ is fixed. The information at time t is denoted as $\mathscr{G}_t = \mathscr{F}_t \vee \mathscr{H}_t$, where $\mathscr{F}_t$ is generated by the standard Brownian motion w in $\mathbb{R}^n$ and $\mathscr{H}_t$ is generated by a pure jump process J_t with jumps $\Delta J_t \in \mathscr{Z} = (0, 1]$. We represent J_t using its associated jump measure $\mu(dt, dz)$ on $[0, T] \times \mathscr{Z}$ as $J_t := \int_0^t \int_{\mathscr{Z}} z\mu(dz, ds)$. The compensator measure of μ under $\mathbb{Q}$ is denoted as ν. The stopping time τ is the time of the first jump: $\tau = inf\{t; J_t > 0\}$. The non-negative intensity process in the jump process is denoted as λ_t and is an -adapted $\mathscr{F}_t$-adapted process. A distribution function on $\mathscr{Z}$ is denoted as F and is an -adapted $\mathscr{F}_t$-adapted function. We assume that the compensator ν satisfies $\mathbf{1}_{\{t\leqslant\tau\}}\nu(dz, dt) = \mathbf{1}_{\{t\leqslant\tau\}}dF_t(z)\lambda_t dt$. The model of the exchange rate with intensity risk is set as follows. We express a domestic measure as $\mathbb{Q}_d$ instead of $\mathbb{Q}$ and λ_d instead of λ for the intensity under $\mathbb{Q}_d$, and a foreign measure as $\mathbb{Q}_f$ instead of $\mathbb{Q}$ and λ_f instead of λ for the intensity under $\mathbb{Q}_f$. The exchange rate between the foreign currency c_f and domestic currency c_d is denoted as $X_t \geqslant 0$.[11] A short-term interest rate process is denoted as $r_{i,t}$ and an instantaneous bank account is denoted as $b_{i,t} := exp(\int_0^t r_{i,s} ds)$ in the currencies c_i and $i = d, f$, respectively. In this setting, it is assumed that under $\mathbb{Q}_d$ X_t satisfies a stochastic differential equation (SDE) of the form

$$\frac{dX_t}{X_t} = \left(r_{d,t} - r_{f,t}\right)dt + \sigma_X dw_x^d + \int_Z \delta^d\left(z, t\right)\left(\mu - \nu^d\right)\left(dz, dt\right),$$

where $\delta^d(\geqslant -1)$ is a predictable function. δ^d represents an appreciation ratio of the foreign currency against local currency at the credit event. Conversely, the local currency depreciates against foreign currency at the credit event. The discounted value of a domestic bank account, $X_t \frac{b_f(t)}{b_d(t)}$, is required to be -local $\mathbb{Q}_d$-local martingale. The drift term of X_t is satisfied with the restriction for the -local $\mathbb{Q}_d$-local martingale.

We can consider two structural relationships between $\lambda_{d,t}$ and X_t. First, if $\lambda_{d,t}$ is increased, the value of the domestic currency depreciates. Second, the exchange rate process jumps following a sovereign credit event. This impact is considered by $\delta^d(z, t)$, then $\Delta X_\tau = +X_{\tau-}\delta^d(z_\tau, \tau)$. In addition to the relationship between X_t and $\lambda_{d,t}$, $r_{d,t}$, $r_{f,t}$, $\lambda_{d,t}$, and X_t could also show correlation. However, in this study, we do not focus on these dependencies.

The discounted value in c_d of a domestic bank account is denoted by $L_t := \frac{X_t}{X_0}\frac{b_f(t)}{b_d(t)}$. The foreign risk-neutral measure $\mathbb{Q}_f$ is defined as follows:

Definition 1 (*Foreign risk-neutral measure*). The equivalent measure $\mathbb{Q}_f \sim \mathbb{Q}_d$ on $(\Omega, \mathscr{G})$ defined by

$$\left.\frac{d\mathbb{Q}_f}{d\mathbb{Q}_d}\right|_{\mathscr{F}_t} := L_t, \tag{1}$$

is called the foreign risk-neutral measure induced by $\mathbb{Q}_d$ and X_t.

Ehlers and Schönbucher (2004) show that $\lambda_{d,t}$ and $\lambda_{f,t}$ do not coincide if X_t jumps at a credit event.

3.2. Recovery rate

In this study, it is assumed that the recovery model is the "recovery of face value." Under "recovery of face value," if a credit event occurs at $\tau(\leqslant T)$, the holder of the bond receives a recovery payment of size $(1 - R)$ at the credit event time τ, where R is the recovery

[10] A pricing formula of foreign currency-denominated CDS spreads is described under a foreign risk-neutral measure.

[11] X_t is the value at time t of one unit of c_f, expressed in units of c_d.

rate. "Recovery of face value" is the model that most closely represents legal practice.[12]

3.3. Local currency-denominated sovereign bond-pricing model

Following Longstaff et al. (2005), the value of the local currency-denominated sovereign bond at time t, $P_t(m)$, which matures at $t+m$, is defined as follows:

$$P_t(m) = E^{\mathbb{Q}_d}\left[e^{-\int_t^{t+m}\left(r_{d,u}+\lambda_{d,u}+\gamma_{b,u}\right)du} \,\middle|\, \mathscr{F}_t \right] + RE^{\mathbb{Q}_d}\left[\int_t^{t+m} \lambda_{d,s} e^{-\int_t^{s}\left(r_{d,u}+\lambda_{d,u}+\gamma_{b,u}\right)du} ds \,\middle|\, \mathscr{F}_t \right], \tag{2}$$

where a non-credit risk process is denoted as $\gamma_{b,u}$ and is an -adapted process $\mathscr{F}_t$-adapted process.[13] A non-credit risk process is used to capture the extra return that investors might require above and beyond compensation for the credit risk from holding sovereign bonds rather than risk-free securities. This feature allows us to capture any liquidity risk, convenience yield, or other non-credit-related components in the local currency-denominated bond price. The convenience yield is lost to an investor wishing to receive fixed rate payments instead of holding a local currency-denominated government bond.

Each of the processes $r_{d,t}$, $\lambda_{d,t}$, and $\gamma_{b,u}$ are stochastic. They are assumed to evolve independently of each other. Given the assumption of independence, we do not need to specify the risk-neutral dynamics of the risk-free rates. In this case, we require only the discount factor. In addition, the recovery rate is assumed to be independent from the credit event time.

The first term of (2) is the present value of face value that the investor receives if the credit event does not occur by maturity. The second term of (2) is the present value of recovery that the investor receives when the credit event occurs by maturity.

3.4. Foreign currency-denominated sovereign CDS pricing model

Next, we describe the value of foreign currency-denominated CDS. We introduce a non-credit risk process in the CDS pricing model. A non-credit risk process is used to capture the extra return that investors might require above and beyond compensation for the credit risk by the buyer or seller. This feature allows us to capture any liquidity risk or other non-credit risk related components in CDS.[14] After estimating the non-credit risk process, we investigate whether this process is related to a liquidity factor or other non-credit risk related factors. Additionally, we do not specify whether the seller or the buyer earns this premium. Bongaerts et al. (2011) note that the sign of the liquidity premium, which depends on investors' exposure, could go in either direction using a general equilibrium pricing model. Therefore, it is assumed that the non-credit risk process takes a negative value.

Proposition 1. [The value of the protection leg in foreign currency-denominated CDS] *The value of the protection leg in foreign currency denominated CDS is given by*

$$B_0\left(1-R\right)E^{\mathbb{Q}_d}\left[\int_t^{T} \bar{\delta}\lambda_{d,s} e^{-\int_t^{s}\left(r_{f,u}+\bar{\delta}\lambda_{d,u}+\gamma_{c,u}\right)du} ds \,\middle|\, \mathscr{F}_t \right],$$

where a non-credit risk process in CDS is denoted as $\gamma_{c,t}$ and is an $\mathscr{F}_t$-adapted process, and the notional of CDS in foreign currency is denoted as B_0. Additionally, $\bar{\delta}$ is defined as $\bar{\delta} \coloneqq 1+\hat{\delta}^d$, where the locally expected appreciation fraction $\hat{\delta}^d(t)$ under $\mathbb{Q}_d$ is $\hat{\delta}^d(t) \coloneqq \int_{\mathscr{Z}} \delta^d(z,t)dF_t^d(z)$. And it is assumed that δ^d is not distributed and constant.

Proof can be found in Appendix A. The value of the CDS spread at time t, which matures at $t+m$, is denoted as $S_{t,m}$. To calculate the depreciation ratio, we define the depreciation ratio as $\hat{\delta}^f = \frac{\hat{\delta}^d}{1+\hat{\delta}^d}$ where $\hat{\delta}^f$ is the locally expected depreciation ratio of local currency against foreign currency.

Proposition 2. [The value of the premium leg in foreign currency-denominated CDS]*The value of the premium leg in foreign currency-denominated CDS is given by*

$$\frac{B_0 S_{t,m}}{4}\left\{ \sum_{k=1}^{4m} E^{\mathbb{Q}_d}\left[e^{-\int_t^{t+\frac{k}{4}}\left(r_{f,u}+\bar{\delta}\lambda_{d,u}\right)du} \,\middle|\, \mathscr{F}_t \right] + \frac{1}{2}E^{\mathbb{Q}_d}\left[\int_t^{T} \bar{\delta}\lambda_{d,s} e^{-\int_t^{s}\left(r_{f,u}+\bar{\delta}\lambda_{d,u}\right)du} ds \,\middle|\, \mathscr{F}_t \right] \right\}.$$

Proof can be found in Appendix A.

[12] In previous CDS research, Jarrow, Li, and Ye (2016), Longstaff et al. (2011), Longstaff et al. (2005) and Pan and Singleton (2008) use this model for CDS pricing.

[13] Details of the fundamental settings are shown in Appendix A.

[14] Unlike Badaoui et al. (2013), we do not consider the differences between bid and ask, because we consider the consistency with bond pricing as in Filipović and Trolle (2013) and Longstaff et al. (2005), where only the mid price is used.

Proposition 3. [Foreign currency-denominated CDS spread] *Sovereign CDS spread denominated in foreign currency is given by*

$$S_{t,m}=\frac{(1-R)E^{Q_d}\left[\int_t^T\bar{\delta}\lambda_{d,s}e^{-\int_t^s(r_{f,u}+\lambda_{d,u}+\gamma_{c,u})du}ds\mid\mathscr{F}_t\right]}{\frac{1}{4}\sum_{k=1}^{4m}E^{Q_d}\left[e^{-\int_t^{t+\frac{k}{4}}\left(r_{f,u}+\bar{\delta}\lambda_{d,u}\right)du}\,\middle|\,\mathscr{F}_t\right]+\frac{1}{8}E^{Q_d}\left[\int_t^T\bar{\delta}\lambda_{d,s}e^{-\int_t^s(r_{f,u}+\bar{\delta}\lambda_{d,u})du}ds\mid\mathscr{F}_t\right]}. \tag{3}$$

Proof. Propositions 2 and 3 are used. □

Otherwise, following Longstaff et al. (2005), a pricing formula for a CDS spread denominated in the domestic currency is described as follows:

$$S_{t,m}^{loc}=\frac{(1-R)E^{Q_d}\left[\int_t^T e^{-\int_t^s(r_{d,u}+\lambda_{d,u}+\gamma_{c,t})du}\lambda_{d,s}ds\mid\mathscr{F}_t\right]}{\frac{1}{4}\sum_{k=1}^{4m}E^{Q_d}\left[e^{-\int_t^{t+\frac{k}{4}}\left(r_{d,u}+\lambda_{d,u}\right)du}\,\middle|\,\mathscr{F}_t\right]+\frac{1}{8}E^{Q_d}\left[\int_t^T e^{-\int_t^s(r_{d,u}+\lambda_{d,u})du}\lambda_{d,s}ds\mid\mathscr{F}_t\right]}. \tag{4}$$

Let us consider the difference between (3) and (4). The effect of the depreciation ratio $\hat{\delta}^f$ makes a difference where $\bar{\delta}=\frac{1}{1-\hat{\delta}^f}$. It is assumed that the value of the interest rate of the local currency is the same as the interest rate of the foreign currency, and these processes are deterministic. Therefore, the difference between (3) and (4) is dependent only on $\hat{\delta}^f$. If $\hat{\delta}^f$ is zero, then $\bar{\delta}=1$ and (3) equals (4). In the case where the local currency depreciates at the credit event ($0<\hat{\delta}^f<1$), the value of the numerator in (3) is less than the value of the numerator in (4). Then, the value of the CDS spread denominated in foreign currency is greater than that in the local currency. This effect is the same as that of Jarrow et al. (2016), who discusses the subject without these formulas. Although we assume that exchange rate X_t is independent from λ_t, the correlation effect can be considered in this model. To confirm the validity of this model, we describe the correlation effect in Appendix B.

3.5. The state variable

In this subsection, the setting of the stochastic processes is described. We use the OIS for the risk-free rate term structure as an alternative variable. We also assume that the risk-free rate is not stochastic.[15] Under a given complete filtered probability space $(\Omega,\mathscr{F},Q)$, $w_{1,t}^{Q,i}$, $w_{2,t}^{Q,i}$, and $w_{3,t}^{Q}(i=bond,cds)$ are standard Brownian motions in $\mathbb{R}^5$. $\{\mathscr{F}_t\colon t\leqslant 0\}$ is the augmented filtration generated by $w_{1,t}^{Q,i}$, $w_{2,t}^{Q,i}$ and $w_{3,t}^{Q}(i=bond,cds)$. The non-credit risk process is assumed to follow a two-factor Vasicek model as follows:

$$\gamma_{i,t}=d_{i,0}+d_{i,1}\gamma_{i,1,t}+d_{i,2}\gamma_{i,2,t},$$
$$d\gamma_{i,1,t}=-k_{i,1}^{Q}\gamma_{i,1,t}dt+dw_{i,1,t}^{Q},\ d\gamma_{i,2,t}=-k_{i,12}^{Q}\gamma_{i,1,t}dt-k_{i,2}^{Q}\gamma_{i,2,t}dt+dw_{i,2,t}^{Q}.$$

The market price of risk for $\gamma_{i,t}$ is assumed to be $-(k_{i,1}^{P}-k_{i,1}^{Q})\gamma_{i,1,t}^{i}$ and $-(k_{i,2}^{P}-k_{i,2}^{Q})\gamma_{i,2,t}$.

It is assumed that the intensity process follows a standard square-root process (CIR process) (Cox, Ingersoll, & Ross, 1985) under Q as follows[16]:

$$d\lambda_{d,t}=k_3^Q(\theta_3^Q-\lambda_{d,t})dt+\sigma_3\sqrt{\lambda_{d,t}}dw_{3,t}^{Q}.$$

For efficient estimation, we use a CIR process.[17] The market price of risk η_t for $\lambda_{d,t}$ is assumed as follows:$\eta_t=\frac{\delta_0}{\sqrt{\lambda_{d,t}}}+\delta_1\sqrt{\lambda_{d,t}}$ where $k_3^Q\theta_3^Q=k_3^P\theta_3^P-\delta_0\sigma_3$, $k_3^Q=k_3^P+\sigma_3\delta_1$.[18]

[15] How to express the risk-free rate term structure remains controversial. Dubecq, Monfort, Renne, and Roussellet (2016) use the OIS for the risk-free rate term structure. Hull and White (2013) conclude that OIS rates should be used in all situations as the risk-free rates to value the derivatives. The OIS is constructed using the unsecured overnight rate, which is continually refreshed. Dubecq et al. (2016) note that the credit risk in continually refreshed 1-day loans is small. The repo rate is a better indicator of the risk-free rate because borrowing is collateralized. However, there appears to be no way to determine a complete term structure for repos. Dubecq et al. (2016) indicate that liquidity risk is not priced in the overnight rate.

[16] Ang and Longstaff (2013), Jarrow et al. (2016), Longstaff et al. (2005), Longstaff et al. (2011), Pan and Singleton (2008) and Zhang (2008) also use the CIR process.

[17] Pan and Singleton (2008) compare the CIR process (Cox et al., 1985), the three-halves process (Ahn & Gao, 1999), and the log-normal process. Pan and Singleton (2008) estimate the model parameters for Turkey, Korea, and Mexico, and calculate pricing errors. The authors show that a single-factor model with intensity following a log-normal process captures most of the variation in the term structures of spreads.

[18] According to Pan and Singleton (2008), this specification of the market price of risk is non-standard. The standard specification has $\delta_0=0$. If δ_0 is not zero, then the market price of risk is allowed to be both a negative and a positive value. Pan and Singleton (2008) find that the flexibility of having non-zero δ_0 and δ_1 is essential for a reasonably good fit with CDS data.

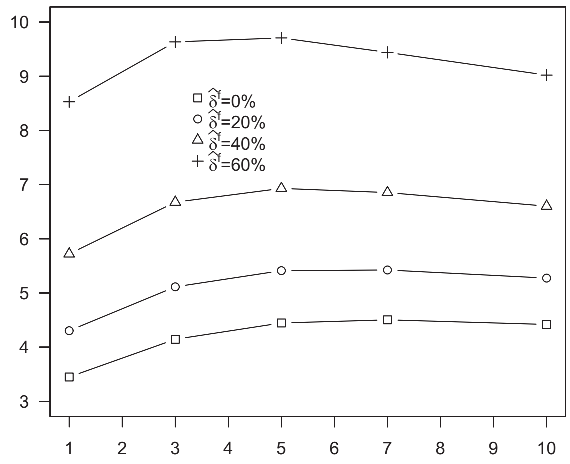

Fig. 1. Depreciation impact on CDS spreads. Units are percentages. The figure shows the term structure of CDS spreads for ea ch devaluation ratio. We apply 0%, 20%, 40%, and 60% to the depreciation ratio $\hat{\delta}^f$ of (3). The estimated intensity and risk-free rate on July 25, 2012 are used. The estimated parameters of sovereign CDS for Italy are used.

3.6. *The effect of the depreciation ratio $\hat{\delta}^f$ on CDS spreads*

In this subsection, we show the effect of the depreciation ratio parameter $\hat{\delta}^f$ on the pricing of foreign currency-denominated CDS spreads with a numerical example using the parameter of sovereign CDS for Italy, which is estimated in the following section. We use the intensity and risk-free rate on July 25, 2012, because the CDS spread is the most widespread on this date during the observation period. We apply 0%, 20%, 40%, and 60% to the depreciation ratio $\hat{\delta}^f$. Fig. 1 shows the term structure of the CDS spreads for each depreciation ratio. The depreciation ratio mainly affects the level of the CDS term structure.

4. Model estimation

We estimate the parameters and time series of the intensity and non-credit risk processes using the term structure data for bond yields and for CDS spreads each country.

4.1. *The state space model*

To estimate the model, we re-cast the model in the framework of a state space model.

First, we describe the measurement equation, which is composed of the pricing formulas (2) and (3). Then, the measurement equations are given by

$$y_{CDS,m,t}=S_t(m,\lambda_{d,t},\gamma_{c,t})+\epsilon_{CDS,m,t},$$
$$y_{Bond,m,t}=P_t(m,\lambda_{d,t},\gamma_{b,t})+\epsilon_{Bond,m,t},\ \epsilon_{l,m,t}\sim i.\ i.\ d.\ N(0,\tau),\ (l=CDS,Bond,\ m=1,3,5,7,10),$$

where the pricing errors $\epsilon_{l,m,t}$ are independent and identically distributed Gaussian. These measurement equations are not linear.

