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Dynamics of the European sovereign bonds and the identification of crisis periods

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FINMAP –

FINANCIAL DISTORTIONS AND MACROECONOMIC
PERFORMANCE: EXPECTATIONS, CONSTRAINTS AND
INTERACTION OF AGENTS

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TITLE

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and the identification of crisis periods

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ABSTRACT

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Keywords: Sovereign bonds; CDS; heterogeneous agents

JEL Classifications: C32; C5; G15

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Dynamics of the European sovereign bonds and the identification of crisis periods¹

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We develop an empirical model of heterogeneous agents to study the dynamics of the European sovereign bonds market. Agents make use of different information from the CDS market and the historical price movements of the sovereign bonds for their trading decisions. Subject to the perceived risk, agents exhibit changing trading behaviors in high risk periods and tranquil times. As a robustness check for the ability of our model to identify crises periods we also run a generalized sup adf test as suggested in Phillips, Shi, and Yu (2015) . Our results indicate that the smooth transition regression framework may provide additional valuable information regarding the timing of crisis events.

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1. INTRODUCTION

The European sovereign bond markets went through a dramatic change during the recent global financial crisis and the Euro debt crisis. As the Euro debt crisis further unfolded, the European sovereign bond markets exhibited contrasting dynamics between core and peripheral countries. The bond yields of the core countries decreased continually while those of the peripheral countries continued to surge up to record-high levels. The different behaviors of the two categories raise questions about the effect of country-specific sovereign risks and interactions between the core and the periphery of the Euro area on sovereign debt price dynamics.

In addition to a set of standard pricing factors, this paper uses two representative countries of the core and periphery, Germany and Greece, to investigate the role of country-sovereign risk in driving the dynamics of bond markets. This is done within a heterogeneous agents framework where the first type of agents reflects arbitrageurs trading on the long-run

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relationship between the bond spread and the underlying sovereign risk differential. While the bond spread is defined as the difference between the respective bond yield and the risk-free interest rate, the sovereign risk is measured by the spread of the Credit Default Swap (CDS). As Duffie (1999) points out, excluding other costs, a theoretical no-arbitrage condition implies that the CDS spread should have the same value as the related bond spread. In the short run, however, the two spreads may deviate from each other and create profit opportunities for arbitrageurs. Instead of looking at the long-run relationship between the bond and CDS spreads the second type of agents, so-called risk traders, makes use of the simultaneous change of CDS spreads to trade the sovereign bond. The third type of agents, called chartists, trade on historical movements of bond spreads, while the fourth group of agents trade on the historical movement of the other bond market. We call these agents inter-market traders.

Our paper contributes to the growing literature of heterogeneous agents models (HAM) investigating the interactions of multiple markets. Westerhoff and Dieci (2006) develop a two-market model and evaluate the effect of the Keynes Tobin transaction tax. De Jong et al. (2009) investigate the stock markets of Hong Kong and Thailand during the Asian crisis. In addition to the typical agents of fundamentalists and chartists, they report the existence of inter-market traders whose decisions are based on foreign factors. Dieci and Westerhoff (2010) develop a HAM model of two stock markets connected by a foreign exchange market to investigate the spillover effects between the two. Huang and Chen (2014) propose a two-market model and theoretically prove the existence of market cross-correlation. Schmitt and Westerhoff (2014) calibrate a number of stylized facts of and between international stock markets based on a two-markets model. Huang and Chen (2015) examine the price dynamics of a system consisting of multiple markets. The introduction of coupling effects results in the formation of market clusters. Frijns and Zwinkels (2015) investigate the interactions between the bond and CDS spreads in the European sovereign debt markets. To our best knowledge, we are the first to investigate the European sovereign bond markets and their mutual interaction using a smooth regime-switching model. Besides the influence from the CDS to the sovereign bonds, we also investigate the time-variant substitution and spillover effects between the German and Greek sovereign bonds.

We capture the time-varying effect of different trader activity by employing CDS spreads to model the influence of high and low risk environments on sovereign debt markets. CDS spreads as an environment risk factor play a role similar to that of stock market uncertainty as studied by Connolly et al. (2005) for financial markets. The empirical analysis is based on Smooth Transition Autoregression (STAR) framework which has been employed to investigate asset pricing and expectation formation in an increasing number of applications. For instance, Reitz and Westerhoff (2007) use a STAR-GARCH model to study the behaviors of heterogeneous speculators in the commodity market. Lof (2012) applies the STAR model to estimate the HAM model using stock market data. Pierdzioch et al. (2014) study the nonlinear expectation formation among heterogeneous forecasters in the US stock market using Panel Smooth Transition Regression (PSTR). Leppin and Reitz (2014) also apply the same model of PSTR to study the changing market environment on the pricing of CDS spreads.

