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On the Reliability of a Credit Default Swap Contract during the EMU Debt Crisis*

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Abstract

The reliability of the credit default swap market was questioned repeatedly during the EMU debt crisis. This article examines whether this development influenced sovereign EMU CDS prices in general. We regress the CDS market price on a model risk neutral CDS price obtained from an adopted reduced form valuation model in the 2009–2013 period. We look for a breakpoint in the single-equation and multi-equation econometric models in order to show the changes in relationships between the CDS market and model prices. Our results differ according to the risk profile of a country. We find that in the case of riskier countries, the relationship between the market and model price changed when market participants started to question the ability of CDS contracts to protect their buyers. Specifically, it weakened after the change. In the case of less risky countries, the change happened earlier and the effect of a weakened relationship is not observed.

1. Introduction

A credit default swap (CDS) is a derivative contract where one counterparty (CDS buyer) agrees to pay regular payments (CDS spread or CDS premium) to another counterparty (CDS seller) either until maturity of the contract or until the credit event of a reference entity, whichever comes sooner. The CDS seller agrees to compensate a loss incurred by the buyer in the case of a credit event before CDS maturity. The compensation usually corresponds to the difference between a nominal amount of some underlying asset issued by the reference entity and its recovery amount. This implies that, for the buyer, the CDS represents a form of insurance against default of the underlying asset and the seller acts asan insurer.

Recent developments in Europe have brought about discussions about sovereign default and financial markets have witnessed how European authorities act under the pressure of a looming default. Also, the terms and conditions of a CDS contract were tested during the European debt crisis and did not pass the test. In this article, we are looking at the proper functioning of a CDS contract and, by using market data, we attempt to verify whether it worsened during the European debt crisis. In the case that it is confirmed, a more serious discussion about CDS contracts needs to be initiated. Not only the terms and conditions should be rephrased, but also the approach of supranational organizations to sovereign default should be made more transparent.

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Specifically, we analyze whether and how recent developments in Europe influenced sovereign EMU CDS market prices. We evaluate the CDS model price using the standard probabilistic CDS pricing model of Hull and White (2000) and compare it with the CDS market price to see whether there was any apparent change in this relationship between 2009 and 2013. Our main hypothesis is that the relationship relaxed at the end of 2011, when the initial uncertainties about the Greek debt restructuring and CDS settlement trigger appeared, i.e. the CDS market price is not driven by the model price to the extent it used to be and investors' trust in the instrument decreased. The change is detected using a break-point analysis and the relationship between the market and the CDS model price is estimated using seemingly unrelated regressions—for five and ten years' maturity of all variables.

The article is divided into eight sections. Section 2 presents our motivation in detail, analyzing the historical context. Section 3 provides a review of the available literature in this field. In Section 4, we present all data needed for a consecutive analysis. Our empirical analysis is performed in the next three sections. In Section 5, we evaluate the CDS model price using a basic no-arbitrage model. In Section 6, we estimate single equation regressions and look for breakpoints in the regressions. In Section 7, the main model is estimated using seemingly unrelated regressions. Section 8 provides policy recommendations in the context of our results. Section 9 concludes the paper and discusses possibilities of further research.

2. Historical Context and Motivation

The European sovereign debt crisis brought forthan important question, which is studied in detail in this paper—the basic purpose of CDSs was questioned. First, while Greece was gradually heading towards default, the definition of the credit event[1] that triggers CDS early settlement caused doubts (Reuters, 2011; Bloomberg, 2012a). After that, when Greek CDSs were finally settled, the fact that Greek CDS holders were compensated for their losses was only a matter of fortunate coincidence and pointed to incorrect formulation of the CDS terms and conditions (IMF, 2013).