Second, we describe the transition equation. The conditional distribution of non-credit risk process is Gaussian, following the two-factor Vasicek. On the other hand, the conditional distribution of intensity is a non-central chi square distribution, and is not Gaussian. We treat this as if the state variable were conditionally normally distributed. Chen et al. (2003) and Duan and Simonato (1999) suggest the approximated methodology of CIR-type state variables. From the simulation result, the authors show that errors in this approach are negligible. Therefore, we apply the unscented Kalman filter. We construct the quasi log likelihood function $L(\Theta)$ of this state space model. The quasi maximum likelihood estimator is given by $\hat{\Theta}=arg\max_{\Theta}L(\Theta)$. In addition, we restrict k_3^P, θ_3^P to be positive to ensure the existence of the CIR process. The risk-neutral measure parameters of the CIR process are unconstrained. The positivity of the filtered CIR process is ensured by setting the joint likelihood of the entire time series to zero whenever the filtered expectation of the CIR process is negative, following Chen et al. (2003).

4.2. *Model for depreciation ratio*

Based on the simulated data, we find that we cannot differentiate between the depreciation ratio and non-credit risk process using local currency-denominated bonds and foreign currency-denominated CDS. Therefore, before we estimate the model between the local currency-denominated bonds and the foreign currency-denominated CDS, we specify a market implied depreciation ratio for each country with market instruments. To estimate the depreciation ratio, we use the local currency-denominated CDS spreads and the foreign currency-denominated CDS spreads, and consider only the credit risk process. Du and Schreger (2016) and Jarrow et al.

(2016) also use these instruments, and ignore the liquidity risk. Although there is a liquidity difference between these instruments, when we consider non-credit risk in pricing, we also cannot differentiate between the depreciation ratio and the non-credit risk process. Solely to estimate the depreciation ratio, we assume no liquidity difference in the CDS pricing models and use the local currency-denominated CDS spreads. We modify (3) and (4) as follows:

$$S_{t,m}^{Credit} = \frac{\left(1-R\right) E^{\mathbb{Q}d}\left[\int_t^T \bar{\delta}\lambda_{d,s} e^{-\int_t^s \left(r_{f,u}+\lambda_{d,u}\right)du} ds \,\middle|\, \mathscr{F}_t\right]}{\frac{1}{4}\sum_{k=1}^{4m} E^{\mathbb{Q}d}\left[e^{-\int_t^{t+\frac{k}{4}}\left(r_{f,u}+\bar{\delta}\lambda_{d,u}\right)du} \,\middle|\, \mathscr{F}_t\right] + \frac{1}{8}E^{\mathbb{Q}d}\left[\int_t^T \bar{\delta}\lambda_{d,s} e^{-\int_t^s \left(r_{f,u}+\bar{\delta}\lambda_{d,u}\right)du} ds \,\middle|\, \mathscr{F}_t\right]},$$

$$S_{t,m}^{loc,Credit} = \frac{\left(1-R\right) E^{\mathbb{Q}d}\left[\int_t^T e^{-\int_t^s (r_{d,u}+\lambda_{d,u})du} \lambda_{d,s} ds \,\middle|\, \mathscr{F}_t\right]}{\frac{1}{4}\sum_{k=1}^{4m} E^{\mathbb{Q}d}\left[e^{-\int_t^{t+\frac{k}{4}}\left(r_{d,u}+\lambda_{d,u}\right)du} \,\middle|\, \mathscr{F}_t\right] + \frac{1}{8}E^{\mathbb{Q}d}\left[\int_t^T e^{-\int_t^s (r_{d,u}+\lambda_{d,u})du} \lambda_{d,s} ds \,\middle|\, \mathscr{F}_t\right]}.$$

Du and Schreger (2016) and Jarrow (2013) also make this assumption. Furthermore, we assume that we fix the recovery rate at 40%. We also estimate the parameter including the recovery rate. In this case, the estimated depreciation parameter shows similar results, but the estimated recovery rate is no reasonable levels. Therefore, the recovery rate is fixed.

4.3. Data

The data for this study include weekly local currency-denominated bond yields and CDS spreads for 1-, 3-, 5-, 7-, and 10-year maturities. Our data comprise the following ten euro area countries, namely, Finland (FI), Germany (DE), the Netherlands (NL), Austria (AT), France (FR), Belgium (BE), Spain (ES), Italy (IT), Ireland (IE), and Portugal (PT). The data for this study covers the 384-week period from August 25, 2010 to December 27, 2017 with a weekly frequency (Wednesday data).[19][20] Although local currency-denominated CDS spreads and foreign currency-denominated CDS spreads are needed for our model, CDS spread quotes for different currencies are not available before August 2010. Therefore, our sample data begins in August 2010. We divide the sample period into two subsamples: August 25, 2010 to December 25, 2013 (the "crisis period") and January 1, 2014 to December 25, 2017 (the "expansion period"). The crisis period is during the European sovereign debt crisis, while the expansion period is the period of economic expansion after the crisis. We compare the dynamics of each component between the two subsample periods. For Greece, the observed CDS spreads stop on March 8, 2012 because of its debt default. Hence, owing to the lack of data availability, we exclude Greece from our sample. Fig. 2 shows the term structures of the sovereign bond yield spreads relative to the OIS and sovereign CDS spreads of selected euro area countries.[21] It is shown that the relationships between the bond yield spread and CDS spread are different among countries. Fig. 2 shows that bond yield spreads relative to the OIS and CDS spreads increased and reached maximum levels between July 2011 and July 2012. Table 1 provides a summary of the descriptive statistics for bond yield spreads relative to the OIS and CDS spreads on a weekly basis. The peripheral (IE, IT, PT, and ES) countries' spreads are higher and exhibit greater volatility than the spreads of core (FI, DE, NL, AT, FR, and BE) countries. On average, the levels of bond yield spreads and CDS spreads increase with maturity. The level of volatility decreases with maturity for the peripheral countries and increases with maturity for core countries. On the whole, for the expansion period, the levels of average and volatility are lower than those in the crisis period. The average and volatility of Ireland is lower than those of Spain, Italy, and Portugal for the expansion period.

5. Empirical results

5.1. Depreciation ratio

Table 2 reports the estimates and asymptotic standard errors of the physical and risk-neutral parameters for each country. The estimated depreciation ratios of core countries are larger than those of the peripheral countries. These results show the similar trend as Jarrow et al. (2016). For the expansion period, the depreciation ratios of the peripheral countries are higher than those for the

[19] Sovereign bond data and OIS data are extracted from Bloomberg. Since we find that Belgian bond yield data extracted from Bloomberg do not capture the observed individual bond's yield at around 1-year and 3-year maturities from June 2014 to February 2015, we calculate constant maturity Belgian bond yields at 1-year and 3-year maturity from individual Belgian bond prices using the Svensson model (Svensson, 1994), and use these data for this period. CDS data are extracted from IHS Markit. CDS spreads are quoted in EUR and USD.

[20] Since Wednesday generally has a lower frequency of holidays then the other days, Wednesday is used in this study. Additionally, in every comparable referenced study in the literature to which we refer and where weekly data is used, Wednesday data is used; specifically, Ang and Longstaff (2013), Longstaff et al. (2005), Longstaff et al. (2011), Fontana and Scheicher (2016).

[21] In order to avoid too many graphs and show the main result, we select the largest four countries, namely, Germany, France, Italy, and Spain, which include lower credit risk countries and higher credit risk countries, and the two highest credit risk countries, namely, Ireland and Portugal.

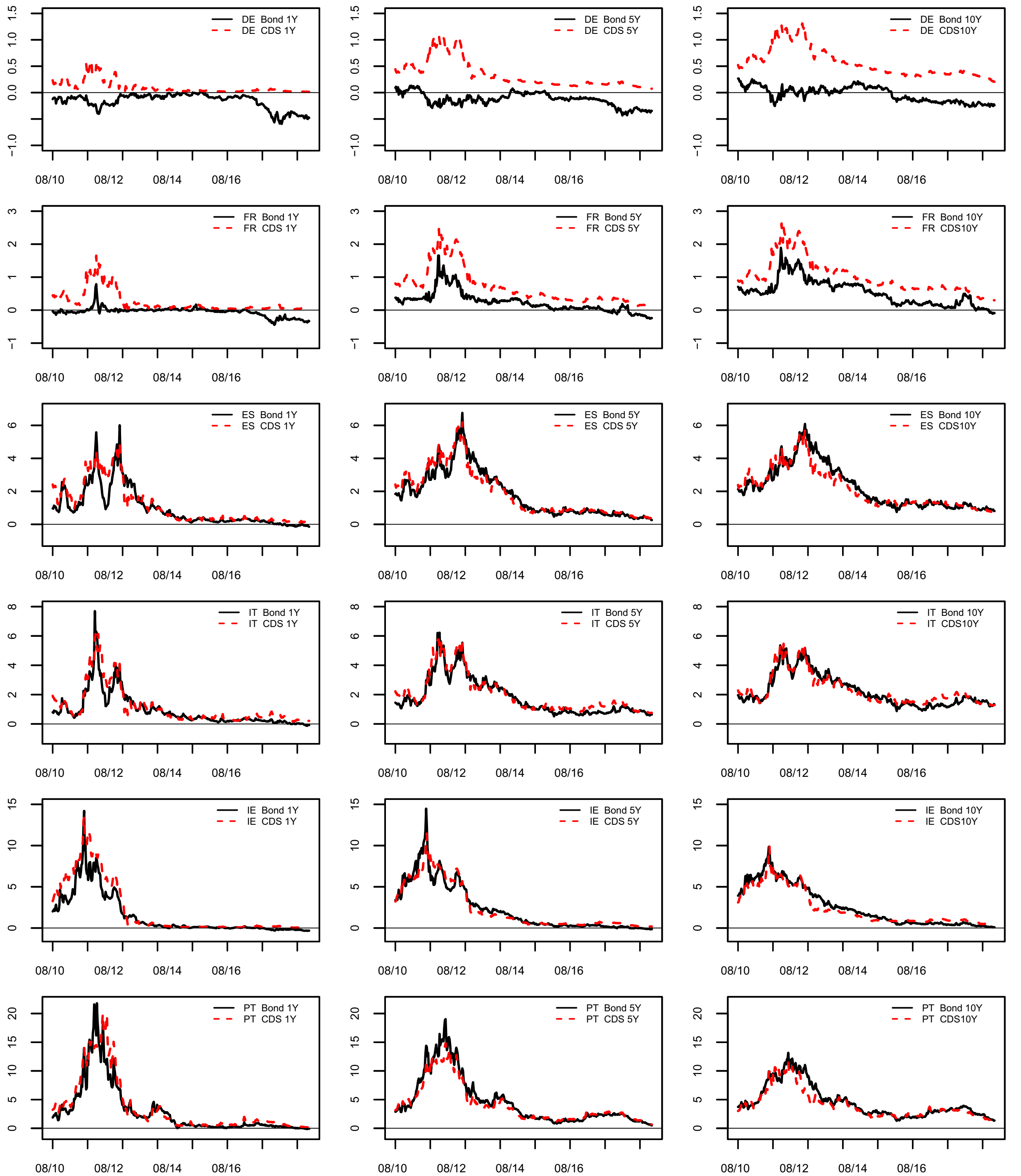

Fig. 2. Bond yield spreads relative to the OIS and CDS spreads. Units are percentages. The figure shows the time series of the bond yield spreads and the CDS spreads for Germany (DE), France (FR), Spain (ES), Italy (IT), Ireland (IE), and Portugal (PT). The sample period is from August 25, 2010 to December 27, 2017 with a weekly frequency.

Table 1

Summary statistics of data. The table shows means and, in parentheses, standard deviations. Panel A1 and Panel B1 show the summary of the bond yield spreads relative to the OIS. Panel A2 and Panel B2 show the summary of the CDS spreads. Units are percentages. The sample period of Panel A1 and Panel A2 is from August 25, 2010 to December 25, 2013 with a weekly frequency. The sample period of Panel B1 and Panel B2 is from January 1, 2014 to December 27, 2017 with a weekly frequency.

Maturity	FI	DE	NL	AT	FR	BE	ES	IT	IE	PT
Panel A1: Crisis Period Bond Spread										
1Y	−0.05	−0.13	−0.07	0.02	0.00	0.33	1.82	1.62	3.08	5.65
	(0.07)	(0.08)	(0.06)	(0.07)	(0.11)	(0.52)	(1.11)	(1.22)	(2.71)	(4.81)
5Y	0.23	−0.07	0.26	0.47	0.46	1.05	2.95	2.69	4.53	7.32
	(0.12)	(0.13)	(0.10)	(0.33)	(0.28)	(0.67)	(1.12)	(1.23)	(2.54)	(4.23)
10Y	0.43	0.07	0.46	0.69	0.83	1.29	3.26	2.93	4.63	6.46
	(0.12)	(0.11)	(0.09)	(0.28)	(0.29)	(0.50)	(1.09)	(1.08)	(1.84)	(2.81)
Panel A2: Crisis Period CDS Spread										
1Y	0.17	0.17	0.26	0.40	0.44	0.83	2.17	1.92	4.22	6.48
	(0.15)	(0.13)	(0.20)	(0.39)	(0.37)	(0.75)	(1.10)	(1.39)	(3.46)	(5.06)
5Y	0.41	0.53	0.64	0.89	1.09	1.50	3.07	2.87	4.36	6.38
	(0.20)	(0.24)	(0.27)	(0.53)	(0.51)	(0.81)	(1.08)	(1.23)	(2.55)	(3.43)
10Y	0.56	0.76	0.84	1.10	1.36	1.67	3.12	2.96	4.02	5.70
	(0.20)	(0.25)	(0.29)	(0.50)	(0.49)	(0.69)	(0.94)	(1.12)	(1.95)	(2.51)
Panel B1: Expansion Period Bond Spread										
1Y	−0.14	−0.19	−0.14	−0.11	−0.11	−0.12	0.19	0.25	−0.01	0.39
	(0.16)	(0.18)	(0.16)	(0.15)	(0.14)	(0.16)	(0.17)	(0.18)	(0.16)	(0.32)
5Y	0.01	−0.15	−0.04	0.01	0.05	0.04	0.75	0.93	0.33	1.82
	(0.14)	(0.13)	(0.16)	(0.14)	(0.13)	(0.17)	(0.30)	(0.26)	(0.31)	(0.66)
10Y	0.14	−0.10	0.07	0.15	0.26	0.26	1.24	1.50	0.73	2.63
	(0.17)	(0.13)	(0.20)	(0.19)	(0.21)	(0.26)	(0.31)	(0.34)	(0.48)	(0.65)
Panel B2: Expansion Period CDS Spread										
1Y	0.06	0.03	0.05	0.06	0.07	0.07	0.26	0.41	0.14	0.73
	(0.02)	(0.01)	(0.02)	(0.03)	(0.03)	(0.04)	(0.10)	(0.14)	(0.06)	(0.36)
5Y	0.22	0.16	0.22	0.25	0.33	0.35	0.77	1.13	0.51	1.91
	(0.03)	(0.04)	(0.06)	(0.07)	(0.11)	(0.11)	(0.22)	(0.21)	(0.18)	(0.58)
10Y	0.44	0.37	0.46	0.50	0.66	0.69	1.21	1.66	0.89	2.47
	(0.04)	(0.07)	(0.10)	(0.11)	(0.17)	(0.18)	(0.24)	(0.24)	(0.22)	(0.57)

crisis period. We use these estimated parameters of the depreciation ratio in the subsequent section.

5.2. Parameter estimation

Tables 3 and 4 report the estimates and asymptotic standard errors of the physical and risk-neutral parameters for each country. The risk-neutral mean reversion parameter k_3^Q is negative for many of countries. This result is consistent with several papers' findings in estimating affine models; see, for example Pan and Singleton (2008) and Zhang (2008) in the case of emerging countries, and Ang and Longstaff (2013)[22] in the case of U.S. and European sovereigns. On the other hand, the physical mean reversion parameter[23] is positive. This implies that intensity will tend to be larger under a risk-neutral than physical measure, and there is a significant negative risk premium embedded in the pricing of the intensity. Market participants require a risk premium for exposure to variation in intensity.

On the whole, the higher the average CDS spread, the lower the recovery rate. The recovery rate of the peripheral countries is less than that of core countries. Jarrow et al. (2016) find that a monotonous relationship exists between the median recovery rates and ratings.

5.3. Decomposition of sovereign bond yields and CDS spreads

In this section, we present the model implied decomposition of the term structure of local currency-denominated sovereign bond yields and foreign currency-denominated sovereign CDS spreads. The decomposition is based on the credit risk and the non-credit risk components. The credit risk component is calculated by assuming that credit risk was the only risk factor in both instruments. In addition, the non-credit risk component is given by the difference between the model implied sovereign bond yields or CDS spreads and the model implied bond yields or CDS spreads with only the credit risk component. Tables 5 and 6 display the summary statistics

[22] Ang and Longstaff (2013) also use the CIR model for the CDS spreads of European countries.

[23] As Chen et al. (2003) and Duan and Simonato (1999) note, some physical measure parameters(e.g., k_3^P, θ_3^P) have relatively higher standard errors.

Table 2

Parameter results for the depreciation ratio. The table shows the quasi maximum likelihood estimator. Asymptotic standard errors are in parentheses. The sample period of Panel A is from August 25, 2010 to December 25, 2013 with a weekly frequency. The sample period of Panel B is from January 1, 2014 to December 27, 2017 with a weekly frequency.