The estimated threshold values from our STAR estimation mark the boundary of the regimes while their interceptions with the transition variable correspond to the dates of the regime switching, suggesting the beginning or end of high and low risk periods. In this sense, the threshold dates contain information for the timing of crisis periods. In order to evaluate the accuracy of crisis identification we compare our results with the generalized sup ADF test (GSADF) as suggested by Phillips et al. (2015). To detect the origination and termination of multiple bubbles the authors apply their test to the S&P 500 over more than 140 years and manage to identify the widely known historical bubbles and crashes. In our empirical agent-based model the GSADF technique is applied to German and Greek bond spreads. It is revealed that the German sovereign bond is free of crisis events during the sample period, while the Greek sovereign bond exhibits multiple crises. We compare the threshold dates implied by our STAR estimation with the crisis beginning dates from the GSADF for the Greek sovereign bond. The threshold dates indicate that the Greek sovereign bond enters the risky period immediately after the bankruptcy of Lehman Brothers. In contrast, the GSADF does not capture the bankruptcy of Lehman Brothers. However, it still manages to identify some surging episodes within the period of the Euro debt crisis. Therefore, our estimation of STAR can provide additional information for the crisis detection and identification.

The rest of the paper is organized as follows. Section 2 presents our empirical model. Section 3 describes the data and specification of the model. Section 4 presents the estimation results. Crises identification and date-stamping are discussed in Section 5. Lastly, Section 6 concludes our paper.

2. EMPIRICAL MODEL

In this section, we develop a model for the dynamic interaction between the German (denoted as *Ge*) and Greek (*Gr*) sovereign bonds by taking into account market risk, chartist trading, interactions between bond markets and a time-varying market environment.

The yield of a sovereign bond $i = Ge$ or Gr can be decomposed into two components: a risk-free rate and a risk premium. The bond spread $BS_{i,t}$ is defined as the difference between the bond yield and the risk-free rate. Meanwhile, the sovereign CDS market trades the risk of sovereign bonds. Therefore the risk premium of the sovereign bond i at time t can be captured by the spread $CDS_{i,t}$. Theoretically, it is expected from the no-arbitrage condition that the CDS spread can fully explain the bond spread, i.e.,

$$BS_{i,t} = CDS_{i,t}.$$

Consequently, the same applies for simultaneous changes of the spreads

$$\Delta BS_{i,t} = \Delta CDS_{i,t},$$

where $\Delta BS_{i,t} = BS_{i,t} - BS_{i,t-1}$ and $\Delta CDS_{i,t} = CDS_{i,t} - CDS_{i,t-1}$. However, due to market limitations and the friction of the financial markets, the spread changes of bonds and the CDS often diverge from each other, i.e.,

$$\Delta BS_{i,t} \neq \Delta CDS_{i,t}.$$

In light of the discrepancy between $\Delta BS_{i,t}$ and $\Delta CDS_{i,t}$, it is still possible to have a long-run relationship between the two variables $BS_{i,t}$ and $CDS_{i,t}$. The long-run relationship can be captured by the error term from the cointegration relationship

$$ERR_{i,t} = \alpha_i + BS_{i,t} - \lambda_i \cdot CDS_{i,t}.$$

The first group of investors in the bond market trades with respect to the observed error terms and is called arbitrageurs. Their excess demands in market i at time t are formulated as

$$D_{a,t} = c_a \cdot ERR_{i,t-1}.$$

A negative c_a indicates that arbitrageurs believe that the error term will decline, while a positive one means that arbitrageurs expect the error term to increase further. The second group of traders, risk traders, also make use of CDS information for trading. Ideally, $BS_{i,t}$ and $CDS_{i,t}$ should move together in the same direction. The risk traders monitor the change of CDS, $\Delta CDS_{i,t}$, and trade simultaneously. Their excess demands are

$$D_{r,t} = c_r \cdot \Delta CDS_{i,t}.$$

Other investors in the debt markets make use of information other than CDS for their trading. One of the groups of traders consists of chartists whose trading decision is based on past spread changes $\Delta BS_{i,t-k}$, where $k = 1, 2, \dots$ is the lag order. Excess demands of chartists in market i are

$$D_{c,t} = \sum_k c_{c,k} \cdot \Delta BS_{i,t-k}.$$

Besides that, in the context of market integration, fluctuations in one market may affect the movements of other markets. In the extreme case, these inter-markets interactions exhibit themselves as crises spillovers. While investigating the contagion during the Asian crisis, De Jong et al. (2009) find that the past returns of Hong Kong's and Thailand's stock markets affect the returns of the other respective market. Therefore, a fourth group of so-called inter-market traders is introduced to take the past spread changes of the other sovereign bond j , $\Delta BS_{j,t-k}$ into account. Excess demands of inter-market traders in a market i at time t are

$$D_{in,t} = \sum_k c_{in,k} \cdot \Delta BS_{j,t-k}.$$

Adding up the excess demands of the four trader groups leads to the linear model for the bond spread change

$$\Delta BS_{i,t} = X'_{i,t} \beta_0,$$

where vector $X_{i,t}$ contains the past error term $ERR_{i,t-1}$, the current spread changes of the CDS i , the past spread changes of bond i and j . The vector β_0 contains the respective coefficients.