The Greek difficulties were to be solved by, among other things, partial restructuring of the country's bonds. This restructuring basically consisted of lengthening their maturity and lowering their coupon. The main Greek bond holders were addressed with the terms of the restructuring and they were asked to agree to its voluntary basis. If this restructuring was voluntary and not binding for all bond holders, it would not trigger CDS settlement according to the ISDA (International Swaps and Derivatives Association) EMEA Determinations Committee, which is responsible for the decision on the occurrence of a credit event (ISDA, 2012a). As a result, Greek bond investors that agreed to the restructuring and that bought protection against Greek bonds in their possession via CDSs would not be compensated for their losses. They would continue to pay for the protection and hold the CDSs, the maturity of which would no longer match the maturity of the new Greek bonds.

[1] A credit event is defined as at least one of the following: bankruptcy, failure to make a principal or interest payment, obligation acceleration, obligation default, repudiation/moratorium (for sovereign borrowers) or restructuring. All these events are referred to as a default.

In February 2012, Greece inserted a collective action clause (CAC) into the existing bonds' terms and conditions. The retroactive insertion of the CAC itself was perceived as a default by some market participants. For example, Standard & Poor's downgraded these bonds to SD—selective default—arguing that "the issuer's unilateral change of the original terms and conditions ofan obligation may be viewed as a de facto restructuring and thus a default by S&P's published definition" (Standard & Poor's, 2012). By contrast, on 1 March 2012, the ISDA EMEA Determinations Committee released a statement that a credit event on Greek bonds had not yet occurred (ISDA, 2012b).

Following negotiations with investors' representatives, Greece finally accomplished that on 9 March 2012 85.8% of Greek debt holders voluntarily accepted the restructuring scheme and exchange of their bonds.[2] This restructuring participation rate enabled Greece to activate the CAC, which also forced the remaining investors to participate in the restructuring. In response, the ISDA EMEA Determination Committee announced a restructuring credit event and early CDS settlement was triggered (ISDA, 2012c).

This persistent period of instability preceding the Greek default was filled with uncertainty and speculation about possibilities that, with European and IMF bailout packages and smart and soft formulation of actual debt restructuring, CDS payment could not be triggered at all in the end (see, for example, Reuters, 2011, or Financial Times, 2012).

Another negative surprise appeared when CDS contracts were settled. At the time of CDS settlement, when investors were expected to hand in Greek bonds, old bonds had already been exchanged for the new package of bonds (a combination of low-risk notes issued by the European Financial and Stability Fund and new, restructured Greek bonds). The CDS settlement price was then determined based on the new Greek bonds' value, i.e. it was dependent only on the new bond value and it did not take into account the structure and value of the restructuring package. Had the structure of the package or the price of the new bonds been different, CDS investors would have either ended up with a loss or gain on the transaction.[3] Considering the fact that this was the biggest sovereign debt restructuring in history, where EUR 200 billion of Greek bonds were exchanged, that was a very fortunate coincidence. Conversely, investors in the CDS of SNS Reaal NV, a Dutch bank that was nationalized in February 2013, were not so lucky. The principle of the CDS settle-

[2] The participation rate among investors was 95.7% and investors tendered 85.8% of sovereign bonds governed by Greek law (Bloomberg, 2012b).

[3] Under the restructuring scheme, for every 100 Greek bonds, bondholders received 15 low-risk notes issued by the European Financial and Stability Fund (EFSF) worth 100% of the bonds' value and 31.5 new Greek bonds worth about 22% of the bonds' value. The total value of the restructuring package was 15 * 100% + + 31.5 * 22% = 21.9, i.e. a loss of 78.1% on bonds. The payout (compensation) on the CDS was set to 78.5%, which more or less covered the loss on bonds. If, for example, the portion of EFSF bonds had been higher, the CDS payout would have been the same, as it was dependent only on the price of the new Greek bonds and the total outcome for the investor would have been positive. Or, imagine a case with no EFSF bonds and only 31.5 new Greek bonds, but with the new bonds having a shorter maturity and some other favourable terms that bring the price to around 100%. The payout on the CDS would then be zero and investors would not be compensated for the loss incurred when exchanging 100 old bonds for 31.5 new bonds.

ment was similar to the Greek case, but the payout on the CDSs covered only 4.5% of their losses.