Parameter	FI	DE	NL	AT	FR	BE	ES	IT	IE	PT
Panel A: Crisis Period										
k_3^P	6.3712	3.8410	5.3235	0.0730	7.7983	2.8503	3.2E−6	0.3219	2.4064	0.6438
	(5.4E−6)	(5.0E−6)	(5.0E−6)	(5.8E−6)	(5.4E−6)	(5.0E−6)	(7.6E−6)	(5.8E−6)	(5.8E−6)	(5.8E−6)
θ_3^P	0.0011	0.0011	0.0021	0.0726	0.0018	0.0084	6.8E−7	0.0669	0.0344	0.1179
	(3.8E−6)	(3.8E−6)	(3.8E−6)	(5.8E−6)	(3.8E−6)	(3.8E−6)	(7.6E−6)	(5.8E−6)	(3.8E−6)	(5.8E−6)
k_3^Q	−0.1153	−0.0873	−0.0577	−0.2169	−0.2317	−3.2E−5	−0.1708	−0.0894	−0.0028	−0.2028
	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.1E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)
$k_3^Q\theta_3^Q$	0.0008	0.0009	0.0013	0.0008	0.0015	0.0028	0.0053	0.0064	0.0087	0.0210
	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(2.1E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)
σ_3	0.1046	0.0537	0.0715	0.1407	0.1671	0.0928	0.2594	0.2368	0.2950	0.5439
	(5.4E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(4.8E−5)	(3.8E−6)	(5.8E−6)	(3.8E−6)
τ	0.0520	0.0834	0.0894	0.0948	0.1273	0.1725	0.2201	0.2690	0.3241	0.3937
	(3.8E−6)	(3.8E−6)	(3.8E−6)	(5.8E−6)	(5.4E−6)	(3.8E−6)	(4.4E−5)	(5.8E−6)	(5.8E−6)	(5.8E−6)
$\hat{\delta}^f$	0.2136	0.4212	0.3394	0.3988	0.4406	0.2652	0.2766	0.2080	0.1030	0.0981
	(6.5E−6)	(5.0E−6)	(5.0E−6)	(8.1E−6)	(6.5E−6)	(5.0E−6)	(1.9E−5)	(8.1E−6)	(8.1E−6)	(8.1E−6)
Panel B: Expansion Period										
k_3^P	8.1890	4.6222	4.6E−5	2.3595	4.1594	13.3856	8.5884	8.3511	10.9086	5.3533
	(4.6E−6)	(4.6E−6)	(1.4E−5)	(4.6E−6)	(4.6E−6)	(4.6E−6)	(2.5E−5)	(5.3E−6)	(4.9E−6)	(5.3E−6)
θ_3^P	0.0005	0.0004	0.0011	0.0008	0.0009	0.0003	0.0018	0.0045	0.0009	0.0061
	(3.5E−6)	(3.5E−6)	(6.2E−6)	(3.5E−6)	(3.5E−6)	(3.5E−6)	(3.3E−6)	(3.5E−6)	(3.5E−6)	(5.3E−6)
k_3^Q	−0.1062	−0.1884	−0.1840	−0.1666	−0.0029	−0.4781	−0.3723	−0.0540	−0.4748	−0.4436
	(3.5E−6)	(3.5E−6)	(6.9E−6)	(3.5E−6)	(3.5E−6)	(3.5E−6)	(1.7E−6)	(3.5E−6)	(3.5E−6)	(3.5E−6)
$k_3^Q\theta_3^Q$	0.0006	0.0003	0.0003	0.0004	0.0014	0.0002	0.0009	0.0040	0.0003	0.0019
	(3.5E−6)	(3.5E−6)	(6.9E−6)	(3.5E−6)	(3.5E−6)	(3.5E−6)	(3.5E−6)	(3.5E−6)	(3.5E−6)	(3.5E−6)
σ_3	0.0138	0.0146	0.0156	0.0181	0.0309	0.1083	0.1594	0.1258	0.1336	0.2034
	(3.5E−6)	(3.5E−6)	(6.9E−6)	(3.5E−6)	(3.5E−6)	(3.5E−6)	(0.0001)	(5.3E−6)	(3.5E−6)	(3.5E−6)
τ	0.0195	0.0211	0.0304	0.0299	0.0796	0.0371	0.0488	0.0794	0.0365	0.0990
	(3.5E−6)	(3.5E−6)	(9.6E−6)	(3.5E−6)	(3.5E−6)	(3.5E−6)	(0.0001)	(5.3E−6)	(4.9E−6)	(5.3E−6)
$\hat{\delta}^f$	0.2912	0.4050	0.3793	0.3515	0.2988	0.3855	0.2703	0.1685	0.2963	0.1916
	(4.6E−6)	(4.6E−6)	(1.1E−5)	(4.6E−6)	(4.6E−6)	(4.6E−6)	(4.9E−5)	(7.4E−6)	(5.9E−6)	(7.4E−6)

of the two components for each country for each period. On the whole, for the expansion period, the levels of each component are much lower than those for the crisis period.

Panel A in both Tables 5 and 6 shows the decomposition of the bond spreads. At 1-year maturity, the non-credit risk component is, on average, negative for most countries for both periods. Additionally, for the crisis period, the absolute value of the non-credit risk component approximates the credit risk component on average in the core countries. For the expansion period, the absolute value of the non-credit risk component is higher than the credit risk component on average in the core countries. At 10-year maturity, the credit risk component is, on average, larger than the non-credit risk component for most countries for the crisis period. Additionally, the absolute value of the non-credit risk component is, on average, smaller than that for the credit risk component. At 5-year maturity, the tendency of the results is similar to at 10-year maturity. For the expansion period, the tendency of the crisis period is weak. In addition to the point of average, the standard deviation of the non-credit risk component is same level as the credit risk component at all maturities in lower credit risk countries, especially for the crisis period. For the expansion period, the fluctuation in the non-credit risk component is relatively more important than that for the crisis period. As the credit risk component increases, its standard deviation also increases.

Panel B of both Tables 5 and 6 shows the decomposition of CDS spreads. For the crisis period, for both the average and the standard deviation, the credit risk component is larger than the non-credit risk component in most countries and at most maturities. For the crisis period, at 10-year maturities, the non-credit risk component is, on average, negative in the peripheral countries. For the expansion period, at 5- and 10-year maturities, the ratio of the non-credit risk component is much higher than that for the crisis period in the core countries.

Figs. 3–6 show the time series of each component of the bond spreads at 1-, 5-, and 10-year maturities for the main countries. In order to avoid too many graphs and show the main result, we select the largest four countries, namely, Germany, France, Italy, and Spain, which include lower credit risk countries and higher credit risk countries, and the two highest credit risk countries, namely, Ireland and Portugal. For the expansion period, to compare the crisis period with the expansion period, the range of the y-axis is fixed at the range of the crisis period for each country. The spreads are driven mainly by the credit risk components in higher credit risk countries. Overall, the credit risk component is more important. However, during the European sovereign debt crisis, the non-credit risk components are volatile, particularly at 1-year maturity. This component takes negative and positive values. In Germany, the spreads are driven by the non-credit risk component rather than the credit risk component.

Fig. 4 displays the time series of each component of the CDS spreads for the crisis period. For most countries, the credit risk component is the main driver of the CDS spreads. Figs. 5 and 6 display the time series of each component of the bond spreads and the

Table 3

Parameter results for the crisis period. The table shows the quasi maximum likelihood estimator. Asymptotic standard errors are in parentheses. The sample period is from August 25, 2010 to December 25, 2013 with a weekly frequency for euro area countries.

Parameter	FI	DE	NL	AT	FR	BE	ES	IT	IE	PT
k_3^P	5.0679	3.0986	1.2380	2.2348	3.8955	1.7870	1.7E−9	0.8620	0.7034	7.3E−11
	(4.5E−5)	(0.0063)	(9.7E−14)	(2.6E−14)	(0.0178)	(0.0033)	(3.8E−6)	(0.0091)	(0.0191)	(8.2E−12)
θ_3^P	0.0011	0.0005	0.0033	0.0044	0.0032	0.0093	6.1E−6	0.0323	0.0175	1.9E−13
	(3.8E−6)	(3.8E−6)	(3.8E−6)	(1.9E−5)	(3.8E−6)	(3.8E−6)	(4.3E−12)	(0.0016)	(0.0010)	(7.5E−12)
k_3^Q	−0.3750	−0.3526	−0.4495	−0.2378	−0.3207	2.9E−5	−0.1638	−0.0246	−0.0017	−0.4439
	(4.5E−5)	(0.0009)	(1.2E−5)	(1.9E−5)	(2.9E−13)	(0.0325)	(4.0E−13)	(0.0023)	(0.0005)	(0.0019)
$k_3^Q\theta_3^Q$	0.0016	0.0005	0.0012	0.0024	0.0019	0.0021	0.0052	0.0122	0.0072	0.0165
	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(3.8E−6)	(2.3E−6)	(0.0003)	(3.8E−6)	(2.5E−5)
σ_3	0.1371	0.1039	0.1299	0.0874	0.0853	0.1020	0.2960	0.1943	0.1332	0.4571
	(3.8E−6)	(0.0009)	(1.2E−5)	(1.9E−5)	(3.8E−6)	(3.6E−13)	(4.8E−12)	(0.0024)	(0.0002)	(0.0002)
$k_1^{P,Bond}$	0.1993	0.0004	0.0001	0.5835	0.2351	0.0001	2.7E−5	0.0002	0.6123	0.2946
	(4.5E−5)	(5.3E−6)	(0.0030)	(2.7E−5)	(0.0052)	(5.0E−12)	(2.6E−12)	(2.8E−5)	(0.0151)	(0.0013)
$k_2^{P,Bond}$	1.1842	0.0271	1.2472	0.2610	0.6069	0.0025	0.0130	0.0014	1.7264	0.9270
	(4.5E−5)	(0.0036)	(0.0008)	(0.0001)	(0.0007)	(0.0004)	(1.1E−6)	(0.0012)	(0.0089)	(0.0060)
$k_{12}^{P,Bond}$	0.0009	−0.0004	−9.0E−7	−1.2E−5	0.0002	−0.0001	−0.0087	−0.0062	−0.0032	0.0002
	(4.5E−5)	(0.0060)	(2.7E−5)	(0.0001)	(0.0032)	(0.0001)	(1.5E−6)	(0.0048)	(0.1160)	(0.0043)
$k_1^{Q,Bond}$	−0.0645	2.0E−6	0.0001	−0.0602	2.6E−5	−0.0479	−0.0023	−0.0210	0.2137	−0.8822
	(4.5E−5)	(1.9E−8)	(1.2E−5)	(1.9E−5)	(2.1E−13)	(0.0018)	(6.1E−6)	(0.0104)	(0.0011)	(0.0226)
$k_2^{Q,Bond}$	0.9052	0.5057	−0.1184	0.1704	0.4232	0.3560	0.9004	0.3988	14.3678	−0.2529
	(4.5E−5)	(0.0071)	(9.4E−6)	(1.1E−13)	(1.3E−12)	(0.0150)	(2.1E−7)	(0.0213)	(0.0111)	(0.0008)
$k_{12}^{Q,Bond}$	−0.0048	0.0064	0.0021	0.3197	−0.0001	−0.0005	0.0021	0.0046	0.0011	2.1E−10
	(4.5E−5)	(0.0629)	(1.9E−14)	(3.8E−6)	(0.0176)	(0.0068)	(1.3E−6)	(0.0026)	(0.0032)	(0.0004)
d_0^{Bond}	−0.0061	0.0005	0.0012	0.0001	0.0043	3.1E−5	0.0220	−0.0003	0.0277	0.0090
	(3.8E−6)	(0.0007)	(1.2E−5)	(2.7E−5)	(1.1E−11)	(0.0013)	(1.4E−5)	(0.0254)	(0.0001)	(7.5E−13)
d_1^{Bond}	0.0027	0.0041	4.9E−5	−0.0005	−0.0047	−0.0055	0.0089	−0.0159	0.0390	4.2E−5
	(3.8E−6)	(0.0009)	(3.8E−6)	(5.3E−14)	(1.4E−13)	(1.4E−12)	(2.8E−6)	(0.0028)	(0.0005)	(3.8E−6)
d_2^{Bond}	0.0038	−0.0046	−0.0028	0.0024	0.0053	0.0118	−0.0224	0.0253	0.4583	−0.0135
	(4.5E−5)	(0.0006)	(3.8E−6)	(3.2E−5)	(7.2E−14)	(0.0003)	(2.1E−7)	(0.0004)	(0.0018)	(0.0003)
$k_1^{P,CDS}$	2.2E−6	6.2E−6	0.1531	5.2E−6	2.2E−6	0.0014	0.3897	0.0012	1.5E−5	0.9394
	(4.5E−11)	(3.2E−12)	(3.8E−12)	(1.7E−14)	(3.8E−12)	(0.0005)	(1.4E−12)	(0.0008)	(3.4E−12)	(0.0021)
$k_2^{P,CDS}$	0.2122	0.0032	0.2621	0.3454	0.5076	0.0124	1.0E−5	0.0012	0.0293	2.2E−6
	(4.5E−5)	(3.6E−5)	(9.4E−6)	(3.6E−14)	(0.0030)	(0.0017)	(5.0E−12)	(0.0001)	(0.0028)	(3.8E−12)
$k_{12}^{P,CDS}$	3.1E−8	−0.0002	0.0044	0.0012	−0.0002	0.0077	0.0031	0.0017	−9.5E−7	−2.2257
	(3.8E−6)	(1.7E−12)	(1.2E−5)	(1.1E−14)	(3.0E−6)	(0.0003)	(3.1E−12)	(0.0031)	(6.6E−8)	(0.0032)
$k_1^{Q,CDS}$	−0.0042	0.0116	0.0832	−0.0001	−2.3E−7	0.0181	0.0814	−8.7E−7	0.8791	50.0855
	(4.5E−5)	(0.0109)	(8.9E−14)	(1.9E−5)	(2.1E−15)	(0.0013)	(2.5E−7)	(7.1E−8)	(0.0303)	(0.0035)
$k_2^{Q,CDS}$	0.0186	0.0002	−0.2260	0.0001	0.1115	−1.5E−5	0.0479	0.0531	−4.6E−6	0.3499
	(4.5E−5)	(0.0028)	(4.8E−13)	(1.9E−5)	(3.2E−6)	(6.4E−7)	(1.2E−12)	(0.0169)	(2.2E−7)	(0.0056)
$k_{12}^{Q,CDS}$	0.0003	0.0094	0.0002	−0.0031	0.0028	0.2007	0.0008	−0.0080	0.0286	−4.1E−9
	(3.0E−6)	(0.0007)	(3.8E−6)	(1.2E−13)	(3.0E−6)	(0.0029)	(2.2E−6)	(0.0004)	(0.0036)	(0.0028)
d_0^{CDS}	−6.5E−10	−0.0025	−3.3E−5	0.0001	−1.4E−6	0.0010	0.0073	0.0113	0.0728	0.1331
	(4.5E−5)	(0.0001)	(1.2E−5)	(1.4E−13)	(9.7E−12)	(0.0090)	(2.3E−7)	(0.0047)	(0.0116)	(0.0018)
d_1^{CDS}	−0.0001	0.0010	0.0609	1.7E−7	0.0002	0.0045	−0.0006	0.0228	−7.6E−7	25.1632
	(3.0E−6)	(1.0E−12)	(3.8E−6)	(1.9E−5)	(3.8E−6)	(0.0013)	(2.4E−12)	(0.0062)	(0.0001)	(0.0015)
d_2^{CDS}	0.0311	−0.0180	−0.0065	0.0358	0.0755	−0.0967	0.0153	0.0431	−0.0644	−0.0003
	(0.0002)	(1.5E−5)	(3.2E−5)	(0.0001)	(2.2E−6)	(0.0019)	(1.8E−5)	(0.0014)	(0.0001)	(7.0E−11)
R	0.7257	0.6708	0.6405	0.7851	0.7230	0.7156	0.0489	0.3756	0.3077	0.2814
	(4.5E−5)	(1.2E−12)	(1.2E−5)	(1.9E−5)	(3.2E−6)	(0.0145)	(1.7E−6)	(0.0029)	(0.0009)	(0.0031)
τ	0.0375	0.0451	0.0758	0.0422	0.0586	0.0948	0.1420	0.1464	0.2657	0.5483
	(3.8E−6)	(5.3E−13)	(1.2E−5)	(1.9E−5)	(3.8E−6)	(6.4E−7)	(6.3E−7)	(0.0011)	(0.0003)	(0.0004)

CDS spreads for the expansion period. The spreads are driven mainly by the non-credit risk components in lower credit risk countries, while the spreads are driven mainly by the credit risk components in higher credit risk countries.

5.4. Principal component analysis

In this section, we study the commonality of the credit risk and the non-credit risk components in both instruments. For the non-credit risk component, we use a theoretical bond yield with only non-credit risk, unlike the previous subsection, in order to investigate the variation of pure non-credit risk. We conduct a principal component analysis of the changes in each risk component at 1-, 5- and 10-year maturities. Table 7 shows the cumulative proportion of the first two principal components (PC1 and PC2). The first principal components show approximately 20%–70% proportions, while the second principal components are approximately 10%–20%. Fig. 7 shows the factor loadings. Factor loadings of all first principal components show the same sign for almost all countries. The loadings of Ireland and Portugal are relatively lower than other countries. Factor loadings of all second principal components show a different sign between lower credit risk countries and higher credit risk countries.

Table 4

Parameter results for the expansion period. The table shows the quasi maximum likelihood estimator. Asymptotic standard errors are in parentheses. The sample period is from August 25, 2010 to December 27, 2017 with a weekly frequency for euro area countries.