In order to allow the trading behavior to be different in highly volatile periods as found in Connolly et al. (2005) we model the structural coefficients in a time-varying fashion by introducing a smooth transition between the two extreme regimes

$$\Delta BS_{i,t} = X'_{i,t}\beta_0 + (X'_{i,t}\beta_1) \cdot g(q_t; \gamma, c), \quad (1)$$

where $g(q_t; \gamma, c)$ determines the transition between the two different regimes. The transition function may be either logistic or exponential and is defined as

$$g(q_t; \gamma, c) = \begin{cases} \left(1 + \exp\left(-\gamma \prod_{r=1}^R (q_t - c_r)\right)\right)^{-1}, & \text{logistic form,} \\ 1 - \exp\left(-\gamma (q_t - c)^2\right), & \text{exponential form,} \end{cases}$$

where c_r or c is one of R location parameters, $R = 1$ or 2 ; γ is a transition parameter measuring the speed of transition between regimes whereas q_t is the transition variable. The choice of the transition function will be determined by the econometric specification in the sequel. For either form of the transition function $g(q_t; \gamma, c)$ is bounded between 0 and 1, resulting in regression coefficients between β_0 and $\beta_0 + \beta_1$. The parameter R determines the specific form of the logistic transition function. For $R = 1$, the logistic form $g(q_t; \gamma, c)$ is a monotonous function of the transition variable q_t , whereas for $R = 2$, $g(q_t; \gamma, c)$ is symmetric around the location point $(c_1 + c_2)/2$. The coefficient γ determines the speed of transition to include the corner solutions β_0 and $\beta_0 + \beta_1$ for $\gamma \rightarrow \infty$. It is also noted that for $\gamma \rightarrow 0$, the solution collapses to $\beta_0 + \frac{1}{2}\beta_1$ (logistic form) or β_0 (exponential form). The transition variable q_t of this model measures the environment of the market with the candidate variables of $CDS_{i,t}$ or $CDS_{j,t}$ indicating the risk.

3. DATA AND MODEL SPECIFICATION

3.1. Data

We obtain daily CDS data for 10-year German and Greek sovereign bonds through Markit. The US dollar CDS contracts are chosen due to their better liquidity. The sample period is from 01/01/2007 to 12/31/2011, due to massive outlier problems in 2012. In the extreme case the Greek CDS spread exceeds 10,000 basis points. Data thereafter is unavailable. We also collect the daily risk-free interest rate and the yields of 10-year German and Greek sovereign bonds through Datastream. The risk-free interest rate r_t^f is measured by the interest rate swaps on EURIBOR with a 10-year maturity. The difference between

the bond yield and the risk-free interest rate is our bond spread $BS_{i,t}$. In this paper, the bond spread and the CDS spread are denoted in percentages. Fig. 1 plots the time series of the spreads of the German and Greek sovereign bonds as well as their corresponding CDS spreads. During the sample period, only the spread of German sovereign bond exhibits a declining trend while the rest of the three time series all have increasing trends, especially for the Greek CDS. Table 1 lists the summary statistics for the spread changes of the sovereign bonds and the corresponding CDS. For Germany, the mean values of spread changes in bonds as well as the CDS are close to zero. In contrast, the mean values of the Greek counterparts are positive and non-negligible, indicating an increasing trend in level. Similarly, in terms of standard deviation, skewness, excess kurtosis and Jarque Bera statistics, the Greek variables have larger values than their German counterparts and exhibit stronger non-normality behaviors. Lastly, the unit root tests indicate that the four variables are stationary³.

We apply the Johansen cointegration test to determine the cointegration relationship between $BS_{i,t}$ and $CDS_{i,t}$. No cointegration relationship is found between BS_{Ge} and CDS_{Ge} while one is detected between BS_{Gr} and CDS_{Gr} . Palladini and Portes (2011) also report the existence of a cointegration relationship for the Greek sovereign bond. Hence, no error correction is included in the estimation of the German variable ΔBS_{Ge} . Meanwhile, in the estimation of Greek variable ΔBS_{Gr} , we will include the error correction term as

$$ERR_{Gr,t} = -5.341 + BS_{Gr,t} - 0.675 \cdot CDS_{i,t}.$$

3.2. Model Specification

The aim of this subsection is to investigate nonlinearity in the daily spreads of sovereign bonds with the appropriate model specifications. To cope with the heteroskedasticity in the changes of bond spreads, we apply the STR-GARCH procedure originally proposed by Lundbergh and Terasvirta (1998). Our empirical model consists of a mean equation and a standard GARCH(1,1) volatility equation. The mean equation contains a smooth transition component:

$$\Delta BS_{i,t} = X'_{i,t}\beta_0 + (X'_{i,t}\beta_1) \cdot g(q_t; \gamma, c) + \varepsilon_{i,t}, \quad (2)$$

³For the four level time series, BS_{Ge} , BS_{Gr} , CDS_{Ge} and CDS_{Gr} , unit root tests already suggest that all these time series are I(1) processes.