There are two indicators that reflect the functioning of the CDS markets: first, if a loss onan underlying asset triggers CDS settlement and, second, if the CDS settlement is triggered, whether investors are fully compensated for their losses. Both of these indicators pointed to malfunctioning of the markets during the EU debt crisis. Our aim is to evaluate the impact of this development on the market prices of CDS.

3. Literature Overview

To be able to compare the model and market price of a CDS, we used the reduced form CDS valuation model. The reduced form or intensity-based model defines default using the hazard rate or default probability function. The model was introduced by Jarrow and Turnbull (1995) and Duffie (1999). In this article, we use the version presented by Hull and White (2000), who apply the theory to CDSs. A CDS is priced based on a default probability function, which is extracted from bond yields. Parity of the model was tested by Longstaff *et al.* (2003), Longstaff *et al.* (2005) and Blanco *et al.* (2005) on selected liquid companies in the corporate and financial sector and by Houweling and Vorst (2005), who recommend using the swap or repo rate as a risk-free rate rather than government bond yields. A drawback of this model is that the bond spreads that are used to determine the CDS spread contain other factors such as liquidity and tax effects which should not influence the CDS spread (Chen *et al.*, 2007). Nevertheless, Longstaff *et al.* (2005) divided the corporate bond spread into default and non-default components and discovered that the default component represents at least the majority of corporate bond spreads even for the highest investment-grade firms. Another weakness is that some researchers documented that it is the bond price that follows the CDS spread in the price discovery process and not *vice versa* (Coudert and Gex, 2010; Delatte, 2012). On the other hand, O’Kane (2012) found that this causality differed for different European sovereigns during 2009–2011 and in the case of some sovereigns, he discovered Granger causality in both directions.

In this paper, we examine eurozone CDSs in the context of the recent European debt crisis. Similar data are examined by, for example, the aforementioned O’Kane (2012), who uses the Granger causality test to compare the CDS and bond prices, and Calice *et al.* (2011), who show credit and liquidity interactions and discover that the liquidity of the CDS market substantially influences bond credit spreads. Annaert *et al.* (2013) study recent euro-area bank CDSs and point out that determinants of their price, such as default risk, liquidity, business cycle and risk aversion, vary strongly in time. Another view is presented by Hull *et al.* (2004), who carried outan analysis showing that credit spreads provide helpful information in estimating the probability of negative credit rating changes and that credit rating downgrades carry no new information for a CDS market. Other authors that deal with CDS determinants during the financial crisis are, for example, Badaoui *et al.* (2013) and Beirne and Fratzscher (2013).

The most recent paper with a similar focus is that of Gũndũz and Kaya (2014), which observes the persistence and co-movements of CDSs of eurozone countries

Table 1 Summary of Downloadable Data

Instrument	Data type	Reference entity	Currency	Bloomberg ticker (5year maturity)	Maturity
government bond	generic bid and ask yield	Austria, Belgium, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal, Spain	EUR	GTATS5Y, GTBEF5Y, GTFIM5Y, GTFRF5Y, GTDEM5Y, GTGRD5Y, GTIEP5Y, GTITL5Y, GTNL5Y, GTPTE5Y, GTESP5Y Govt	3M, 6M, 1Y, 2Y, 3Y, 4Y, 5Y, 6Y, 7Y, 8Y, 9Y, 10Y
credit default swap	bid and ask spread		USD	AUST CDS USD SR, BELG CDS USD SR 5Y, FINL CDS USD SR 5Y, FRTR CDS USD SR 5Y, GERMAN CDS USD SR 5Y, GREECE CDS USD SR 5Y, IRELND CDS USD SR 5Y, ITALY CDS USD SR 5Y, NETHER CDS USD SR 5Y, PORTUG CDS USD SR 5Y, SPAIN CDS USD SR 5Y Corp	5Y, 10Y
credit default swap	mid spread	Goldman Sachs, Morgan Stanley, JP Morgan Chase, Bank of America Merrill Lynch, Deutsche Bank, Citigroup, Credit Suisse, Barclay's Capital, UBS, HSBC Holdings	EUR or USD	GS CDS USD SR 5Y D14, MS CDS USD SR 5Y D14, JPMCC CDS USD SR 5Y D14, BOFA CDS USD SR 5Y D14, DB CDS EUR SR 5Y D14, CINC CDS USD SR 5Y D14, CRDSUI CDS EUR SR 5Y D14, BACR CDS EUR SR 5Y D14, UBS CDS EUR SR 5Y D14, HSBC BK CDS EUR SR 5Y D14 Corp	
cross-currency swap	bid and ask swap rate		EUR/USD	EUBS5, EUBS10 Curncy	