Parameter	FI	DE	NL	AT	FR	BE	ES	IT	IE	PT
k_3^P	2.1E−5	0.1496	0.0137	2.0E−7	0.0121	0.3186	1.0905	0.0003	0.0033	0.0995
	(1.2E−5)	(0.0017)	(3.2E−6)	(0.0022)	(1.8E−5)	(2.7E−6)	(0.0041)	(2.2E−11)	(3.5E−6)	(0.0008)
θ_3^P	5.0E−6	0.0075	0.0273	0.0045	0.0119	0.0028	0.0048	0.0400	0.0626	0.0406
	(1.2E−5)	(1.4E−5)	(8.2E−6)	(0.0035)	(1.7E−5)	(5.3E−14)	(1.5E−5)	(3.8E−6)	(0.0004)	(9.6E−14)
k_3^Q	−0.2351	0.0004	−0.2799	−0.1635	−0.0003	−0.1563	−0.2599	−0.1204	−0.2248	−0.2695
	(0.0077)	(0.0010)	(8.5E−7)	(0.0128)	(7.8E−7)	(2.4E−6)	(0.0009)	(0.0001)	(0.0010)	(3.0E−6)
$k_3^Q\theta_3^Q$	0.0029	0.0016	0.0026	0.0003	0.0320	0.0007	0.0032	0.0043	0.0033	0.0093
	(0.0004)	(5.1E−6)	(1.2E−6)	(0.0007)	(2.6E−5)	(3.5E−6)	(1.6E−5)	(2.6E−6)	(1.8E−13)	(3.5E−6)
σ_3	0.0360	0.0468	0.0471	0.0188	0.2688	0.0255	0.1007	0.1667	0.0848	0.2494
	(0.0026)	(0.0002)	(7.8E−6)	(0.0069)	(3.6E−7)	(1.5E−6)	(0.0001)	(3.0E−6)	(0.0002)	(3.0E−6)
$k_1^{P,Bond}$	0.0810	0.0547	2.6E−5	0.0043	0.0003	0.0006	0.2017	0.0009	0.0065	0.0069
	(0.0007)	(0.0004)	(7.3E−7)	(3.1E−12)	(1.0E−5)	(3.1E−6)	(0.0005)	(1.2E−5)	(1.8E−5)	(0.0001)
$k_2^{P,Bond}$	0.4679	0.3622	0.0003	0.0414	0.0003	3.2E−5	1.4854	1.6E−5	0.0001	1.6561
	(0.0006)	(0.0033)	(7.2E−6)	(3.8E−6)	(6.0E−6)	(5.6E−13)	(0.0003)	(1.8E−11)	(3.5E−12)	(0.0035)
$k_{12}^{P,Bond}$	0.0041	−1.2E−5	−0.0015	0.0001	−0.0024	−0.0038	−1.5123	−4.6E−5	−4.0E−6	0.0002
	(0.0001)	(3.9E−6)	(6.5E−6)	(0.0007)	(1.7E−5)	(4.3E−6)	(0.0024)	(9.5E−6)	(5.2E−7)	(0.0036)
$k_1^{Q,Bond}$	−0.2959	−0.2874	−0.4127	−0.1207	−0.3610	−0.1564	0.0978	0.0003	−0.0191	−0.2156
	(0.0081)	(0.0003)	(1.2E−5)	(0.0254)	(1.1E−5)	(2.7E−6)	(0.0007)	(1.3E−5)	(1.5E−5)	(3.5E−6)
$k_2^{Q,Bond}$	0.4038	0.2029	0.3487	0.2166	0.1934	0.3396	0.0499	0.3458	−0.2119	0.6447
	(0.0012)	(8.5E−6)	(1.5E−6)	(0.0071)	(6.8E−6)	(1.9E−7)	(0.0011)	(2.4E−5)	(1.8E−6)	(3.3E−14)
$k_{12}^{Q,Bond}$	0.2254	0.0483	−4.5E−6	0.0005	−0.0015	4.7E−7	−0.7159	0.0001	−0.3142	0.0121
	(0.0145)	(0.0012)	(4.6E−6)	(0.0091)	(5.9E−6)	(0.0027)	(0.0005)	(2.8E−5)	(0.0018)	(2.0E−6)
d_0^{Bond}	−0.0023	−0.0024	−0.0017	−0.0001	−0.0209	−0.0017	−0.0028	0.0011	0.0329	−0.0146
	(0.0001)	(1.6E−6)	(7.0E−7)	(0.0002)	(4.7E−5)	(2.8E−6)	(1.9E−6)	(1.1E−5)	(7.0E−6)	(3.5E−6)
d_1^{Bond}	0.0001	0.0001	−0.0003	−0.0009	0.0013	0.0011	0.0013	0.0066	−0.0015	−0.0047
	(0.0001)	(3.0E−6)	(2.1E−6)	(3.8E−6)	(6.9E−7)	(1.0E−6)	(2.7E−6)	(8.4E−6)	(2.0E−6)	(3.5E−6)
d_2^{Bond}	0.0017	−0.0018	0.0020	0.0020	0.0025	−0.0018	−0.0026	0.0077	0.0019	0.0141
	(0.0001)	(8.3E−7)	(2.1E−6)	(0.0001)	(1.3E−6)	(4.1E−6)	(2.1E−6)	(2.0E−5)	(2.8E−6)	(1.1E−5)
$k_1^{P,CDS}$	2.2E−6	2.2E−6	2.7E−6	3.2E−6	0.0006	0.0682	0.0036	0.0489	0.1647	0.1344
	(3.5E−12)	(3.5E−12)	(9.2E−12)	(2.0E−12)	(2.2E−5)	(4.2E−6)	(0.0002)	(2.6E−5)	(0.0023)	(0.0107)
$k_2^{P,CDS}$	0.2889	0.0002	0.0001	0.0063	6.8E−6	0.1301	0.0131	6.3E−6	0.0397	0.1898
	(0.0019)	(0.0E+0)	(1.2E−5)	(5.4E−6)	(3.1E−11)	(5.3E−6)	(0.0007)	(2.1E−11)	(0.0012)	(0.0049)
$k_{12}^{P,CDS}$	0.0015	−0.0006	0.0003	0.0005	−6.6E−6	2.9E−6	−3.4E−10	−0.0001	−0.0001	−1.3E−11
	(0.0004)	(0.0E+0)	(1.3E−5)	(4.0E−5)	(2.8E−7)	(2.1E−6)	(6.6E−7)	(6.1E−6)	(2.7E−6)	(1.4E−6)
$k_1^{Q,CDS}$	−9.9E−6	0.0352	−2.5E−7	0.0550	9.5498	−0.2360	0.1459	0.1993	−0.5535	0.6384
	(9.3E−8)	(0.0003)	(7.1E−6)	(1.1E−7)	(1.9E−5)	(2.3E−6)	(0.0008)	(1.2E−5)	(0.0014)	(2.5E−5)
$k_2^{Q,CDS}$	−0.0001	0.0761	0.0772	−0.0131	0.2337	0.3661	0.6496	−0.0291	0.9003	6.6875
	(9.2E−6)	(0.0001)	(2.0E−6)	(0.0099)	(3.4E−5)	(2.7E−6)	(0.0001)	(1.3E−11)	(0.0008)	(0.0010)
$k_{12}^{Q,CDS}$	0.0091	−0.1119	6.3E−7	−0.0002	−37.0467	−0.0090	−0.4394	−1.4E−5	4.6E−10	0.5934
	(0.0001)	(0.0013)	(8.6E−6)	(0.0079)	(5.0E−6)	(3.0E−7)	(0.0026)	(3.6E−7)	(1.0E−5)	(1.4E−5)
d_0^{CDS}	−1.2E−5	−0.0001	−0.0045	0.0003	3.7E−5	5.6E−8	−0.0411	−4.5E−5	7.9E−7	0.1720
	(0.0046)	(0.0001)	(1.5E−7)	(0.0039)	(1.1E−5)	(2.4E−6)	(0.0001)	(6.4E−6)	(0.0010)	(1.9E−14)
d_1^{CDS}	−0.0007	−0.0183	−0.0061	−0.0005	−7.8577	0.0001	−0.0542	0.0845	0.0005	0.0002
	(2.7E−5)	(5.1E−6)	(1.1E−5)	(0.0004)	(9.3E−6)	(3.0E−7)	(0.0009)	(2.5E−5)	(2.8E−6)	(3.8E−14)
d_2^{CDS}	−0.0149	0.0048	0.0016	0.0045	0.0549	0.0009	0.1101	0.0301	0.1632	2.7818
	(0.0005)	(3.6E−13)	(5.9E−6)	(0.0003)	(4.4E−6)	(3.7E−6)	(0.0004)	(6.7E−6)	(0.0003)	(1.4E−5)
R	0.9578	0.9803	0.9646	0.7765	0.9796	0.7069	0.7467	0.4040	0.9573	0.6895
	(0.0017)	(3.8E−5)	(8.7E−7)	(0.0064)	(8.6E−6)	(9.6E−7)	(0.0006)	(9.0E−6)	(0.0002)	(2.9E−14)
τ	0.0189	0.0113	0.0136	0.0165	0.0118	0.0167	0.0260	0.0294	0.0213	0.0416
	(4.7E−5)	(3.3E−7)	(2.0E−6)	(3.2E−5)	(4.9E−6)	(3.1E−6)	(7.5E−6)	(0.0001)	(2.7E−7)	(8.0E−14)

5.5. Relation to risk factors

To explain the determinants of the credit risk component and the non-credit risk component, we investigate the relationship with certain market risk factors. For the non-credit risk component, we use a theoretical bond yield with only non-credit risk. Especially, we focus on whether the non-credit risk component is affected by the liquidity factor or other risk factors.

Since these components show a high correlation among all countries and a difference between core countries (FI, DE, NL, AT, FR, BE) and peripheral countries (ES, IT, IE, PT),[24] we use the first principal components of the credit risk components, the non-credit risk components, and total spreads in the core countries and the peripheral countries.

[24] To verify the robustness of our results, we carry out the regression analysis with including Belgium in the peripheral countries group. The results are similar. Additionally, we have used a regression analysis to carry out a robustness check at 3- and 7-year maturities. In this case, almost all the results are consistent with the results at 1-, 5-, and 10-year maturities.

Table 5

Bond yield spread and CDS spread decomposition for the crisis period. The table shows the means and standard deviations of the decomposed component for the sovereign bond yields and CDS spreads for each country at 1-, 5-, and 10-year maturities. Panel A shows the decomposition of bond spreads. Panel B shows the decomposition of CDS spreads. The sample period is from August 25, 2010 to December 25, 2013 with a weekly frequency.

Maturity	Component	FI	DE	NL	AT	FR	BE	ES	IT	IE	PT
Panel A: Crisis Period Bond Spread											
1Y	Credit	0.14	0.09	0.26	0.15	0.23	0.52	1.63	1.57	3.55	4.56
		(0.11)	(0.06)	(0.25)	(0.12)	(0.20)	(0.50)	(0.82)	(1.12)	(2.92)	(4.05)
	Non-Credit	−0.18	−0.22	−0.20	−0.23	−0.22	−0.17	0.28	0.20	−0.27	1.60
		(0.16)	(0.13)	(0.19)	(0.15)	(0.16)	(0.29)	(0.61)	(0.49)	(0.78)	(1.28)
5Y	Credit	0.39	0.22	0.74	0.34	0.54	0.52	2.63	2.72	3.93	6.36
		(0.19)	(0.11)	(0.52)	(0.16)	(0.32)	(0.39)	(0.77)	(0.90)	(2.38)	(2.83)
	Non-Credit	−0.19	−0.32	−0.29	−0.10	−0.08	0.56	0.46	0.14	0.67	1.72
		(0.13)	(0.18)	(0.23)	(0.12)	(0.18)	(0.31)	(0.72)	(0.55)	(0.88)	(1.90)
10Y	Credit	0.57	0.40	1.09	0.45	0.87	0.39	3.00	3.17	3.76	5.44
		(0.15)	(0.15)	(0.44)	(0.12)	(0.29)	(0.20)	(0.50)	(0.49)	(1.48)	(1.02)
	Non-Credit	−0.14	−0.35	−0.40	−0.01	−0.04	0.91	0.40	−0.16	0.77	1.46
		(0.14)	(0.20)	(0.24)	(0.12)	(0.18)	(0.34)	(0.80)	(0.67)	(0.57)	(1.99)
Panel B: Crisis Period CDS Spread											
1Y	Credit	0.18	0.15	0.44	0.24	0.42	0.72	2.25	2.00	4.02	5.13
		(0.14)	(0.11)	(0.43)	(0.19)	(0.36)	(0.69)	(1.12)	(1.43)	(3.31)	(4.59)
	Non-Credit	−0.01	0.01	−0.03	0.02	0.02	0.13	−0.02	−0.03	0.42	1.68
		(0.01)	(0.01)	(0.04)	(0.02)	(0.02)	(0.10)	(0.04)	(0.05)	(0.28)	(1.96)
5Y	Credit	0.53	0.38	1.21	0.58	1.05	0.85	3.32	3.53	4.78	7.49
		(0.27)	(0.20)	(0.87)	(0.29)	(0.64)	(0.66)	(0.97)	(1.25)	(3.08)	(4.06)
	Non-Credit	−0.12	0.14	−0.34	0.06	0.06	0.69	−0.17	−0.51	−0.11	−0.68
		(0.08)	(0.06)	(0.36)	(0.08)	(0.21)	(0.27)	(0.25)	(0.34)	(0.60)	(1.88)
10Y	Credit	0.96	0.68	1.86	1.07	1.90	0.92	3.58	4.44	5.21	7.55
		(0.31)	(0.26)	(0.93)	(0.35)	(0.79)	(0.58)	(0.65)	(0.98)	(2.68)	(2.95)
	Non-Credit	−0.37	0.10	−0.73	−0.20	−0.48	0.80	−0.30	−1.35	−0.99	−1.57
		(0.17)	(0.15)	(0.52)	(0.21)	(0.50)	(0.24)	(0.42)	(0.50)	(0.97)	(1.53)

5.5.1. Variables

We use two variables for the global financial market variables. The first variable is the returns of the S&P500 index. The second variable is the changes in the average CDS spreads of global banks, which we use as a proxy of capital relief for regulatory purposes. Klingler and Lando (2018) argue that CDS spreads for safe sovereigns are primarily driven by regulatory incentive. We use the average CDS spreads of the 12 largest banks dealing in derivatives, specifically the G16 banks excluding euro area banks.[25]

For the local financial market variables, we use the difference between the returns of local equity market variables and returns of the S&P500 index which is used as a proxy for the global financial risk factors. In the regression of the core countries, the average return of local market equity indexes in the core countries is used.[26] In the regression of the peripheral countries, the average return of local market equity indexes in the peripheral countries is used. We explain these variables in more detail in Appendix C.

For the proxy of global funding liquidity, we use the cross currency basis swap spread between euro and U.S. dollar. Funding liquidity tends to be affected by market liquidity, as in Brunnermeier and Pedersen (2008) and Pelizzon et al. (2016). Market participants consider the cross currency basis swap spread as a measure of the liquidity imbalances in currency flows between the euro and the U.S. dollar. We use the changes of the spreads at 1-, 5- and 10-year maturities to match the maturities of the bond spreads and the CDS spreads.

We use two alternative variables for market liquidity risk. The first variable is the change in the bid-ask spreads for bonds and CDSs. For the bond bid-ask spreads, we use the bonds' bid-ask price with maturity of less than 10 years at a specified time on a trading day. For the CDS bid-ask spreads, we use the CDS spreads at 5-year maturity. We use the changes of these bid-ask spreads. We explain these variables in more detail in Appendix C. The second variable is the spread between government bonds and government guaranteed agency bonds with lower liquidity, although these have the same credit risk. We use the spreads between yields on bonds issued by KfW, which are guaranteed by the Federal Republic of Germany, and German bonds.[27] We use the changes of the spreads at 1-, 5- and 10-year maturities to match the maturities of the bond spreads and the CDS spreads.

[25] Klingler and Lando (2018) use the average of the Moody's Expected Default Frequency(EDF), but this data is not available. Therefore, we use the CDS spreads instead. Additionally, since there is a possibility of sovereign risk impact on the euro area banks' CDS, we exclude euro area banks.

[26] To check the robustness, the EURO STOXX50 index is used for the local equity market variable. The EURO STOXX50 index is the leading blue-chip index for the Eurozone. In this case, the almost results are same.

[27] Filipović and Trolle (2013) and Monfort and Renne (2014) use the KfW spread as a proxy for liquidity.

Table 6

Bond yield spread and CDS spread decomposition for the expansion period. The table shows the means and standard deviations of the decomposed component for the sovereign bond yields and CDS spreads for each country at 1-, 5-, and 10-year maturities. Panel A shows the decomposition of bond spreads. Panel B shows the decomposition of CDS spreads. The sample period is from January 1, 2014 to December 27, 2017 with a weekly frequency.

Maturity	Component	FI	DE	NL	AT	FR	BE	ES	IT	IE	PT
Panel A: Expansion Period Bond Spread											
1Y	Credit	0.03	0.01	0.03	0.02	0.18	0.03	0.16	0.34	0.06	0.86
		(0.01)	(0.00)	(0.01)	(0.01)	(0.08)	(0.02)	(0.06)	(0.11)	(0.03)	(0.44)
	Non-Credit	−0.17	−0.21	−0.14	−0.17	−0.28	−0.17	0.03	−0.09	−0.07	−0.46
		(0.16)	(0.18)	(0.15)	(0.16)	(0.18)	(0.14)	(0.15)	(0.18)	(0.16)	(0.27)
5Y	Credit	0.08	0.01	0.07	0.05	0.16	0.10	0.49	0.95	0.11	1.64
		(0.02)	(0.01)	(0.02)	(0.02)	(0.10)	(0.02)	(0.08)	(0.13)	(0.04)	(0.42)
	Non-Credit	−0.07	−0.17	−0.06	−0.09	−0.11	−0.06	0.26	−0.02	0.21	0.18
		(0.14)	(0.13)	(0.14)	(0.16)	(0.19)	(0.16)	(0.26)	(0.27)	(0.31)	(0.32)
10Y	Credit	0.00	−0.04	−0.05	0.10	−0.28	0.20	0.88	1.54	−0.02	1.63
		(0.08)	(0.03)	(0.11)	(0.02)	(0.18)	(0.04)	(0.09)	(0.11)	(0.11)	(0.18)
	Non-Credit	0.14	−0.06	0.20	−0.02	0.54	0.07	0.35	−0.03	0.74	0.99
		(0.23)	(0.16)	(0.29)	(0.20)	(0.36)	(0.26)	(0.33)	(0.34)	(0.57)	(0.56)
Panel B: Expansion Period CDS Spread											
1Y	Credit	0.05	0.02	0.05	0.04	0.28	0.06	0.23	0.41	0.09	1.08
		(0.01)	(0.01)	(0.02)	(0.02)	(0.10)	(0.03)	(0.08)	(0.14)	(0.04)	(0.56)
	Non-Credit	0.01	0.01	0.01	0.01	−0.21	0.02	0.04	0.01	0.05	−0.35
		(0.00)	(0.00)	(0.00)	(0.00)	(0.10)	(0.01)	(0.03)	(0.01)	(0.02)	(0.42)
5Y	Credit	0.13	0.03	0.14	0.09	0.35	0.16	0.68	1.13	0.19	2.11
		(0.02)	(0.01)	(0.04)	(0.03)	(0.07)	(0.04)	(0.12)	(0.15)	(0.06)	(0.63)
	Non-Credit	0.08	0.13	0.12	0.12	−0.02	0.19	0.10	0.03	0.32	−0.20
		(0.01)	(0.03)	(0.03)	(0.03)	(0.15)	(0.08)	(0.12)	(0.12)	(0.13)	(0.40)
10Y	Credit	0.29	0.04	0.29	0.18	0.37	0.35	1.34	1.81	0.32	2.59
		(0.03)	(0.01)	(0.05)	(0.04)	(0.06)	(0.06)	(0.14)	(0.13)	(0.07)	(0.50)
	Non-Credit	0.15	0.33	0.21	0.22	0.30	0.35	−0.13	−0.08	0.57	−0.13
		(0.02)	(0.06)	(0.06)	(0.05)	(0.20)	(0.14)	(0.15)	(0.24)	(0.17)	(0.40)

For the proxy variable of central bank intervention, the purchase amount under the Securities Markets Program (SMP) of the European Central Bank is used first. The dummy variables for longer-term refinancing operations (LTRO) announcements in euro area countries are used second. We explain these variables in more detail in Appendix C.

5.5.2. Regression

To understand the determinants of the credit risk component and the non-credit risk component, we investigate their relationship with global and local financial risk factors and the effects of central bank intervention. We use the market determined risk factors, since these are available at a weekly frequency. The regression specification is as follows:

$$\Delta PC1-Comp_{i,j,m,t} = \alpha + \beta_1 r_{t,LocalEq} + \beta_2 r_{t,GlobalEq} + \beta_3 \Delta BankCDS_t + \beta_4 \Delta Basis_t + \beta_5 \Delta KfW_{m,t} + \beta_6 \Delta BA_{j,t} + \beta_7 SMP_t + \beta_8 LTRO_t + \epsilon_{i,j,m,t},$$

where i = Total Spread, Credit risk component, Non-Credit risk component, j = Bond, CDS, $m = 1-,5-,10$-year.

5.5.3. Core countries

Tables 8 and 9 [28] report the results of the regressions of changes in the first principal components of the bond spreads and CDS spreads, the credit risk components, and the non-credit risk components on the explanatory variables. Panel A1 and Panel B1 show the results of the total spreads for bonds and CDSs. In this subsection, we focus on the different results for core and peripheral countries.

First, we discuss the results of the credit risk component. Panel A2 and Panel B2 in Tables 8 and 9 show the results of the credit risk components. The credit components of bonds and CDSs are driven by the same hidden process. Therefore, the results for the different instruments are similar. The adjusted R^2s for the crisis period are around 0.60. Hence, the financial market variables explain a substantial proportion of the credit risk components for both components at all maturities. On the other hand, the adjusted R^2s for

[28] We also regress each variable using univariate regression. For the significant variables, the signs of the coefficients are the same as the results of the multivariate regression in Tables 8 and 9.