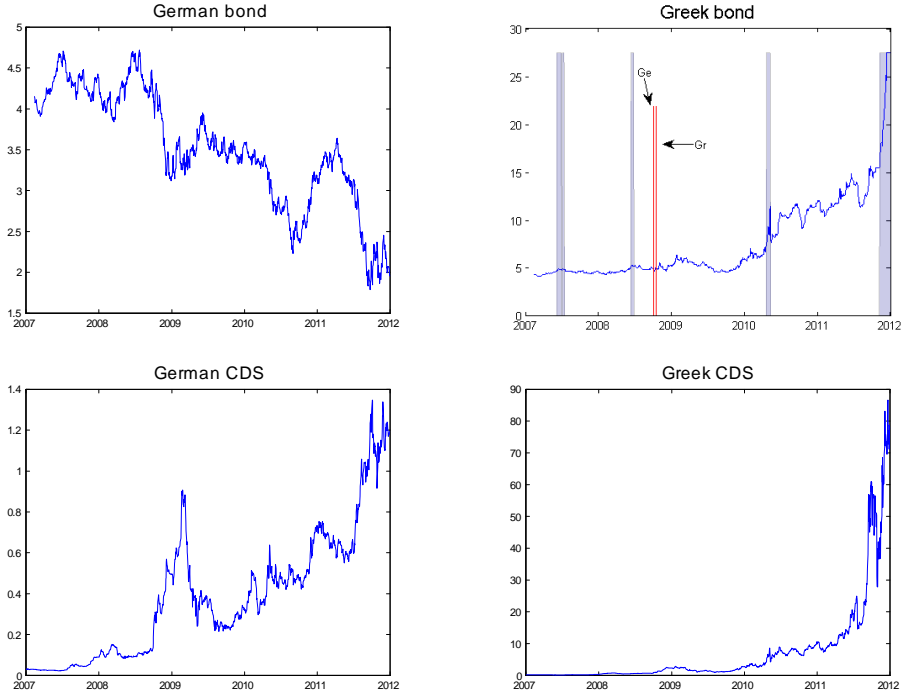


FIG. 1 Spreads of German and Greek sovereign bonds (in percentage) and the corresponding CDS spreads (in percentage). The grey area in the Greek bond highlights the explosive periods suggested by the GSADF test. The two vertical lines indicate the threshold dates from the estimation using German and Greek CDS.

TABLE 1
Summary statistics of spread changes of sovereign bonds and CDS.

	Germany		Greece	
	ΔBS_{Ge}	ΔCDS_{Ge}	ΔBS_{Gr}	ΔCDS_{Gr}
Mean	-0.000	0.001	0.019	0.054
Standard deviation	0.028	0.019	0.206	4.531
Skewness	-0.067	0.046	-0.448	-1.418
Excess Kurtosis	6.746	8.138	94.127	254.999
JB	2471.516	3596.476	481061.500	3530730.000
DF	-150.517***	-22.402***	-37.000***	-9.570***

Note: JB is the Jarque Bera test statistic. DF is the Dickey-Fuller test statistic with the optimal lag order based on the SIC information criterion. *, ** and *** denote significance at the 10%, 5% and 1% level.

$$g(q_t; \gamma, c) = \begin{cases} \left(1 + \exp\left(-\gamma \prod_{r=1}^R (q_t - c_r)\right)\right)^{-1}, & \text{logistic form;} \\ 1 - \exp\left(-\gamma (q_t - c)^2\right), & \text{exponential form.} \end{cases} \quad (3)$$

$$h_{i,t} = \alpha_0 + \alpha_1 \varepsilon_{i,t-1}^2 + \alpha_2 h_{i,t-1}, \quad (4)$$

where $\varepsilon_{i,t} = \nu_t \cdot \sqrt{h_{i,t}}$ and $\nu_t \sim iidN(0, 1)$. The parameter vector β_0 measures the time-invariant linear component impact from the explanatory variables while the parameter vector β_1 denotes the potential time-variant effect of the nonlinear component arising from the transition function $g(q_t; \gamma, c)$. The transition parameter γ is a slope parameter measuring the transition speed between the regimes. The location parameter c_r or c determines the threshold of the transition variable or the boundary of the regimes.

In view of the potential simultaneous bias between $\Delta BS_{i,t}$ and $\Delta CDS_{i,t}$, we apply instrumental variables of lagged $\Delta CDS_{i,t}$ with lag order up to 8 for the variable of $\Delta CDS_{i,t}$. After that, we follow the procedure of Terasvirta (1994) to determine the model specification. First, we use the Akaike Information criterion (AIC) and the Bayes information criterion (BIC) to choose the appropriate lag order k of the linear models. For Germany, AIC and BIC suggest different values: $k = 2$ and $k = 1$ respectively. For the sake of parsimony, we follow BIC and choose $k = 1$. Similarly, for Greece, AIC and BIC also suggest different values, $k = 9$ and $k = 1$ respectively. Again, we follow BIC and set $k = 1$. Second, we test linearity against STAR alternative using the lag order k for individual German and Greek bonds. To perform this test, we conduct the following auxiliary regression based on the Taylor approximation around $\gamma = 0$:

$$\Delta BS_{i,t} = X'_{i,t} \beta_0^* + (X'_{i,t} \beta_1^*) \cdot q_t + (X'_{i,t} \beta_2^*) \cdot q_t^2 + (X'_{i,t} \beta_3^*) \cdot q_t^3 + \varepsilon_{i,t},$$

The nonlinearity test can also determine the functional form of the transition function as well as the order R by testing $H_{03}^* : \beta_3^* = 0$, $H_{02}^* : \beta_2^* = 0 | \beta_3^* = 0$ and $H_{01}^* : \beta_1^* = 0 | \beta_2^* = \beta_3^* = 0$. Following Terasvirta (1998), in case of strongest rejection of the hypotheses H_{01}^* or H_{03}^* , the logistic transition function with $R = 1$ is chosen. If the rejection of the hypothesis H_{02}^* is the strongest, either logistic transition function with $R = 2$ or exponential form is chosen. In practice, usually the logistic form is chosen first followed by a test for $c_1 = c_2$ after estimation. If $c_1 = c_2$ cannot be rejected, the logistic form is valid. Otherwise, the exponential form is preferred for the estimation. For each sovereign bond, we evaluate the

CDS spread for Germany and Greece as a transition variable. For both sovereign bonds the linearity is rejected and the transition function is logistic with $R = 1$ for all the cases.