after the global financial crisis. The paper documents the spread of persistent CDS uncertainty among peripheral eurozone countries and spillover effects increasing the probability of contagion among those countries.

4. Data Specification

The time series data downloaded from Bloomberg and used for the purposes of this article are summarized in *Table 1*.

We chose to study ten eurozone member states with the most liquid market data at beginning of our observation period: Austria, Belgium, Finland, France, Germany, Ireland, Italy, the Netherlands, Portugal and Spain. Germany is used as a benchmark for calculation of the other countries' risk spread; therefore, Germany is not displayed in the results. Greece is excluded because of its default during the observation period and its very high and illiquid prices preceding the default event. Because of the lack of liquidity and unavailability of generic bond yields, we did not include Cyprus, Luxembourg, Malta, Slovenia or Slovakia.

The date 1 December 2009 is chosen as the starting date for our analysis. The reason for this is that at the end of October 2009 Greece admitted to having the highest debt in modern history, revising its budget deficit forecast from 3.7% to 12.5% of GDP (European Commission, 2010) and soon after that the European debt crisis started. Our aim is to study the change that occurred during the second half of 2011. The end point is 31 January 2013, which leaves us enough time thereafter. We use daily frequency of all data, which provides us with 828 observations.

Government bond yields enable us to evaluate CDSs and reach the CDS model price in Section 5. The resulting model CDSs have a different denomination than market CDSs. Therefore, market CDSs are adjusted by the EUR/USD cross-currency swap value.[4]

There are several factors that may cause the market price of a CDS to deviate from the CDS model price. Recent literature points to the two main factors—counterparty risk and liquidity risk. Therefore, we included proxies of both of these factors in the regression analysis in Section 6 and Section 7.

With respect to the counterparty risk, the CDS model price is derived from government bond spreads and does not take into account the riskiness of the seller of a CDS. If the seller defaults, he does not compensate the buyer in the event that there is a default of the underlying asset and the CDS buyer is no longer protected. As a result, it is expected that the CDS premium will rise with increasing counterparty risk.

A counterparty credit risk might be included directly in the reduced form model for a CDS valuation (e.g. Hull and White, 2001) or its effect can be observed using a regression analysis of CDS prices (e.g. Arora *et al.*, 2012). The advantage of the second approach is that it takes into account risk mitigation techniques such as collateralization of liabilities. These techniques are often applied in practice and might result in a significant decrease of the role of counterparty risk.

As a measure of CDS counterparty risk, we used the average CDS quotes of the top ten investment banks according to their fee revenue in 2011 collected by Bloomberg Markets Magazine (2011). These banks are significant CDS dealers. The following banks were included: Goldman Sachs, Morgan Stanley, JP Morgan Chase, Bank of America Merrill Lynch, Deutsche Bank, Citigroup, Credit Suisse, Barclay's Capital, UBS and HSBC Holdings. For more details on the data, see *Table 1*. These CDS dealers are comparable to those used by Arora *et al.* (2012) in their analysis of CDS counterparty risk. They use CDS quotes of 14 CDS dealers. In addition to all of the CDS sellers that we used, they include BNP Paribas, the defaulted Lehman Brothers and the Royal Bank of Scotland.[5]

The second measure to be included in the regression analysis is liquidity risk. The CDS market, which has the effect that the scope of liquidity proxies is limited.