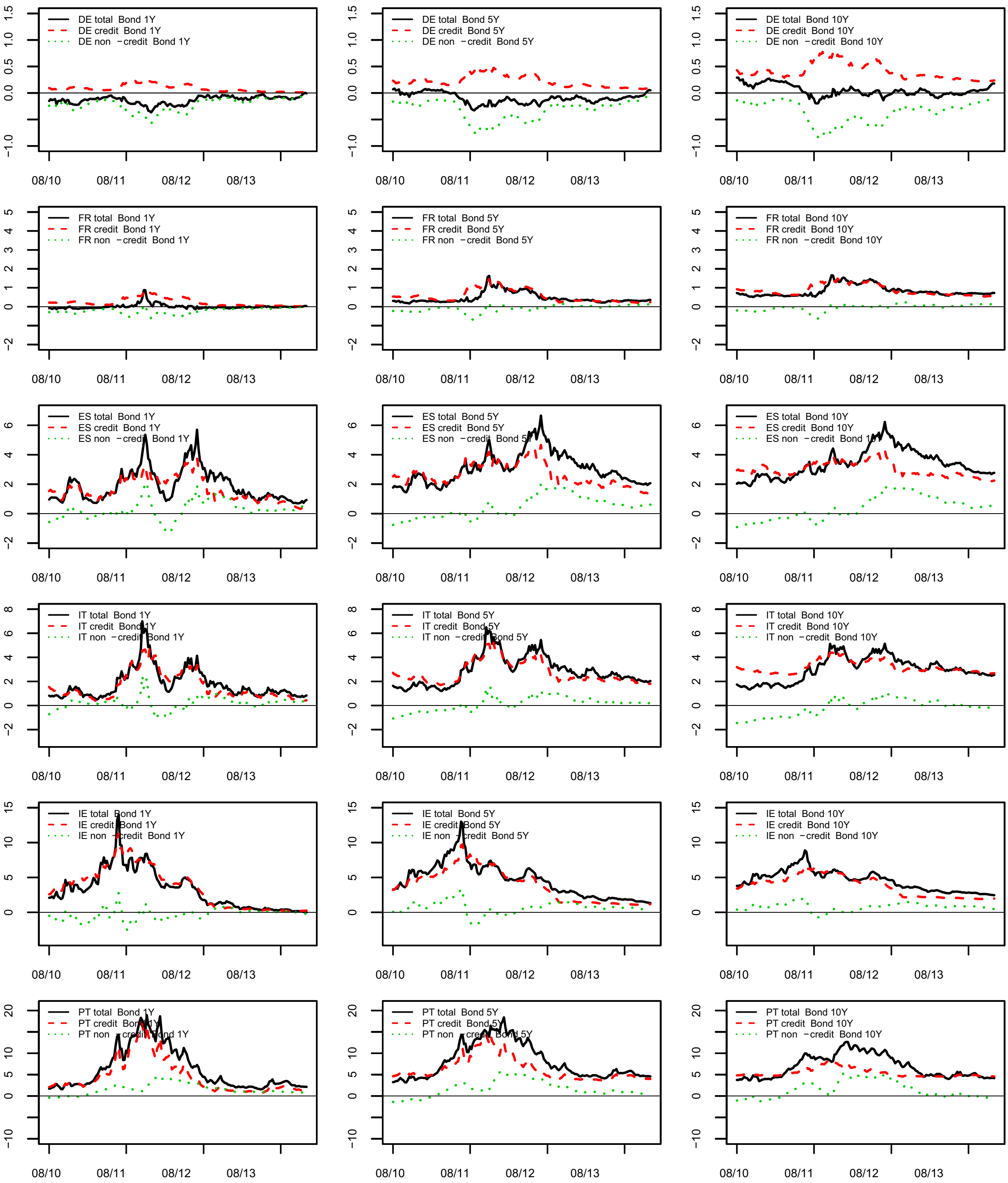

Fig. 3. Bond yield spread decomposition for the crisis period. Units are percentages. The figure shows the decomposition of the model for implied bond yield spreads relative to the OIS for Germany (DE), France (FR), Spain (ES), Italy (IT), Ireland (IE), and Portugal (PT) at 1-, 5-, and 10-year maturities. The sample period is from August 25, 2010 to December 25, 2013 with a weekly frequency.

the expansion period are around 0.15, less than those for the crisis period. For the crisis period, the returns of the local market equity index, changes in banks' CDS, and changes in the currency basis are significant variables at all maturities. At 5- and 10-year maturities, the local market equity index and changes in banks' CDS are also significant in total spreads. The t-values for the changes in banks' CDS are higher than the other variables. The signs of the coefficients of local market equity index are negative. This is not in

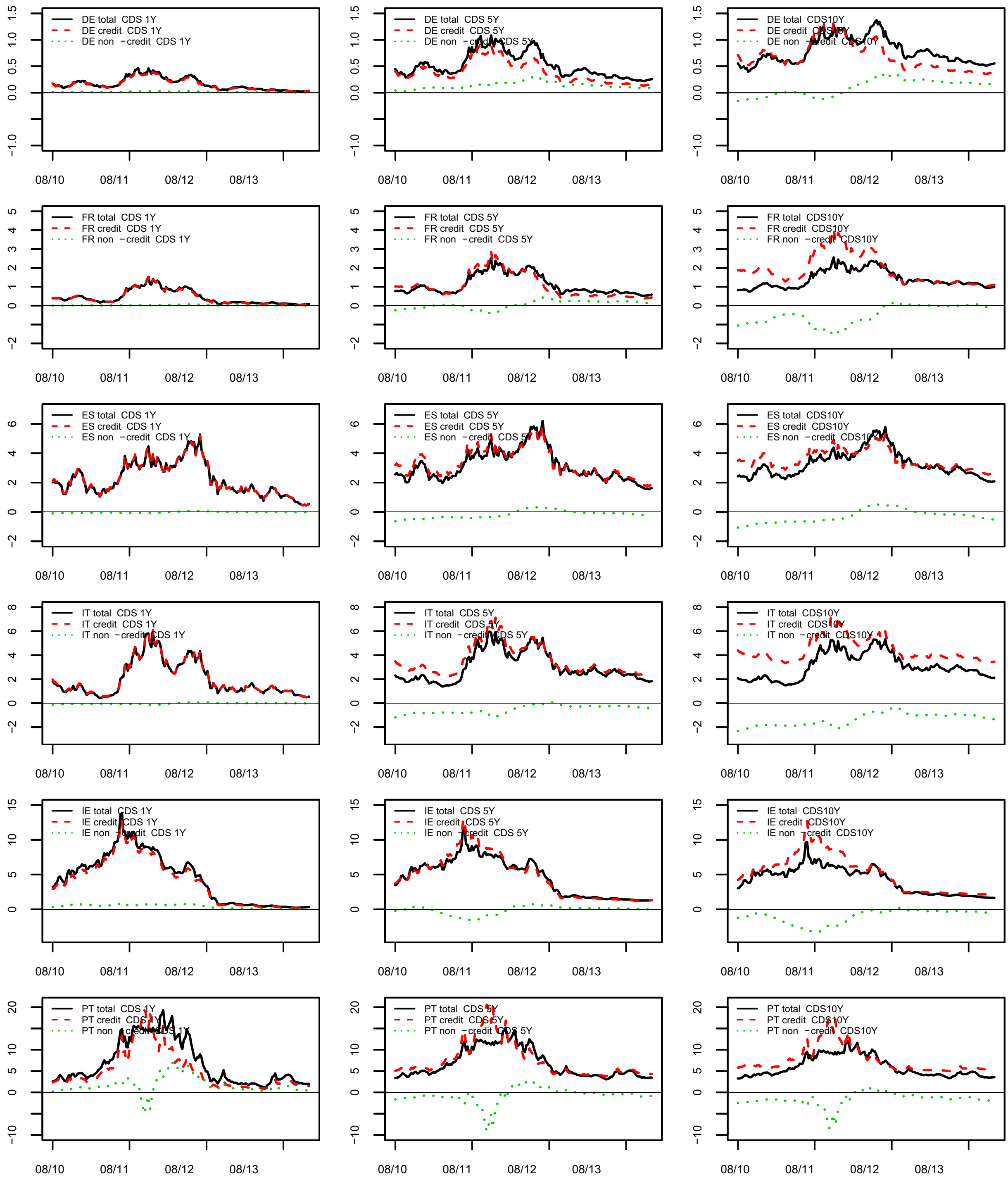

Fig. 4. CDS spread decomposition for the crisis period. Units are percentages. The figure shows the decomposition of the model for implied CDS spreads for Germany (DE), France (FR), Spain (ES), Italy (IT), Ireland (IE), and Portugal (PT) at 1-, 5-, and 10-year maturities. The sample period is from August 25, 2010 to December 25, 2013 with a weekly frequency.

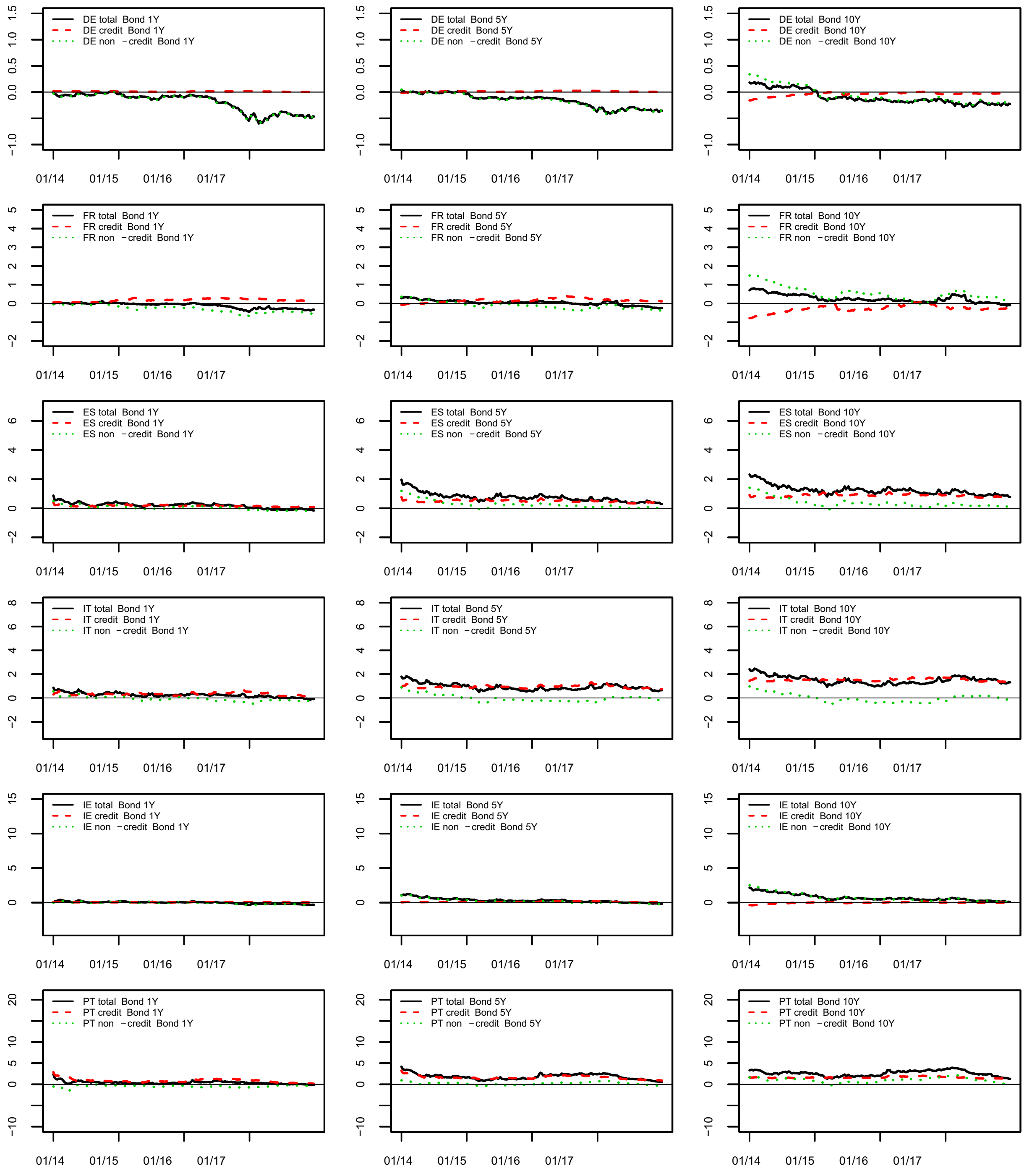

Fig. 5. Bond yield spread decomposition for the expansion period. Units are percentages. The figure shows the decomposition of the model for implied bond yield spreads relative to the OIS for Germany (DE), France (FR), Spain (ES), Italy (IT), Ireland (IE), and Portugal (PT) at 1-, 5-, and 10-year maturities. The sample period is from January 1, 2014 to December 27, 2017 with a weekly frequency. For comparison purposes, the range of the y-axis is fixed at the range of that in Fig. 3 for each country.

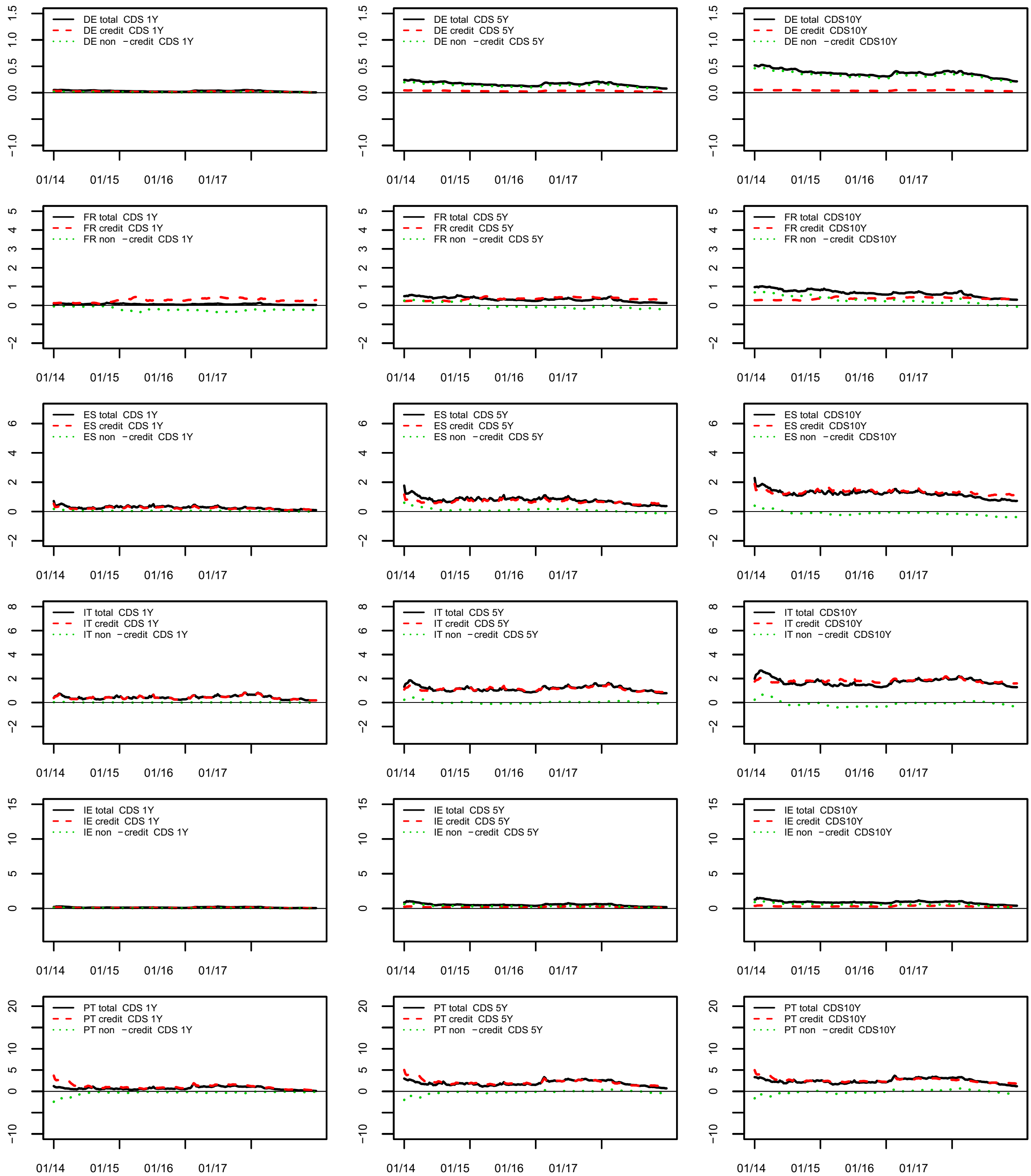

Fig. 6. CDS spread decomposition for the expansion period. Units are percentages. The figure shows the decomposition of the model for implied CDS spreads for Germany (DE), France (FR), Spain (ES), Italy (IT), Ireland (IE), and Portugal (PT) at 1-, 5-, and 10-year maturities. The sample period is from January 1, 2014 to December 27, 2017 with a weekly frequency. For comparison purposes, the range of the y-axis is fixed at the range of that in Fig. 4 for each country.

Table 7
Cumulative Proportion of Principal Component Analysis. The table shows the cumulative proportion for the principal component analysis of the correlation matrix of the credit and the non-credit risk components changes at 1- and 10-year maturities. The table shows the cumulative proportion of the first two principal components (PC1 and PC2). The sample period of the crisis period is from August 25, 2010 to December 25, 2013 with a weekly frequency. The sample period of the expansion period is from January 1, 2014 to December 27, 2017 with a weekly frequency.

		Crisis Period				Expansion Period			
		Bond Spread		CDS Spread		Bond Spread		CDS Spread	
Maturity	Component	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
1Y	Total	0.46	0.69	0.62	0.78	0.51	0.71	0.49	0.62
	Credit	0.61	0.78	0.61	0.78	0.45	0.59	0.44	0.58
	Non-Credit	0.41	0.59	0.52	0.69	0.49	0.64	0.25	0.43
5Y	Total	0.49	0.71	0.63	0.79	0.58	0.78	0.50	0.62
	Credit	0.63	0.79	0.61	0.78	0.54	0.73	0.45	0.58
	Non-Credit	0.41	0.59	0.51	0.67	0.56	0.73	0.27	0.45
10Y	Total	0.49	0.70	0.64	0.79	0.61	0.78	0.49	0.61
	Credit	0.68	0.82	0.62	0.77	0.65	0.82	0.46	0.59
	Non-Credit	0.40	0.59	0.46	0.63	0.60	0.76	0.27	0.45

line with Dufour et al. (2017). They show that the negative relationship[29] between bond excess returns and local equity index returns in low-risk countries, which imply the positive relationship between the bond yield changes and the local equity index returns. To calculate the bond excess returns, they assume that a proxy for the risk-free rate is 3-month ECB AAA yields,[30] and the term factor which is a proxy for maturity effects is not used in their regression.[31] On the other hand, we use the OIS for the risk-free rate term structure as an alternative variable, so that in our results the effect corresponding to the term factor of the risk-free rate term structure is considered to investigate the term structures relationship as Dubecq et al. (2016), Filipović and Trolle (2013), and Longstaff et al. (2005). Consequently, our results indicate a positive relationship between the bond spreads or the credit risk components, and the local equity index in core countries[32] for the crisis period. It is indicated that the bond spreads increase as the local equity market risk decreases in core countries for the crisis period when considering risk-free rate term structures through the credit risk components. Furthermore, the returns of the global equity index are not significant. These findings are not in line with the results of Ang and Longstaff (2013) and Longstaff et al. (2011), who note the strong relationship between sovereign risk and global market risk factors, not local market risk factors, although the signs of coefficients of the equity index are same as these studies regardless of global or local market risk. For the expansion period, the local market equity index is not significant at any maturity. The changes in the banks' CDS are also significant at all maturities.