4. ESTIMATION RESULTS

We use Eviews programming for maximum likelihood estimations. As the assumption of conditional normality is not satisfied, a heteroskedasticity consistent covariance is applied to calculate robust parameter estimates. Following Terasvirta (1994), the estimation is carried out by first fixing the transition parameter γ followed by a completed estimation. Table 2 shows the estimation results for the spread changes of the German sovereign bond, ΔBS_{Ge} . Using the German CDS CDS_{Ge} as a transition variable, the nonlinear time-variant part is statistically insignificant. For the linear part, the coefficient of ΔCDS_{Ge} is statistically significant but negative, contradictory to the expectations of the theory. Risk traders trade in a way contrary to the simultaneous movement of the CDS. In terms of past variables, $\Delta BS_{Ge,t-1}$ is statistically significant with a negative value, indicating that chartists assume a mean-reversion for the German sovereign bond. The insignificant nonlinear part can be understood from Fig. 2, which plots the transition threshold values and the corresponding transition function. As the values of the transition variable are below the threshold value 2.574, the transition function is negligible with values at the order of 10^{-4} . On the other hand, using the Greek CDS CDS_{Gr} as a transition variable, $\Delta BS_{Ge,t-1}$ of the linear part retains its significantly negative coefficient while the coefficient of ΔCDS_{Ge} becomes insignificant. Notice that the past spread change of Greece $\Delta BS_{Gr,t-1}$ turns out to be significantly negative, indicating the existence of inter-market traders and a substitution effect between the two sovereign bonds. An increase of the spread of the Greek sovereign bond is followed by a decrease of the spread of the German sovereign bond. In addition, the nonlinear part becomes significant using CDS_{Gr} as a transition variable. $\Delta BS_{Gr,t-1}$ has a nonlinear positive coefficient, indicating a spillover from the Greek market to the spread of German sovereign bonds in high-risk periods. The spillover effect cancels out the substitution effect resulting in a seemingly zero net effect from $\Delta BS_{Gr,t-1}$ or the inactivity of inter-market traders. The high-risk periods are 11/17/2008 to 03/20/2009 and after 11/13/2009 when the values of the transition variable are larger than the threshold value 1.640, as shown in Fig. 2. The period during 11/17/2008 and 03/20/2009 immediately

follows the peak of the 2008 global financial crisis when several major institutions either failed or were subject to takeovers by governments. For example, Lehman Brothers went bankrupt on 09/15/2008. The global financial crisis severely impacted the confidence of markets, including the European sovereign bond markets. The period after 11/13/2009 coincides with the outbreak of the European debt crisis.

Table 3 displays the estimation results for the spread changes of Greek sovereign bonds, ΔBS_{Gr} . The nonlinear time-variant part is significant for the transition variables using either CDS_{Ge} or CDS_{Gr} . We first look at the estimation results using CDS_{Ge} as the transition variable. The coefficient $ERR_{Gr,t-1}$ for the linear component is significantly negative, indicating an error correction of BS_{Gr} to its long-run relationship with its CDS_{Gr} . Arbitrageurs are active in the Greek bond market but the error correction is very weak, only 0.9% per trading day. Regarding the effect of inter-market interaction from the German sovereign bond, the coefficient of ΔBS_{Ge} is significantly negative. This suggests a substitution effect from the German sovereign bond to the Greek sovereign bond and the existence of inter-market traders. Chartists are also observed in the Greek bond market. They follow a positive-feedback process or momentum trading as $\Delta BS_{Gr,t-1}$ has a significantly positive coefficient. For the nonlinear component, as shown in Fig. 3, the threshold value 0.175 intersects with the CDS_{Ge} at the threshold date 10/01/2008 after which the CDS_{Ge} is larger than the threshold value. The implied threshold date is two weeks after the bankruptcy of Lehman Brothers. Since the transition parameter γ is negative, the effect of the nonlinear component diminishes when CDS_{Ge} is large, exhibited by the transition function. The linear component dominates the Greek bond market in the high risk period. The coefficient $ERR_{Gr,t-1}$ of the nonlinear component is significant but positive, indicating an amplified deviation from the long run relationship with CDS_{Gr} . In the normal time when CDS_{Ge} is below the threshold value, the net effect of arbitrageurs is negligible or very small when we take into account the coefficients of $ERR_{Gr,t-1}$ of both the linear and nonlinear components and the values of transition function. Inter-market traders do not have a time-varying behavior as the coefficient of $\Delta BS_{Ge,t-1}$ is insignificant. They always transmit the substitution effect from the German to the Greek market. For chartists, the coefficient of $\Delta BS_{Gr,t-1}$ of the nonlinear component is still significant but with a negative value, indicating a mean-reversion behavior of chartists. As the coefficient of the nonlinear component

has a much larger magnitude than that of the linear component, overall, chartists follow a mean-reversion belief in normal times and a positive-feedback one in high risk periods. Using CDS_{Gr} as a transition variable, the estimation results are similar to the ones using CDS_{Ge} . The implied threshold date is 10/16/2008, close to the one suggested by CDS_{Ge} . As shown in Fig. 3, the transition function based on CDS_{Gr} switches more abruptly due to the large values of CDS_{Gr} . In our estimation for the German and Greek sovereign bonds, we also conduct likelihood ratio tests for the transition parameter λ . The tests are highly significant for all cases, further confirming the existing of the nonlinear component.