[4] The cross-currency swap may be used to compare the yields of the same floating rate bonds with a different denomination. Buying a bond in one currency should be equivalent to buying a similar bond in another currency together with a cross-currency swap between the two currencies. Although the liquidity profile is different in the case of credit default swaps, we find this adjustment of market CDSs denominated in USD as the most suitable solution to account for different currency denominations.

[5] The article analyzes the time range from 31 March 2008 to 20 January 2009, i.e. the period before Lehman Brothers defaulted and when Bank of America and Merrill Lynch were still separate entities. Both of these dealers are included in the analysis. Bank of America acquired Merrill Lynch in January 2009.

The most heavily used proxy for liquidity in the academic literature is the bid-ask spread of prices or yield bid-asked (e.g. Calice *et al.*, 2013; Badaoui *et al.*, 2013). In line with this approach, we used the bid-ask spread of the sovereign CDS quotes. Calice *et al.* (2013) model the CDS spreads using a Merton model to analyze liquidity spillovers of sovereign CDSs in Europe. In their article, they discuss the appropriate measure of liquidity and emphasize that for the CDS and bond markets the bid-ask spread or the yield bid-asked is in fact the only available liquidity proxy. On one hand, if liquidity is low, the buying side of a CDS will have to pay more for protection to compensate the seller for credit and liquidity risk. On the other hand, the seller sells the CDS for a cheap price to the buying dealer, i.e. at a low bid. As a result, in the case of poor liquidity, the bid-ask spread of a CDS premium is expected to rise. All data are available for two maturities—five and ten years. The reason for having only these two maturities is that they are the most liquid ones. As a result, the CDS quotes are the most reliable.

5. CDS Model Price Calculation

To be able see how the CDS market price reacts to the CDS model price, we first need to evaluate the CDS model price. To do so, we use the widely-used basic no-arbitrage CDS valuation model presented by Hull and White (2000). In Hull and White (2001), this model is enhanced by including the risk of the CDS writer in the CDS price. Being aware of the fact that counterparty risk might playan important role in CDS pricing, we account for counterparty risk in a subsequent analysis.

The Hull and White model is based on several assumptions about the calculation itself and about the input parameters. The fact that these assumptions were made might affect the resulting model price and the model risk might deflect our results in the subsequent sections. Therefore, we adequately discuss the assumptions in the following sub-sections and conscientiously select the inputs. It was verified by the authors of the model themselves (Hull and White, 2000) and also by other authors (Longstaff *et al.*, 2003; Longstaff *et al.*, 2005; and Blanco *et al.*, 2005) that the model matches reality well and it is the most common model used for CDS valuation. However, using any type of a model price is a source of model risk, which also needs to be taken into account when interpreting the results.

5.1 Extraction of Default Intensity Q(T) from Bond Prices

If we assume that the the possibility of default is the only reason why the present value of a defaultable bond differs from the present value of a default-free bond with the same cash flows, we can estimate the risk-neutral probability of default from bond prices. The model presented in this article works on this assumption.

We consider plain-vanilla CDSs with a nominal amount of one unit of currency. Suppose that for each CDS reference entity (in this case, a eurozone member state) there are N bonds issued by the reference entity (hereinafter referred to as the "*issuer*" in this section). Also, suppose that the maturity of the j-th bond is t_j and $t_1 < t_2 < t_3 < \ldots < t_N$. Assume that time t is a continuous variable expressed in years and $t \geq 0$. Define $q(t)\Delta t$ as the probability of default of the issuer between times t and $t + \Delta t$ as seen at time 0, i.e. $q(t)$ stands for the default probability density.

As the first step, the model extracts $q(t)\Delta t$. Assume that $q(t)$ is constant and equal to q_i for $t_{i-1} < t < t_i$. This simplified assumption is limiting to some extent; the probability of default takes as many values as the number of bonds from which it is extracted. Also, assume that default events, risk-free interest rates and recovery rates are mutually independent. In our calculations, all bonds from one issuer have the same seniority and, therefore, they should have the same recovery rate at a given time. Additionally, we add the assumption that the recovery rate is independent of time.