Next, Panel A3 in Tables 8 and 9 shows the results of the non-credit risk components for the bond spreads. The adjusted R^2s of the non-credit risk components of bonds are around 0.20–0.30 for both periods. Hence, the financial market variables explain a part of bonds' non-credit risk components at all maturities. The changes in KfW spreads are significant variables at all maturities for both periods. The signs of the estimated parameters are negative. For the crisis period, the dummy variable for LTRO announcements is also significant and the signs of its coefficients are negative. The changes in a banks' CDS are also significant and their coefficients and the signs of their coefficients are negative. In the bond spreads of the core countries, the effect of flight to liquidity and the LTRO announcement effect are priced in the non-credit risk components. Additionally, at 1-year maturity, the local market equity index, changes in banks' CDS, and changes in the currency basis are not significant in total spreads, which is attributed to the non-credit risk components, although these variables are significant for the credit risk components. As discussed in Section 5.3, the non-credit risk components of the core countries are negative on average. In summary, the non-credit risk components of the core countries are mainly related to the effect of flight to liquidity for the core countries, this makes the levels of non-credit risk components negative in the bond spreads. The non-credit risk component for the core countries function as convenience yield.

Finally, Panel B3 in Tables 8 and 9 shows the results of the non-credit risk components for the CDS spreads. The adjusted R^2s for the crisis period are around 0.05. Hence, the financial market variables do not explain a significant proportion of CDSs' non-credit risk components for both principal components at all maturities. Furthermore, the adjusted R^2s for the expansion period are around 0, less than those for the crisis period. For the crisis period, although changes in bank's CDS, changes in bid–ask spread, SMP purchase amount, and LTRO announcement dummy are significant at all maturities, the bid-ask spread and SMP purchase amount are not significant in the total spread regression. Therefore, the fluctuation of the CDSs' non-credit risk component has little relation to the

[29] Note that Dufour et al. (2017) use the bond excess returns instead of the bond yield changes which are used in this study. Therefore, their signs should be interpreted in reverse when comparing these with our results.

[30] This yield is calculated from Euro area government bond prices rated AAA by Fitch using the Svensson model (Svensson, 1994).

[31] They mention that on using a term factor in their regressions, several variables exhibit different signs.

[32] Dufour et al. (2017) define the group composed of Germany, the Netherlands, and Finland as low-risk countries. To check the robustness, we calculate the regression coefficients when grouping Germany, the Netherlands, and Finland only. We also find a negative relationship.

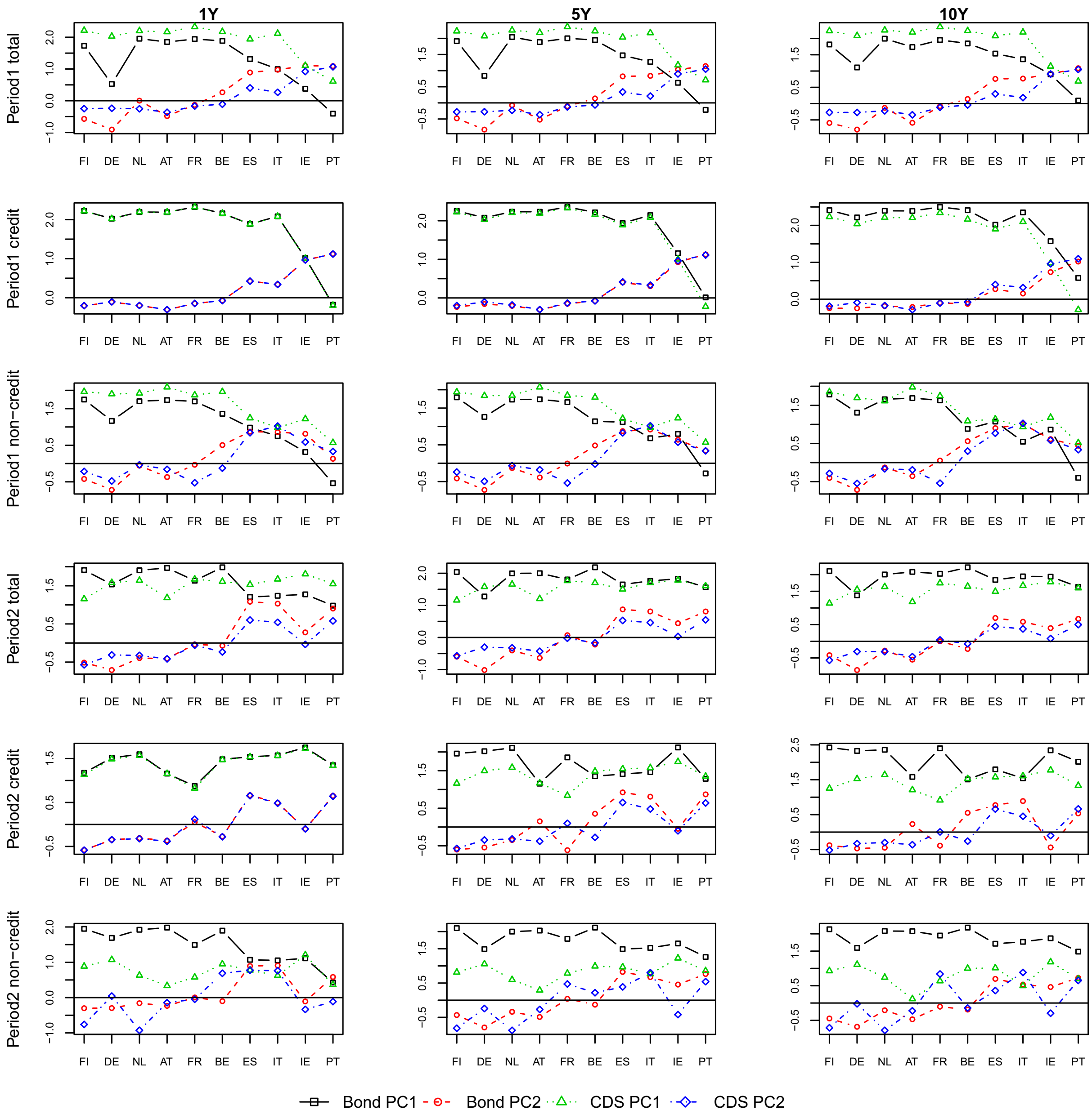

Fig. 7. Factor loadings of the first and second Principal Components. The figure shows the factor loadings of the first and second principal components for each decomposed component at 1-, 5- and 10-year maturities. The sample period of the crisis period is from August 25, 2010 to December 25, 2013 with a weekly frequency. The sample period of the expansion period is from January 1, 2014 to December 27, 2017 with a weekly frequency.

fluctuation of CDSs' total spreads. For the expansion period, as described in Section 5.3, the fluctuation of the non-credit risk component is relatively more important than for the crisis period. The returns of the local equity market index are significant; however, the adjusted R^2s for the expansion period are around 0. Additionally, the significant variables in the total spread regression are the almost same as those in the credit risk component regression. In summary, for crisis period, the CDSs' non-credit risk component has little relation to some variables which are the proxy of liquidity risk and central bank's intervention. This component is less important and become positive or negative value as described in Section 5.3. For expansion period, the CDSs' non-credit risk component has much little relation to the market risk factors; however, the CDSs' non-credit risk component makes credit risk component strong. The levels of CDS spreads are higher than those of theoretical credit risk component, and its difference is constantly earned by seller especially at 5- and 10-years for the expansion period.

Table 8

Core countries regression for the crisis period: coefficients and t-statistics. We regress the changes of first principal components in the total bond and CDS spreads, credit risk components, and non-credit risk components for the core countries on alternative variables of risk factors at 1-, 5- and 10-year maturities. The table shows the multiple regression coefficients and t-statistics (in parentheses) for the indicated regression explanatory variables, which are adjusted for heteroskedasticity and autocorrelation with the optimal number of lags according to Andrews (1991). *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Panel A shows the results for bonds. Panel B shows the results for CDSs. The sample period is from August 25, 2010 to December 25, 2013 with a weekly frequency.

Maturity	Intecept	Local Equity	Global Equity	Bank CDS	Currency Basis	KfW Spread	Bid Ask	SMP	LTRO	*Adj.* R^2
Panel A1 : Bond spread Total										
1Y	0.10	−0.20	−0.15	1.06	−3.53	−1.96	16.92	0.02	−4.47***	0.20
	(1.02)	(−1.41)	(−1.26)	(0.50)	(−0.69)	(−0.58)	(0.63)	(0.34)	(−6.15)	
5Y	0.03	−0.28**	−0.10	4.77**	−5.43	−10.57***	26.10	0.03	−1.95***	0.33
	(0.22)	(−2.01)	(−0.80)	(2.47)	(−1.40)	(−4.36)	(1.15)	(0.41)	(−5.27)	
10Y	0.05	−0.29**	−0.14*	4.38***	−6.26	−8.29***	24.19	0.02	−1.86***	0.34
	(0.38)	(−2.25)	(−1.72)	(2.79)	(−1.36)	(−3.06)	(1.12)	(0.20)	(−4.76)	
Panel A2: Bond spread Credit										
1Y	0.01	−0.23*	−0.16	6.31***	−10.64***	2.16	13.43	0.05	0.69	0.59
	(0.08)	(−1.76)	(−1.27)	(3.21)	(−3.32)	(0.68)	(0.93)	(1.21)	(0.93)	
5Y	−0.02	−0.24**	−0.18	7.81***	−9.21***	0.55	12.44	0.07*	1.22	0.58
	(−0.18)	(−2.00)	(−1.44)	(4.14)	(−2.72)	(0.23)	(0.94)	(1.79)	(1.37)	
10Y	−0.03	−0.23**	−0.17	9.50***	−9.86**	0.25	5.98	0.06	1.49**	0.59
	(−0.18)	(−2.31)	(−1.64)	(5.03)	(−2.31)	(0.11)	(0.69)	(1.33)	(2.24)	
Panel A3: Bond spread Non-Credit										
1Y	0.12	−0.05	−0.08	−3.76**	4.56	−4.14*	7.86	−0.02	−5.91***	0.21
	(0.78)	(−0.44)	(−0.93)	(−2.38)	(1.41)	(−1.71)	(0.37)	(−0.36)	(−7.71)	
5Y	0.07	−0.13	0.04	−2.19*	3.34	−15.03***	21.99	−0.04	−3.93***	0.27
	(0.42)	(−1.06)	(0.46)	(−1.93)	(1.05)	(−6.24)	(1.09)	(−0.44)	(−9.56)	
10Y	0.08	−0.12	−0.01	−4.18***	2.43	−9.86***	23.28	−0.04	−3.35***	0.20
	(0.46)	(−0.94)	(−0.19)	(−4.31)	(0.53)	(−3.28)	(1.02)	(−0.40)	(−7.95)	
Panel B1 : CDS spread Total										
1Y	0.00	−0.23*	−0.16	6.59***	−11.59***	2.14	−0.34	0.05	0.62	0.58
	(0.04)	(−1.88)	(−1.29)	(3.12)	(−3.73)	(0.67)	(−0.15)	(1.11)	(1.16)	
5Y	0.00	−0.25**	−0.18	8.62***	−9.38***	0.35	−2.18	0.04	1.28*	0.58
	(−0.03)	(−2.13)	(−1.44)	(3.94)	(−3.16)	(0.17)	(−0.90)	(0.94)	(1.88)	
10Y	0.00	−0.25*	−0.18	9.68***	−8.40***	−1.14	−3.54	0.02	1.68***	0.59
	(0.03)	(−1.91)	(−1.38)	(4.16)	(−2.65)	(−0.44)	(−1.54)	(0.43)	(2.63)	
Panel B2: CDS spread Credit										
1Y	0.00	−0.23*	−0.16	6.35***	−11.78***	2.32	−0.05	0.05	0.51	0.58
	(0.01)	(−1.85)	(−1.29)	(3.01)	(−3.83)	(0.74)	(−0.02)	(1.25)	(1.02)	
5Y	−0.03	−0.25**	−0.19	7.49***	−10.83***	0.32	−0.46	0.07*	0.80	0.55
	(−0.20)	(−2.02)	(−1.44)	(3.74)	(−3.21)	(0.15)	(−0.19)	(1.71)	(1.25)	
10Y	−0.04	−0.27*	−0.20	8.12***	−10.62**	−1.50	−0.93	0.07*	0.99	0.56
	(−0.27)	(−1.95)	(−1.51)	(4.00)	(−2.45)	(−0.56)	(−0.38)	(1.68)	(1.53)	
Panel B3: CDS spread Non-Credit										
1Y	0.07	0.13	0.04	3.84***	3.27	−12.91***	−4.37*	−0.13**	2.94***	0.11
	(0.23)	(1.11)	(0.56)	(2.76)	(0.77)	(−2.82)	(−1.81)	(−2.34)	(5.34)	
5Y	0.11	0.11	0.04	3.89**	6.97	−2.00	−5.54**	−0.15***	2.63***	0.05
	(0.31)	(0.91)	(0.45)	(2.34)	(1.15)	(−0.57)	(−2.12)	(−2.73)	(3.93)	
10Y	0.10	0.15	0.04	3.18*	5.98	0.91	−5.12*	−0.13**	2.34***	0.04
	(0.35)	(1.20)	(0.45)	(1.92)	(0.79)	(0.39)	(−1.97)	(−2.33)	(3.46)	

5.5.4. Peripheral countries

Tables 10 and 11[33] report the results of the regressions of changes in the first principal components of the bond spreads and CDS spreads, the credit risk components , and the non-credit risk components on the explanatory variables. Panel A1 and Panel B1 show the results of the total spreads for bonds and CDSs. In this subsection, we focus on the different results for core and peripheral countries.

First, Panel A2 and Panel B2 in Tables 10 and 11 show the results of the credit risk components. The adjusted R^2s for both periods are around 0.50. Hence, the financial market variables explain a substantial proportion of the credit risk components at all maturities. Also, the returns of the local market equity index and the changes in banks' CDS are significant for both periods. For both periods, the t-values for the returns of the local market equity index are higher than the other variables. The signs of the coefficients of the local

[33] We also regress each variable using univariate regression. For the significant variables, the signs of the coefficients are the same as the results of the multivariate regression in Tables 10 and 11.

Table 9

Core countries regression for the expansion period: coefficients and t-statistics. We regress the changes of first principal components in the total bond and CDS spreads, credit risk components, and non-credit risk components for the core countries on alternative variables of risk factors at 1-, 5- and 10-year maturities. The table shows the multiple regression coefficients and t-statistics (in parentheses) for the indicated regression explanatory variables, which are adjusted for heteroskedasticity and autocorrelation with the optimal number of lags according to Andrews (1991). *, * *, and * * * denote significance at the 10%, 5%, and 1% levels, respectively. Panel A shows the results for bonds. Panel B shows the results for CDSs. The sample period is from January 1, 2014 to December 27, 2017 with a weekly frequency.

Maturity	Intecept	Local Equity	Global Equity	Bank CDS	Currency Basis	KfW Spread	Bid Ask	20pt*Adj.* R^2
Panel A1 : Bond spread Total								
1Y	0.05	−0.07	−0.06	4.55	7.09*	−31.74* * *	−9.86	0.33
	(0.49)	(−1.13)	(−0.81)	(1.63)	(1.85)	(−6.80)	(−1.31)	
5Y	0.02	−0.12	−0.07	6.29**	5.37	−39.48* * *	−6.76	0.35
	(0.21)	(−1.50)	(−0.87)	(2.11)	(0.82)	(−7.60)	(−1.18)	
10Y	0.04	−0.25* * *	−0.15*	3.56	8.35	−28.18* * *	−5.65	0.22
	(0.40)	(−2.98)	(−1.81)	(1.05)	(1.32)	(−7.08)	(−0.74)	
Panel A2: Bond spread Credit								
1Y	−0.01	0.03	0.17*	15.04* * *	−2.33	4.05	−9.63*	0.15
	(−0.07)	(0.81)	(1.83)	(4.37)	(−0.66)	(1.25)	(−1.81)	
5Y	0.01	0.05	0.06	11.80* * *	−6.33	15.24* * *	−9.00*	0.18
	(0.07)	(0.88)	(0.68)	(4.04)	(−1.20)	(3.65)	(−1.69)	
10Y	0.01	0.01	0.03	13.04* * *	−3.53	−0.10	−0.76	0.09
	(0.07)	(0.08)	(0.30)	(3.14)	(−0.62)	(−0.02)	(−0.13)	
Panel A3: Bond spread Non-Credit								
1Y	0.05	−0.07	−0.06	3.69	7.20*	−31.81* * *	−9.24	0.33
	(0.48)	(−1.16)	(−0.95)	(1.32)	(1.91)	(−6.79)	(−1.25)	
5Y	0.02	−0.12	−0.08	4.22	6.37	−40.81* * *	−5.15	0.37
	(0.20)	(−1.60)	(−1.01)	(1.51)	(1.02)	(−7.91)	(−0.95)	
10Y	0.04	−0.24* * *	−0.15**	−0.81	9.31	−27.16* * *	−5.37	0.18
	(0.30)	(−2.86)	(−2.03)	(−0.28)	(1.58)	(−6.26)	(−0.75)	
Panel B1 : CDS spread Total								
1Y	−0.01	0.02	0.15	14.06* * *	−1.16	3.74	1.15	0.13
	(−0.11)	(0.38)	(1.65)	(3.98)	(−0.34)	(1.15)	(0.55)	
5Y	−0.01	0.02	0.15*	14.79* * *	−3.30	1.46	1.16	0.14
	(−0.10)	(0.43)	(1.76)	(4.55)	(−0.78)	(0.41)	(0.50)	
10Y	−0.01	0.03	0.14*	15.44* * *	−4.13	2.16	0.71	0.15
	(−0.09)	(0.78)	(1.75)	(5.15)	(−1.03)	(0.63)	(0.30)	
Panel B2: CDS spread Credit								
1Y	−0.01	0.02	0.15	14.03* * *	−1.18	3.74	1.16	0.13
	(−0.11)	(0.36)	(1.64)	(3.97)	(−0.35)	(1.16)	(0.56)	
5YY	−0.01	0.01	0.15*	14.62* * *	−3.68	0.95	1.27	0.13
	(−0.12)	(0.26)	(1.76)	(4.38)	(−0.82)	(0.28)	(0.57)	
10	−0.01	0.01	0.14	15.60* * *	−5.04	0.61	0.94	0.16
	(−0.10)	(0.19)	(1.58)	(4.89)	(−1.12)	(0.17)	(0.43)	
Panel B3: CDS spread Non-Credit								
1Y	−0.01	0.09**	0.10	3.72	2.71	1.57	−0.07	-0.01
	(−0.05)	(1.98)	(1.61)	(1.50)	(0.80)	(0.38)	(−0.05)	
5Y	0.00	0.09**	0.08	3.02	3.83	4.16	−0.34	0.00
	(−0.03)	(1.98)	(1.40)	(1.27)	(0.92)	(1.03)	(−0.21)	
10Y	−0.01	0.11**	0.09	2.51	3.39	7.33**	−0.58	0.01
	(−0.04)	(2.41)	(1.56)	(1.20)	(0.97)	(2.56)	(−0.33)	

market equity index are negative, which are same as core countries. This result is in line with Dufour et al. (2017). For the crisis period, the relations to the changes in the currency basis are also significant at 1- and 5-year maturities. Additionally, the changes in the bid-ask spread are significant variables at all maturities as opposed to the results for the core countries. At 5-year maturity, the changes in the KfW spread are also significant, and the signs of these estimated parameters are positive. In addition to the results for the core countries, this indicate that the credit risk component of the peripheral countries is related to bond market liquidity for the crisis period. Furthermore, the signs of estimated parameters for the SMP purchase amount are negative; however these t-values are smaller than other significant variables. For the period of economic expansion, this tendency of bid–ask spread is not observed.