TABLE 2
Parameter estimates of STAR-GARCH models for spread changes of German sovereign bond.

Germany		
	$q_t = CDS_{Ge}$	$q_t = CDS_{Gr}$
ΔCDS_{Ge}	-0.386* (0.200)	0.298 (0.620)
$\Delta BS_{Ge,t-1}$	-0.285*** (0.036)	-0.188*** (0.055)
$\Delta BS_{Gr,t-1}$	-0.005 (0.005)	-0.137*** (0.051)
Below for the time-variant part		
γ	7.207 (13.388)	3.086 (2.684)
c	2.574 (3312.131)	1.640*** (0.386)
ΔCDS_{Ge}	-9341.193 ($2.2 \cdot 10^8$)	-0.970 (0.708)
$\Delta BS_{Ge,t-1}$	6006.570 ($1.4 \cdot 10^8$)	-0.082 (0.076)
$\Delta BS_{Gr,t-1}$	46.366 ($1.1 \cdot 10^6$)	0.136*** (0.052)
GARCH component		
α_0	0.000 (0.000)	0.000*** (0.000)
α_1	0.105*** (0.023)	0.136*** (0.023)
α_2	0.898*** (0.019)	0.863*** (0.021)
LLh	3059.720	3051.504
LRT	8.900***	17.666***

Note: The sample contains daily observations from January 2007 to December 2011. Standard errors are in the parentheses. *, **, and *** denote significance at 10%, 5% and 1%. LLh is the log likelihood value and LRT the likelihood ratio test statistic with restriction $\gamma = 0$.

TABLE 3

Parameter estimates of STAR-GARCH models for spread changes of Greek sovereign bond.

Greece		
	$q_t = CDS_{Ge}$	$q_t = CDS_{Gr}$
$ERR_{Gr,t-1}$	-0.009** (0.004)	-0.009** (0.004)
ΔCDS_{Gr}	-0.002 (0.004)	-0.002 (0.004)
$\Delta BS_{Ge,t-1}$	-0.354** (0.156)	-0.362** (0.166)
$\Delta BS_{Gr,t-1}$	0.228*** (0.077)	0.222** (0.069)
Below for the time-variant part		
γ	-12.230 (9.381)	-2.252 (1.935)
c	0.175* (0.092)	0.967** (0.487)
$ERR_{Gr,t-1}$	0.011* (0.006)	0.011* (0.006)
ΔCDS_{Gr}	-0.056 (0.126)	-0.079 (0.118)
$\Delta BS_{Ge,t-1}$	0.359 (0.263)	0.352 (0.258)
$\Delta BS_{Gr,t-1}$	-0.699** (0.337)	-0.654** (0.299)
GARCH component		
α_0	0.000 (0.000)	0.000 (0.000)
α_1	0.216*** (0.037)	0.218*** (0.038)
α_2	0.833*** (0.021)	0.831*** (0.022)
LLh	1605.736	1605.083
LRT	83.416***	82.110***

Note: The sample contains daily observations from January 2007 to December 2011. Standard errors are in the parentheses. *, **, and *** denote significance at 10%, 5% and 1%. LLh is the log likelihood value and LRT the likelihood ratio test statistic with restriction $\gamma = 0$.

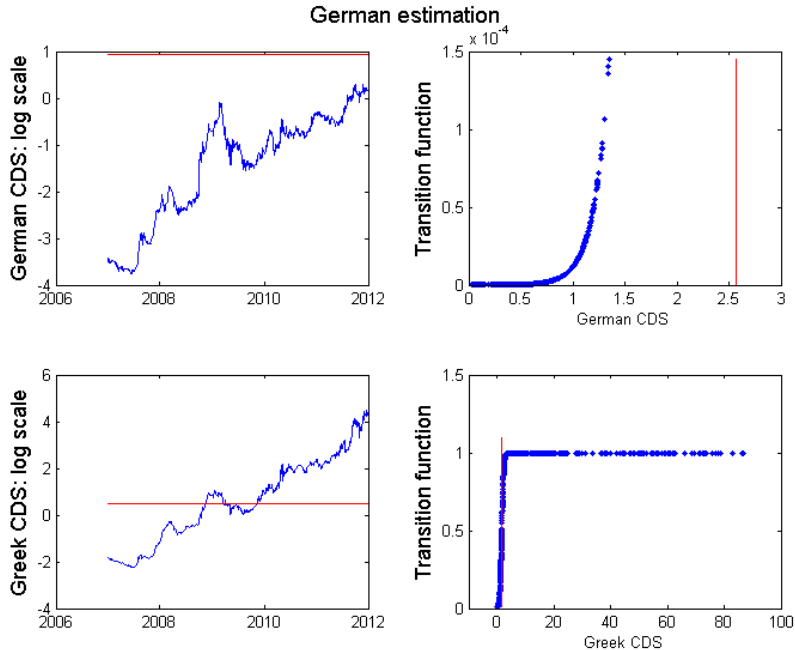


FIG. 2 Transition thresholds and transition functions for the spread changes of German sovereign bond. The red horizontal and vertical lines denote the threshold values. The figures of row one use the German CDS as a transition variable while those of row two use the Greek CDS.

To summarize, our estimation results suggest the existence of risk traders, chartists and inter-market traders in the German sovereign bond market. Chartists have a mean-reversion belief. Inter-market traders are responsible for the substitution effect in low-risk periods. The contribution of inter-market traders to the substitution effect is weakened in the high-risk period as they also impose the spillover effect from the Greek sovereign debt market. On the other hand, risk traders in the Greek market are inactive while arbitrageurs are observed. Arbitrageurs correct the error of the long-run relationship between the sovereign bond and the CDS, especially in the high-risk period. Chartists follow a mean-reversion belief in normal times and a positive-feedback one in the high-risk period. Inter-market traders are responsible for the substitution effect from the German sovereign bond market.

5. CRISES DETECTION

In this section we apply the GSADF technique of Phillips et al. (2015) to detect any potential crises/explosive events in the German and Greek sovereign bonds. The GSADF

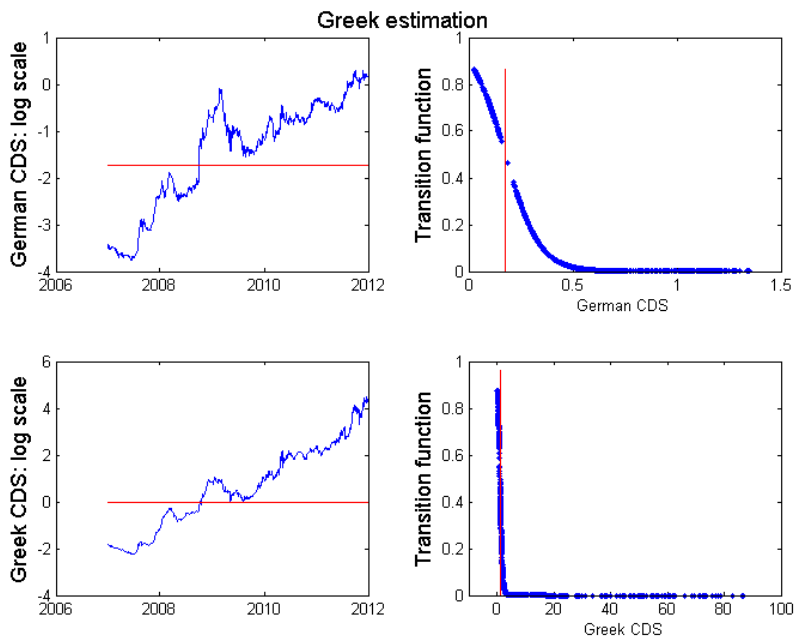


FIG. 3 Transition thresholds and transition functions for the spread changes of the Greek sovereign bond. The red horizontal and vertical lines denote the threshold values. Figures of row one use the German CDS as a transition variable while those of row two use the Greek CDS.

is designed to detect the existence of multiple crises or bubble formation with an explosive behavior for a time series using the classic wisdom of ADF unit root test. For a given time series y_t , the null hypothesis has the weak intercept form as

$$y_t = dT^{-\eta} + \theta y_{t-1} + \varepsilon_t, \varepsilon_t \sim iid(0, \sigma^2), \theta = 1,$$

where d is a constant, T is the sample size of the time series and the localizing parameter $\eta > 0.5$ makes y_t a process following a pure random walk. The crisis detection involves a rolling time window ADF test starting from the r_1 fraction of the total sample T and ending at r_2 fraction, where $r_2 = r_1 + r_w$ and $r_w > r_0$ is the fractional window size. The empirical regression model can be written as

$$\Delta y_t = \alpha_{r_1, r_2} + \beta_{r_1, r_2} y_{t-1} + \sum_{i=1}^k \psi_{r_1, r_2}^i \Delta y_{t-i} + \varepsilon_t,$$

where k is the (transient) lag order. The number of observations in the regression is the window size $T_w = \lfloor Tr_w \rfloor$, where $\lfloor \cdot \rfloor$ is the floor function. The ADF statistic based on this regression is denoted by $ADF_{r_1}^{r_2}$. The statistic for the whole time series, $GSADF$ is the largest $ADF_{r_1}^{r_2}$ over all feasible ranges of r_1 and r_2 . It is denoted as

$$GSADF(r_0) = \sup_{r_2 \in [r_0, 1], r_1 \in [0, r_2 - r_0]} (ADF_{r_1}^{r_2}).$$