Next, Panel A3 in Tables 10 and 11 shows the results of the non-credit risk components for the bond spreads. The adjusted R^2s for the crisis period are around 0.20 at 5- and 10-year maturities and the adjusted R^2 for the crisis period are around 0.31 at 1-year maturity. Thus, the financial market variables explain a part of bonds' non-credit risk components at all maturities; however, the levels of the adjusted R^2s are lower than those of the credit risk component regression. On the other hand, at 5- and 10-year maturities, the adjusted R^2s for the expansion period are around 0.20, slightly less than those for the crisis period. However, at 1-year maturity, the adjusted R^2 is around 0. For the crisis period, the changes in the bid–ask spread and the returns of the local market

Table 10

Peripheral countries regression for the crisis period: coefficients and t-statistics. We regress the changes of first principal components in the total bond and CDS spreads, credit risk components, and non-credit risk components for the peripheral countries on alternative variables of risk factors at 1-, 5- and 10-year maturities. The table shows the multiple regression coefficients and t-statistics (in parentheses) for the indicated regression explanatory variables, which are adjusted for heteroskedasticity and autocorrelation with the optimal number of lags according to Andrews (1991). *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Panel A shows the results for bonds. Panel B shows the results for CDSs. The sample period is from from August 25, 2010 to December 25, 2013 with a weekly frequency.

Maturity	Intecept	Local Equity	Global Equity	Bank CDS	Currency Basis	KfW Spread	Bid Ask	SMP	LTRO	*Adj.* R^2
Panel A1 : Bond spread Total										
1Y	0.08	−0.33***	0.02	2.13*	−3.65**	4.26**	3.42***	−0.08	−3.23***	0.52
	(1.17)	(−6.08)	(0.19)	(1.67)	(−2.01)	(2.31)	(3.44)	(−1.11)	(−15.82)	
5Y	0.08	−0.30***	0.03	2.90**	−7.82***	3.85*	3.48***	−0.10	−1.86***	0.54
	(1.12)	(−5.43)	(0.39)	(1.98)	(−3.21)	(1.77)	(4.59)	(−1.50)	(−3.64)	
10Y	0.06	−0.34***	0.04	4.13**	−4.15	1.19	3.71***	−0.12	−0.60	0.50
	(0.83)	(−6.35)	(0.39)	(2.45)	(−1.29)	(0.67)	(5.52)	(−1.63)	(−1.25)	
Panel A2: Bond spread Credit										
1Y	0.06	−0.31***	0.00	3.56**	−6.31**	1.34	2.69***	−0.09*	−0.79	0.52
	(0.76)	(−5.33)	(0.03)	(2.15)	(−2.58)	(0.66)	(2.76)	(−1.70)	(−0.97)	
5Y	0.06	−0.28***	−0.02	3.50**	−8.39***	5.22***	2.59***	−0.07	−0.95	0.54
	(0.79)	(−4.55)	(−0.22)	(2.08)	(−3.48)	(2.77)	(3.01)	(−1.60)	(−1.45)	
10Y	0.03	−0.31***	−0.01	4.97***	−5.48	2.25	2.82***	−0.06	−0.54	0.51
	(0.41)	(−4.91)	(−0.09)	(3.16)	(−1.61)	(1.23)	(3.23)	(−1.20)	(−0.53)	
Panel A3: Bond spread Non-Credit										
1Y	0.07	−0.18***	0.00	−0.23	1.21	5.89***	1.65*	−0.02	−4.91***	0.31
	(0.90)	(−3.02)	(0.05)	(−0.19)	(0.45)	(3.79)	(1.77)	(−0.41)	(−5.60)	
5Y	0.07	−0.20***	0.09	0.95	−3.25	−1.16	2.98***	−0.09	−2.56**	0.24
	(0.90)	(−3.07)	(0.74)	(0.64)	(−1.10)	(−0.44)	(3.31)	(−1.19)	(−2.31)	
10Y	0.07	−0.19***	0.10	1.52	−2.80	−0.73	3.18***	−0.11	−1.46	0.23
	(0.81)	(−3.19)	(0.89)	(0.95)	(−0.85)	(−0.34)	(3.94)	(−1.31)	(−1.26)	
Panel B1 : CDS spread Total										
1Y	0.05	−0.32***	0.01	3.78**	−7.83***	1.04	0.75**	−0.09*	−0.39	0.50
	(0.54)	(−5.19)	(0.18)	(2.22)	(−3.32)	(0.51)	(2.28)	(−1.85)	(−0.49)	
5Y	0.04	−0.29***	−0.01	3.99**	−8.57***	4.98**	0.57*	−0.07*	−0.45	0.52
	(0.47)	(−4.67)	(−0.20)	(2.55)	(−3.29)	(2.48)	(1.67)	(−1.70)	(−0.48)	
10Y	0.02	−0.32***	0.01	5.13***	−4.88	1.94	0.70**	−0.07	−0.19	0.48
	(0.17)	(−5.20)	(0.07)	(3.18)	(−1.57)	(1.10)	(2.06)	(−1.33)	(−0.18)	
Panel B2: CDS spread Credit										
1Y	0.05	−0.31***	0.02	3.50**	−7.73***	1.39	0.62*	−0.08*	−0.97	0.50
	(0.55)	(−5.31)	(0.29)	(2.18)	(−3.27)	(0.74)	(1.89)	(−1.69)	(−1.23)	
5Y	0.05	−0.27***	−0.01	3.63**	−8.74***	5.01***	0.42	−0.07	−1.11	0.50
	(0.52)	(−4.70)	(−0.08)	(2.60)	(−3.14)	(2.67)	(1.33)	(−1.54)	(−0.86)	
10Y	0.02	−0.29***	0.01	4.78***	−5.69*	2.03	0.50	−0.06	−0.83	0.46
	(0.29)	(−4.81)	(0.10)	(3.08)	(−1.80)	(1.17)	(1.53)	(−1.18)	(−0.61)	
Panel B3: CDS spread Non-Credit										
1Y	−0.08	−0.20***	−0.02	2.26*	1.16	−2.30	0.02	0.02	1.39***	0.09
	(−0.29)	(−3.42)	(−0.30)	(1.71)	(0.49)	(−0.82)	(0.13)	(0.43)	(4.52)	
5Y	−0.06	−0.20***	−0.02	1.86	0.72	1.04	0.00	0.01	1.17***	0.09
	(−0.25)	(−3.35)	(−0.32)	(1.65)	(0.23)	(0.49)	(−0.00)	(0.30)	(4.28)	
10Y	−0.07	−0.19***	−0.01	1.99*	0.84	1.62	0.00	0.01	1.09***	0.09
	(−0.25)	(−3.28)	(−0.11)	(1.95)	(0.23)	(1.46)	(−0.03)	(0.36)	(4.47)	

equity index are significant variables at all maturities as opposed to the results for the core countries. At 1-year maturity, the changes in the KfW spread are significant variables and its adjusted R^2 is higher than those at 5- and 10-year maturities. For the crisis period, especially at 1-year maturity, the effect of flight to liquidity is priced in the non-credit risk components and its sign is the opposite of that of the core countries. For the expansion period, the changes in the KfW spread are not significant variables at all maturities as opposed to the results for the core countries. Furthermore, at 1-year maturity, the non-credit risk component is not related to the market risk variables for the expansion period. At 5- and 10-year maturities, the returns of the local market equity index, and the global market index are significant variables. In summary, for the crisis period, the bonds' non-credit risk components are related to the liquidity risk, and this relation is strong at 1-year maturity. This relation makes the non-credit risk components volatile and positive value. For the expansion period, the increase of the equity index following improvement of economic environment makes the non-credit risk is related to the decrease of the bond's non-credit risk at 5- and 10-year maturities.

Finally, Panel B3 in Table 10 and 11 shows the results of the non-credit risk components for the CDS spreads. The adjusted R^2s for the crisis period are around 0.05. Hence, the financial market variables do not explain a significant proportion of the CDSs' non-credit risk components for both principal components at all maturities. For the crisis period, at all maturities, the returns of the local market

Table 11

Peripheral countries regression for the expansion period: coefficients and t-statistics. We regress the changes of first principal components in the total bond and CDS spreads, credit risk components, and non-credit risk components for the peripheral countries on alternative variables of risk factors at 1-, 5- and 10-year maturities. The table shows the multiple regression t-statistics for the indicated regression explanatory variables, which are adjusted for heteroskedasticity and autocorrelation with the optimal number of lags according to Andrews (1991). $*$, $**$, and $***$ denote significance at the 10%, 5%, and 1% levels, respectively. Panel A shows the results for bonds. Panel B shows the results for CDSs. The sample period is from January 1, 2014 to December 27, 2017 with a weekly frequency.

Maturity	Intecept	Local Equity	Global Equity	Bank CDS	Currency Basis	KfW Spread	Bid Ask	*Adj.* R^2
Panel A1 : Bond spread Total								
1Y	0.01	−0.27***	−0.15**	6.47**	−3.81	−1.64	14.48	0.26
	(0.14)	(−4.03)	(−2.19)	(2.22)	(−1.03)	(−0.44)	(1.51)	
5Y	0.04	−0.35***	−0.23***	10.06***	0.41	3.99	5.87	0.39
	(0.41)	(−5.02)	(−2.91)	(2.96)	(0.09)	(0.99)	(0.73)	
10Y	0.04	−0.37***	−0.25***	10.80***	2.86	−4.92	1.33	0.39
	(0.49)	(−5.39)	(−3.06)	(3.59)	(0.63)	(−1.23)	(0.21)	
Panel A2: Bond spread Credit								
1Y	0.02	−0.29***	−0.13*	14.06***	−4.96	5.00*	7.60	0.47
	(0.20)	(−4.64)	(−1.73)	(4.57)	(−1.15)	(1.75)	(1.23)	
5Y	0.03	−0.30***	−0.16**	13.51***	−1.06	12.98***	3.68	0.50
	(0.39)	(−5.28)	(−2.03)	(4.16)	(−0.24)	(3.81)	(0.58)	
10Y	0.03	−0.27***	−0.14	14.90***	−0.73	3.30	1.72	0.41
	(0.32)	(−4.42)	(−1.43)	(4.04)	(−0.15)	(0.76)	(0.28)	
Panel A3: Bond spread Non-Credit								
1Y	0.00	−0.07	−0.02	−2.41	−1.72	−5.35	11.01	0.01
	(−0.04)	(−1.16)	(−0.33)	(−0.81)	(−0.49)	(−1.39)	(1.33)	
5Y	0.02	−0.27***	−0.19***	4.95	−0.93	−1.82	4.59	0.20
	(0.22)	(−4.41)	(−2.60)	(1.28)	(−0.21)	(−0.47)	(0.61)	
10Y	0.03	−0.31***	−0.22***	7.32**	2.75	−8.86*	3.38	0.25
	(0.29)	(−4.86)	(−3.00)	(2.13)	(0.64)	(−1.94)	(0.48)	
Panel B1 : CDS spread Total								
1Y	0.02	−0.28***	−0.15*	15.39***	−3.74	5.38*	0.64	0.48
	(0.32)	(−4.31)	(−1.92)	(5.04)	(−0.84)	(1.96)	(0.68)	
5Y	0.04	−0.27***	−0.18**	14.32***	3.12	11.73***	0.61	0.49
	(0.57)	(−4.46)	(−2.39)	(4.37)	(0.72)	(4.04)	(0.70)	
10Y	0.05	−0.23***	−0.16**	16.46***	4.70	2.79	0.64	0.46
	(0.55)	(−3.56)	(−2.11)	(4.57)	(1.12)	(0.73)	(0.88)	
Panel B2: CDS spread Credit								
1Y	0.02	−0.29***	−0.14*	13.78***	−4.73	5.13*	0.63	0.46
	(0.23)	(−4.54)	(−1.89)	(4.40)	(−1.11)	(1.81)	(0.63)	
5Y	0.03	−0.30***	−0.16**	13.25***	−0.20	9.95***	0.69	0.47
	(0.38)	(−4.81)	(−2.05)	(4.10)	(−0.05)	(3.13)	(0.70)	
10Y	0.03	−0.28***	−0.14*	15.56***	0.41	1.68	0.82	0.46
	(0.38)	(−4.35)	(−1.81)	(4.67)	(0.11)	(0.44)	(0.89)	
Panel B3: CDS spread Non-Credit								
1Y	0.02	−0.04	−0.06	4.73*	3.80	2.16	−0.18	0.03
	(0.17)	(−0.68)	(−1.11)	(1.76)	(1.12)	(0.71)	(−0.25)	
5Y	0.04	−0.08	−0.13**	3.06	8.80*	9.67***	−0.28	0.09
	(0.30)	(−1.24)	(−2.20)	(1.10)	(1.86)	(2.72)	(−0.35)	
10Y	0.03	−0.07	−0.11*	3.11	10.36**	6.04	−0.32	0.08
	(0.29)	(−0.97)	(−1.70)	(1.18)	(2.36)	(1.56)	(−0.35)	

equity index are significant variables. As described in Section 5.3, for the crisis period, for both the average and the standard deviation, the credit risk component is larger than the non-credit risk component in most countries and at most maturities. The role of the non-credit risk is weak; however, as the local market equity index decreases, the absolute value of the non-credit risk component also increases for the crisis period. For the expansion period, its portion is lower than those of the core countries and has little relation to the market variables. Although Badaoui et al. (2013) treat a hidden process other than the credit risk process as liquidity risk in emerging market, little attention has been paid to investigating whether an estimated risk process is related to the alternative variables of liquidity risk or other risk factors. Also, they indicate that sovereign CDS spreads are highly driven by liquidity. However, we find that the relationships between the non-credit risk components of CDS spreads and risk factors are weak and the fluctuations of the CDS spread is mainly driven by the credit risk components in both country groups unlike the findings of Badaoui et al. (2013).

6. Conclusion

This study contributes to the literature on the relationship between the term structure of local currency-denominated sovereign bond yields and foreign currency-denominated sovereign CDS spreads. Sovereign CDSs are mainly traded in foreign currency. We develop a consistent pricing model between the term structure of local currency-denominated sovereign bond yields and foreign currency-denominated sovereign CDS spreads, which allows us to decompose these term structures into credit risk and non-credit risk. We consider non-credit risk in both instruments. To study the instruments denominated in different currencies, we consider the depreciation risk of the exchange rate following a sovereign credit event. Solely to estimate depreciation ratio, different currency denominated CDS spreads are used.

We apply the model to study the relationship between the term structures of euro area countries during two periods: the European sovereign debt crisis and the period of economic expansion after the crisis. In the crisis period, we find that, on average, the non-credit risk component of the bond spreads is negative in bond spreads at the short end of the term structure. At longer maturities, the non-credit risk component of the bond spreads is less important in bond spreads. In addition, in the peripheral countries, the non-credit risk component of the bond spreads is more volatile than the credit risk components at the short end of the term structure. On the other hand, in CDS spreads, the credit risk component is more important for crisis period. For the expansion period, in the core countries, the levels of CDS spreads are higher than those of theoretical credit risk component, and its difference is constantly earned by seller especially at 5- and 10-years.

Following the regression analysis, for the crisis period, the credit risk components in core countries have negative relationship with the local equity market. Further, the bond spreads increase as the local equity market risk decreases even in the core countries for the crisis period unlike Dufour et al. (2017). When considering the effect of the risk-free rate term structures, we find that the bond spreads are affected by the local market risk through the credit risk components. Furthermore, the global risk factor is not related to the credit risk components, unlike the findings of Ang and Longstaff (2013) and Longstaff et al. (2011), who study the period before the European sovereign debt crisis for both country groups. In the peripheral countries, the credit risk component is also related to the local equity market for the expansion period. These results in peripheral countries are in line with Dufour et al. (2017). The credit risk component is also related to the proxy for global dealer banks' regulatory incentives for both periods in both country groups. This supports the results of Klingler and Lando (2018). We can infer that this relationship is priced in the credit risk component. In the core countries, the non-credit risk component of the bond yield is mainly related to flight to liquidity effect, for which the KfW spread is the proxy, and function as convenience yield. In the peripheral countries, for the crisis period, the non-credit risk component of the bond spread is also mainly related to market liquidity, for which the bid–ask spread is the proxy. Especially, at 1-year maturity, it is also related to the KfW spreads. On the whole, the relationships between CDSs' non-credit risk components and risk factors are weak and these fluctuations have little effect on the fluctuation of CDS spreads in both country groups unlike the findings of Badaoui et al. (2013).