Following the recommendations in Phillips et al. (2015), we set $r_0 = 0.01 + 1.8/\sqrt{T}$, $d = \eta = 1$ and use the Eviews add-in developed by Caspi (2013) to detect any crisis in the German and Greek sovereign bonds during the sample period. As shown in Table 4, no explosive event is detected in the spread of German sovereign bonds during the sample period while Greek sovereign bonds exhibit multiple potentially explosive events. There are four periods with explosive increments which are shown in Table 5 and highlighted in Fig. 1. Note that the detected explosive periods do not have exact overlapping with the threshold dates suggested from our regression of ΔBS_{Gr} . The GSADF procedure indicates that the starting date of the explosive period in 2008 is 06/11/2008, three months before the bankruptcy of Lehman Brothers. The threshold dates suggested by CDS_{Ge} and CDS_{Gr} are 10/01/2008 and 10/16/2008 respectively. As shown in Fig. 1, the spread of Greek sovereign bond worsens after the bankruptcy of Lehman Brothers, with BS_{Gr} increasing by 30% from 4.89% at 09/15/2008 to 6.38% at 01/26/2009. After that, BS_{Gr} still remains elevated and

TABLE 4
Explosive process detection for spreads of German and Greek sovereign bonds.

	Germany	Greece
	BS_{Ge}	BS_{Gr}
GSADF	1.944	7.345***
95% level	2.526	2.526
p-value	0.230	0.000

Note: 95% level is the 95% critical values of the GSADF test. *, ** and *** denote significance at the 10%, 5% and 1% level.

TABLE 5
Periods of explosive increment in the spreads of Greek sovereign bonds identified by GSADF.

	BS_{Gr}	Threshold dates from regression of ΔBS_{Gr}
1	06/07/2007-07/13/2007	
2	06/11/2008-06/25/2008	Threshold dates are 10/01/2008 (using German CDS) and 10/16/2008 (using Greek CDS)
3	04/19/2010-05/07/2010	
4	11/04/2011-12/30/2011	

then rapidly deteriorates at the end of 2009 when with the outbreak of the Euro debt crisis. Although GSADF can still capture some explosive episodes in the sample periods, those events are sub-events of the crises. GSADF does not manage to identify the critical event of Lehman Brothers which marks the beginning of the deterioration of the Greek sovereign bond.

Our STAR regression on ΔBS_{Gr} has already shown that $ERR_{Gr,t-1}$ has an overall negative coefficient for the error correction, implying a certain comovement between BS_{Gr} and CDS_{Gr} . The better fitting of the coincidence of threshold dates suggested by CDS_{Gr} and CDS_{Ge} for the deterioration of BS_{Gr} immediately after the bankruptcy of Lehman Brothers in 2008 further evidences the predictive power of CDS for the crisis of the sovereign bond. From the perspective of crisis detection, our result highlights the value and potential of using additional measures such as CDS to improve the accuracy of crisis detection of GSADF.

6. CONCLUSION

We develop an empirical agent-based model to investigate the dynamics of German and Greek sovereign bond markets. Traders in the markets make use of CDS information as well as the historical movement of the domestic and foreign government bonds. There is no cointegration relationship between the German sovereign bond and its CDS while a long-run relationship is found for the Greek variables. The missing long run relationship between the German bond spread and its CDS indicates a certain friction or limitation of the markets. Although a long run relationship is found in Greek markets, market friction still exists as the CDS spread is not equal to the bond spread. The existence of inter-market traders in the European sovereign bond implies a certain integration of the European markets. This market integration can be further evidenced by the capability of both German and Greek CDS in affecting the sovereign bonds, especially in the Greek sovereign bond market.

Using CDS spreads as transition variables, our smooth transition regression shows that agents vary their behaviors in periods of high risk and normal times. In the German sovereign bond market, risk traders are found only in the case of using the German CDS as a transition variable. They seem to trade in a way contrary to the simultaneous change of the CDS, contradicting the theoretical priors. Their trading aligns with the simultaneous CDS change when we use the Greek CDS as a transition variable, but the coefficient is insignificant. Chartists always have a mean-reversion belief. Inter-market traders behave differently in different periods. Their trading using information from the Greek bond market creates a substitution effect in the normal time. The substitution effect is weakened in the high risk period as the inter-market traders meanwhile transmit the spillover effect from the Greek sovereign debt market. In the Greek sovereign bond market, arbitrageurs are active while risk traders become inactive. Arbitrageurs correct the error terms towards the long run relationship, especially in the high risk periods. Chartists have a mean-reversion belief in the normal time but switch to a positive-feedback one in the high risk period. Inter-market traders always contribute to the substitution effect from the German sovereign bond market. As the German sovereign bond spread continues to decrease, trading of inter-market traders has an effect of driving up the Greek sovereign bond spread.

In order to test the ability of the smooth transition regression approach in identifying crisis periods in financial markets we also apply the GSADF technique to the two sovereign bonds. Comparing the results from the different frameworks, we find that the identified starting dates of the crises are different from the threshold dates from our STAR regression. Threshold dates implied by both German and Greek CDS suggest that the Greek sovereign bond enters the high-risk periods immediately after the bankruptcy of Lehman Brothers. In contrast, the GSADF procedure does not capture the event of Lehman Brothers but only identifies the surging episodes within the crisis period, which indicates the limitation of GSADF in identifying the crisis formation. In this sense, the CDS provides additional information to GSADF in detecting the crisis in the sovereign bonds.

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