Our results provide important insights into the main drivers and dynamics of sovereign bond yields' and CDS spreads' term structures for developed countries. These insights should prove useful for practitioners and policy makers.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Pricing Formula

A.1. Proof of Propositions

Proof. [Proposition 1] To derive the value of the protection leg in foreign currency, we must consider the value of loss at the credit event. The buyer of protection receives the loss value, which is $(1 - R)B_0$ at the credit event. First, we consider the value with the foreign risk-neutral measure. The value of the protection leg is given by

$$E^{\mathbb{Q}_f}\left[\mathbf{1}_{\{\tau>t\}}\left(1-R\right)B_0 e^{-\int_t^\tau\left(r_{f,u}+\gamma_{c,u}\right)du}\mathbf{1}_{\{\tau\leqslant T\}}\;\middle|\;\mathcal{G}_t\right] = B_0\left(1-R\right)E^{\mathbb{Q}_f}\left[\int_t^T\int_Z e^{-\int_t^s\left(r_{f,u}+\gamma_{c,u}\right)du}\mathbf{1}_{\{s\leqslant\tau\}}\mu\left(dz,ds\right)\;\middle|\;\mathcal{G}_t\right].$$

Then, we introduce (1) and change the foreign risk-neutral measure to the domestic risk-neutral measure as follows:

$$\begin{aligned}&B_0(1-R)E^{\mathbb{Q}_f}\left[\int_t^T\int_Z e^{-\int_t^s(r_{f,u}+\gamma_{c,u})du}\mathbf{1}_{\{s\leqslant\tau\}}\mu(dz,ds)\mid\mathcal{G}_t\right]\\&=B_0(1-R)E^{\mathbb{Q}_d}\left[\int_t^T\int_Z X_{s-}(1+\delta^d(z,s))e^{-\int_t^s(r_{d,u}+\gamma_{c,u})du}\mathbf{1}_{\{s\leqslant\tau\}}\mu(dz,ds)\mid\mathcal{G}_t\right].\end{aligned}$$

Under $\mathbb{Q}_d$, the SDE of X_t is given by

$$\frac{dX_t}{X_t}=\left(r_{d,t}-r_{f,t}\right)dt+\sigma_x dw_{x,t}^d+\int_Z\delta^d\left(z,t\right)\left(\mu-\nu^d\right)\left(dz,dt\right).$$

Then, before occuring the credit event, X_t is given by

$$X_t = X_0 e^{\int_0^t \left(r_{d,t} - r_{f,t} - \frac{1}{2}\sigma_x^2 - \hat{\delta}^d(t)\lambda_{d,t}\right)dt + \int_0^t \sigma_x dw_{x,t}^d},$$

where the locally expected appreciation fraction $\hat{\delta}^d(t)$ under $\mathbb{Q}_d$ is $\hat{\delta}^d(t) := \int_{\mathscr{Z}} \delta^d(z, t) dF_t^d(z)$. Additionally, it is assumed that $dw_{x,t}^d$ is independent of $\lambda_{d,t}$, σ_x, and $\bar{\delta} := 1 + \hat{\delta}^d$. Also, it is assumed that δ^d is not distributed and constant. To calculate the depreciation ratio, we define $\hat{\delta}^f = \frac{\hat{\delta}^d}{1+\hat{\delta}^d}$ where $\hat{\delta}^f$ is the locally expected depreciation ratio of local currency against foreign currency.

$$B_0\left(1 - R\right)E^{\mathbb{Q}_d}\left[\int_t^T e^{-\int_t^s \left(r_{f,u} + \bar{\delta}\lambda_{d,u} + \gamma_{c,u}\right)du} \bar{\delta}\lambda_{d,s} ds \;\middle|\; \mathscr{F}_t\right].$$

Proposition 3.1 of Lando (1998) is used. □

Proof. [Proposition 2] It is assumed that $r_{d,t}$ is independent from $\lambda_{d,t}$ and $dw_{x,t}^d$. We change the foreign risk-neutral measure to the domestic risk-neutral measure as follows:

$$\begin{aligned}\frac{B_0 S_{t,m}}{4}\sum_{k=1}^{4m} E^{\mathbb{Q}_f}\left[e^{-\int_t^{t+\frac{k}{4}} r_{f,u}du}\mathbf{1}_{\{t+\frac{k}{4}<\tau\}} \;\middle|\; \mathscr{G}_t\right] &= \frac{B_0 S_{t,m}}{4}\sum_{k=1}^{4m} E^{\mathbb{Q}_d}\left[\mathbf{1}_{\{t+\frac{k}{4}<\tau\}} e^{-\int_t^{t+\frac{k}{4}}\left(r_{f,u} + \frac{\sigma_x^2}{2} + \hat{\delta}^d(u)\lambda_{d,u}\right)du + \int_t^{t+\frac{k}{4}} \sigma_x dw_{x,u}^d} \;\middle|\; \mathscr{G}_t\right] \\ &= \frac{B_0 S_{t,m}}{4}\sum_{k=1}^{4m} E^{\mathbb{Q}_d}\left[e^{-\int_t^{t+\frac{k}{4}}\left(r_{f,u} + \frac{\sigma_x^2}{2} + \bar{\delta}\lambda_{d,u}\right)du + \int_t^{t+\frac{k}{4}} \sigma_x dw_{x,u}^d} \;\middle|\; \mathscr{F}_t\right]\end{aligned} \tag{A.1}$$

$$= \frac{B_0 S_{t,m}}{4}\sum_{k=1}^{4m} E^{\mathbb{Q}_d}\left[e^{-\int_t^{t+\frac{k}{4}}\left(r_{f,u} + \bar{\delta}\lambda_{d,u} + \gamma_{c,u}\right)du} \;\middle|\; \mathscr{F}_t\right]. \tag{A.2}$$

Proposition 3.1 of Lando (1998) and Corollary 9.4 of McNeil, Frey, and Embrechts (2015) are used for the last equation. □

A.2. ODE solution

Let us consider the pricing formula under the stochastic process assumption. We express $x_{i,t}$ as $(\gamma_{i,t}, \lambda_{d,t})'$.
The second term of (2) can be expressed with discrete approximation as follows:

$$E^{\mathbb{Q}_d}\left[\int_t^{t+m} \lambda_{d,s} e^{-\int_t^s \left(\gamma_{i,u} + \lambda_{d,u}\right)du} ds \;\middle|\; \mathscr{F}_t\right] = \sum_{n=1}^{N} \Delta t \cdot E^{\mathbb{Q}_d}\left[\lambda_{d,t+\Delta t\cdot n} e^{-\int_t^{t+\Delta t\cdot n}\left(\gamma_{i,u} + \lambda_{d,u}\right)du} \;\middle|\; \mathscr{F}_t\right],$$

where $\Delta t \cdot N := m$. $X(s, x_{i,t}, \nu)$ and $Y(s, x_{i,t}, \nu)$ are defined as $X(s, x_{i,t}, \nu) = E^{\mathbb{Q}_d}[e^{-\int_t^{t+s}\gamma_{i,u} + \nu\lambda_{d,u}du} \mid \mathscr{F}_t]$, $Y(s, x_{i,t}, \nu) = E^{\mathbb{Q}_d}[\nu\lambda_{d,t+s} e^{-\int_t^{t+s}\gamma_{i,u} + \nu\lambda_{d,u}du} \mid \mathscr{F}_t]$. Then, (2) can be expressed as follows:

$$P_t(m) = X\left(m, x_{b,t}, 1\right)DF_{d,t}(m) + R\sum_{n=1}^{N} \Delta t \cdot Y\left(\Delta t \cdot n, x_{b,t}, 1\right)DF_{d,t}\left(\Delta t \cdot n\right).$$

Next, $U(s, \lambda_{d,t}, \nu)$ and $V(s, \lambda_{d,t}, \nu)$ is defined as $U(s, \lambda_{d,t}, \nu) = E^{\mathbb{Q}_d}[e^{-\int_t^{t+s}\nu\lambda_{d,u}du} \mid \mathscr{F}_t]$, $V(s, \lambda_{d,t}, \nu) = E^{\mathbb{Q}_d}[\nu\lambda_{d,t+s} e^{-\int_t^{t+s}\nu\lambda_{d,u}du} \mid \mathscr{F}_t]$. Then, we can express (3) as follows:

$$S_{t,m} = \frac{\left(1 - R\right)\sum_{n=1}^{N} \Delta t \cdot Y\left(\Delta t \cdot n, x_{c,t}, \bar{\delta}\right)DF_{f,t}\left(\Delta t \cdot n\right)}{\frac{1}{4}\sum_{k=1}^{4m} DF_{f,t}\left(k/4\right)U\left(k/4, \lambda_{d,t}, \bar{\delta}\right) + \frac{1}{8}\sum_{n=1}^{N} \Delta t \cdot V\left(\Delta t \cdot n, x_t, \bar{\delta}\right)DF_{f,t}\left(\Delta t \cdot n\right)}.$$

First, we guess that $X(s, x_i, \nu) = \exp(-A - B'x_i - \delta_{i,0}s)$ and $Y(s, x_i) = (C + D'x_i)X(s, x_i)$, where $B = (b_1, b_2, b_3)'$ and $D = (0, 0, d_3)'$.

We apply Ito's formula to $X(s, x_{i,t}, \nu)$ and $Y(s, x_{i,t}, \nu)$, then a partial differential equation (PDE) can be derived by the no-arbitrage condition. The following ordinally differential equation (ODE) can be derived by applying the Feynman-Kac formula to the PDE.

$$\dot{A} = \mu' B - \tfrac{1}{2}b_1^2 - \tfrac{1}{2}b_2^2,\ \ \dot{B} = KB + \begin{pmatrix} d_{i,1} \\ d_{i,2} \\ 1 \end{pmatrix} - \tfrac{1}{2}\begin{pmatrix} 0 \\ 0 \\ b_3^2 \nu \sigma_3^2 \end{pmatrix},\ \ \dot{C} = \mu' D - B' D,\ \ \dot{D} = K' D - \begin{pmatrix} 0 \\ 0 \\ b_3 d_3 \nu \sigma_3^2 \end{pmatrix},$$

$$\mu = \begin{pmatrix} 0 \\ 0 \\ k_3^Q \theta_3^Q \nu \end{pmatrix},\ \ K = \begin{pmatrix} -k_{i,1}^Q & 0 & 0 \\ -k_{i,12}^Q & -k_{i,2}^Q & 0 \\ 0 & 0 & -k_3^Q \end{pmatrix}$$

where $A(0) = 0$, $B(0) = (0, 0, 0)'$, $C(0) = 0$, $D(0) = (0, 0, 1)'$. This ODE can be solved analytically as follows:

$$\begin{aligned} A =& \frac{k_3^Q \theta_3^Q}{\sigma_3^2}\left[2\log\left\{\frac{(\xi + k_3^Q)e^{\xi s} + (\xi - k_3^Q)}{2\xi}\right\} - (\xi + k_3^Q)s\right] \\ & - \frac{d_{i,2}^2}{2k_{i,2}^{Q\,2}}\left\{s + \frac{2}{k_{i,2}^Q}(e^{-k_{i,2}^Q s} - 1) - \frac{1}{2k_{i,2}^Q}(e^{-2k_{i,2}^Q s} - 1)\right\} - \frac{1}{2}\left[A_1^2\left\{s + \frac{2}{k_{i,1}^Q}(e^{-k_{i,1}^Q s} - 1) - \frac{1}{2k_{i,1}^Q}(e^{-2k_{i,1}^Q s} - 1)\right\}\right. \\ & + 2A_1A_2\left\{\frac{1}{k_{i,1}^Q}(e^{-k_{i,1}^Q s} - 1) - \frac{1}{k_{i,2}^Q}(e^{-k_{i,2}^Q s} - 1) + \frac{1}{k_{i,1}^Q + k_{i,2}^Q}(e^{-(k_{i,1}^Q + k_{i,2}^Q)s} - 1) - \frac{1}{2k_{i,1}^Q}(e^{-2k_{i,1}^Q s} - 1)\right\} \\ & \left. + A_2^2\left\{-\frac{1}{2k_{i,1}^Q}(e^{-2k_{i,1}^Q s} - 1) - \frac{1}{2k_{i,2}^Q}(e^{-2k_{i,2}^Q s} - 1) + \frac{2}{k_{i,1}^Q + k_{i,2}^Q}(e^{-2(k_{i,1}^Q + k_{i,2}^Q)s} - 1)\right\}\right], \\ b_1 =& A_1\frac{d_{i,1}}{k_{i,1}^Q}(1 - e^{-k_{i,1}^Q s}) + A_2(e^{-k_{i,2}^Q s} - e^{-k_{i,1}^Q s}),\ b_2 = \frac{d_{i,2}}{k_{i,2}^Q}(1 - e^{-k_{i,2}^Q s}),\ b_3 = \frac{1}{\sigma_3^2}\frac{e^{\xi s} - 1}{\frac{e^{\xi s}}{\xi - k_3^Q} + \frac{1}{\xi + k_3^Q}}, \\ C =& \frac{2k_3^Q \theta_3^Q}{\xi + k_3^Q} - \frac{4\xi k_3^Q \theta_3^Q}{\{(\xi + k_3^Q)e^{\xi s} + (\xi - k_3^Q)\}(\xi + k_3^Q)},\ d_3 = e^{\xi s}\left\{\frac{(\xi + k_3^Q)e^{\xi s} + (\xi - k_3^Q)}{2\xi}\right\}^{-2}, \end{aligned}$$

where $\xi = \sqrt{k_3^{Q2} + 2\nu\sigma_3^2}$, $A_1 = \frac{1}{k_{i,1}^Q}\left(d_{i,1} - \frac{k_{i,12}^Q d_{i,2}}{k_{i,2}^Q}\right)$, $A_2 = \frac{k_{i,12}^Q d_{i,2}}{k_{i,2}(k_{i,1} - k_{i,2})}$. Addtionally, we guess that $V\left(s, x_i\right) = \left(C + D'x_i\right)\exp\left(-A_3 - b_3\lambda\right)$, where $A_3 = \frac{k_3^Q \theta_3^Q}{\sigma_3^2}\left[2\log\left\{\frac{(\xi + k_3^Q)e^{\xi s} + (\xi - k_3^Q)}{2\xi}\right\} - \left(\xi + k_3^Q\right)s\right]$. We guess that $U(s, \lambda, \nu) = \exp(-G - H\lambda)$. We apply Ito's formula to $U(s, \lambda, \nu)$, then a PDE can be derived by the no-arbitrage condition. The following ODE can be derived by applying the Feynman–Kac formula to the PDE.

$$\dot{G} = H\overline{\delta}_\nu k_3^Q \theta_3^Q,\ \ \dot{H} = -k_3^Q H + 1 - \frac{1}{2}\overline{\delta}_\nu \sigma_3^2 H^2,$$

where $G(0) = 0$, $H(0) = 0$. This ODE can be solved analytically as follows:

$$\begin{aligned} G =& \frac{k_3^Q \theta_3^Q}{\sigma_3^2}\left[2\log\left\{\frac{(\xi_2 + k_3^Q)e^{\xi_2 s} + (\xi_2 - k_3^Q)}{2\xi_2}\right\} - \left(\xi_2 + k_3^Q\right)s\right],\ \ H = \frac{1}{\sigma_3^2}\frac{e^{\xi_2 s} - 1}{\frac{e^{\xi_2 s}}{\xi_2 - k_3^Q} + \frac{1}{\xi_2 + k_3^Q}}, \\ \xi_2 :=& \sqrt{k_3^{Q2} + 2\overline{\delta}_\nu \sigma_3^2}. \end{aligned}$$

Appendix B. Correlation effect in foreign currency denominated CDS

The effect of the relationship between $\lambda_{d,t}$ and X_t can be considered in the formula(A.2). We assume that $\sigma_{x,t}$ is independent of time and constant at σ_x. The final expectation term of (A.2) is described as follows:

$$e^{-\frac{k\sigma_x^2}{8}}E^{Q_d}\left[e^{-\int_t^{t+k/4}\overline{\delta}\lambda_{d,u}du}e^{-\sigma_x\int_t^{t+k/4}dw_{x,u}^d}\ \middle|\ \mathscr{F}_t\right]. \tag{B.1}$$

Let us denote $e^{-\int_t^{t+k/4}\overline{\delta}\lambda_{d,u}du}$ as U, and $e^{-\sigma_x\int_t^{t+k/4}dw_{x,u}^d}$as V. (B.1) can be re-expressed using U and V as follows:

$$e^{-\frac{k\sigma_x^2}{8}}E^{Q_d}\left[e^{-\int_t^{t+k/4}\left(\overline{\delta}(u)\right)\lambda_{d,u}du}e^{-\sigma_x\int_t^{t+k/4}dw_{x,u}^f}\ \middle|\ \mathscr{F}_t\right] = \frac{1}{E^{Q_d}[V]}E^{Q_d}[UV] \tag{B.2}$$

$$= E^{Q_d}[U] + \frac{COV^{Q_d}(U, V)}{E^{Q_d}[V]}. \tag{B.3}$$

When there is a negative correlation between $\lambda_{d,t}$ and X_t, the correlation between U and V is also negative. The second term of (B.3) is negative. (3) is derived with the assumption that U is independent of V. Therefore, if the correlation between $\lambda_{d,t}$ and X_t is negative, the value of the foreign currency-denominated sovereign CDS is more than the value of (3).

Appendix C. Data description

This appendix provides additional details about the data used for our analysis.

1. **Sovereign CDS Spreads**. The sovereign CDS spreads in our study are obtained from IHS Markit. These CDS spreads are mid quotes for 1-, 3-, 5-, 7-, and 10-year maturities. The denominated currencies are USD and EUR.
2. **Sovereign bond yields**. The sovereign bond yields in our study are obtained from Bloomberg's fair market curves. These bond yields are mid quotes for 1-, 3-, 5-, 7-, and 10-year maturities. Since we find that Belgian bond yield data extracted from Bloomberg don't capture the observed individual bond's yield at around 1-year and 3-year maturities from June 2014 to February 2015, we calculate constant maturity Belgian bond yields at 1-year and 3-year maturity from individual Belgian bond prices by using the Svensson model (Svensson, 1994), and use these data for this period.
3. **Local Market Equity Return**. The differences between the returns of the local market equity index and the returns of the S&P500 are used, and are obtained from Bloomberg. For the core countries, we use the average returns of local equity indexes in the core countries as the returns of the local market equity index. We use OMX Helsinki Index (Finland), DAX Index (Germany), AEX Index (Netherlands), Austrian Traded Index (Austria), CAC 40 Index (France), and BEL 20 Index (Belgium). For the peripheral countries, we use the average returns of local equity indexes in the peripheral countries as the returns of the local market equity index. We use IBEX 35 Index (Spain), FTSE MIB Index (Italy), ISEQ® Index (Ireland), and PSI Geral Index (Portugal).
4. **Global Market Equity Returns**. The returns of the S&P500 index are used, and are obtained from Bloomberg.
5. **Bank CDS Spreads**. The average changes of global banks' CDS spreads are used as proxies for capital relief. The maturity of CDS spreads is 5 years. We use the average CDS spreads of the 12 largest banks dealing in derivatives (G16 banks except euro area banks). Since there is a possibility of sovereign risk impact on the euro area banks' CDS, we exclude euro area banks. These banks are Morgan Stanley, JPMorgan, Bank of America, Wells Fargo, Citigroup, Goldman Sachs, Nomura, Barclays, HSBC, Credit Suisse, Royal Bank of Scotland, and UBS. The data are obtained from Bloomberg.
6. **Purchase amount under the Securities Markets Program (SMP) of the European Central Bank (ECB)**. We use the weekly purchase amount under the Securities Markets Program by the ECB. Amounts are in billion euro as of Friday of each given week. The data are obtained from Bloomberg.
7. **Longer-term refinancing operations dummy**. The Governing Council of the ECB decided on 8 December 2011 to implement longer-term refinancing operations (LTRO). We use dummy variables to account for the announcement effect of LTRO in euro area countries between the announcement date and the first operation date on 21 December 2011.
8. **Bond Bid-Ask spread**. For the analysis of bond yields, we use bid-ask spread as a proxy for bond liquidity. We use the bonds' bid-ask price with maturity of less than 10 years at a specified time on a trading day.[34] We use the average changes of the spreads for each country group.
9. **CDS Bid-Ask spread**. For the analysis of CDS spreads, we use bid-ask spread as a proxy for CDS liquidity. To obtain consistency with the bonds' bid-ask spreads, we first convert the bid/mid/ask of CDS spreads at 5-year maturity to the hypothetical bond prices using the simple yield formula. Next, we calculate the CDS bid-ask spreads from the hypothetical bond prices, similar to the bond yields. We use the average changes of the spreads for each country group.
10. **KfW Spread**. We use the changes of the spreads between government (German) bonds and government guaranteed (KfW) agency bonds with lower liquidity but the same credit risk. We use the changes of the spreads at 1-, 5- and 10-year maturities to match the maturities of the bond spreads and the CDS spreads. These data are obtained from Bloomberg.
11. **Cross currency basis swap spreads**. The changes of cross currency basis swap spreads between the euro and the U.S. dollar are used. Market participants consider this a measure of the liquidity imbalances in currency flows between the euro and the dollar. We use the changes of the spreads at 1-, 5- and 10-year maturities to match the maturities of the bond spreads and the CDS spreads. The data are obtained from Bloomberg.

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