Then, ifan issuer defaults at time $t_i < t_j$, then the holders of the j-th bond receive the claim amount $C_j(t_i)$ times the recovery rate R. As discussed by the originators of this model, a reasonable assumption is that the claim amount corresponds to the nominal amount of the bond plus accrued interest. It follows that the present value of the loss incurred by the j-th bond holder at time t_i denoted as α_{ij} is

$$\alpha_{ij} = v(t_i)\left[F_j(t_i) - RC_j(t_i)\right] \tag{1}$$

where $v(t_i)$ is a risk-free discount factor, i.e. the present value of one unit of currency received at time t_i with certainty, and $F_j(t_i)$ is the forward market price of the j-th bond for a forward contract maturing at time t_i including accrued interest.

Let us denote the present value of the j-th bond B_j and the present value of the j-bond as if it was a risk-free bond (i.e. future cash flows of the bond are discounted by a risk-free rate) G_j. Then the difference between these two prices should correspond to the sum of possible losses multiplied by their probabilities:

$$G_j - B_j = \sum_{i=1}^{j} q_i \beta_{ij} \tag{2}$$

where $\beta_{ij} = \int_{t_{i-1}}^{t_i} v(t)\left[F_j(t) - RC_j(t)\right]dt$.

From equation (2), we can deductively cal-culate q:

$$q_j = \frac{G_j - B_j - \sum_{i=1}^{j-1} q_i \beta_{ij}}{\beta_{ij}} \tag{3}$$

5.2 CDS Spread Determination

Having estimated the risk-neutral probabilities of default, the next step is to calculate the expected present value of CDS cash flows.

Firstly, we will evaluate the expected value of CDS premium payments. If there is no default, then yearly premium payments w, made by the CDS buyer, continue until maturity of the swap T. The probability of no default over the whole life of the swap is π.

$$\pi = 1 - \int_0^T q(t)\,dt \tag{4}$$

On the other hand, if there is a default at time $t < T$, there isan early settlement and the CDS buyer pays regular premium payments and the last premium payment before the default is reduced toan accrual part from the preceding premium payment. As a result, the expected present value of CDS premium payments is

$$w\int_0^T q(t)\left[u(t)+e(t)\right]dt + w\pi u(T) \tag{5}$$

where $u(t)$ and $e(t)$ denote the discount factors: $u(t)$ is the present value of payments at the rate of one unit of currency per year on payment dates between time 0 and t and $e(t)$ is the present value ofan accrual payment at time t, which accrued between t^* and t, where t^* is the payment date immediately preceding time t. The first part of equation (5) corresponds to the expected present value of CDS premium payments in the case that there is a default during the life of the swap and the second part corresponds to the expected present value of premium payments in the case of no default over the whole life of the swap.

Secondly, we will evaluate the expected present value of the payment from the CDS seller to the CDS buyer, i.e. the settlement amount in the case of default. It corresponds to the nominal value of the reference bond minus its value just after the default, which is—based on the assumption about the claim amount—the nominal value plus accrued interest expressed as a percentage of nominal value $A(t)$, both multiplied by the recovery rate R: $1-\left[1+A(t)\right]R$. The expected present value of the CDS payoff is then

$$\int_0^T \left[1-R-A(t)R\right]q(t)v(t)\,dt \tag{6}$$

The fair value of CDS premium payment w is the value of w, which makes the net present value of CDS cash flows equal to zero, i.e. a value which makes expressions (5) and (6) equal:

$$s=\frac{\int_0^T\left[1-R-A(t)R\right]q(t)v(t)\,dt}{\int_0^T q(t)\left[u(t)+e(t)\right]dt+\pi u(T)} \tag{7}$$

The value of s in equation (7) then shows the yearly CDS premium payment expressed as a percentage of the CDS nominal amount.

5.3 Model Inputs

We calculated the CDS model price for a five-year and ten-year maturity for each of the eurozone countries listed in Section 4. For each country, we extracted the probability of default in equation (3) using j = 12 benchmark bond mid-market yields with the following maturities: three months, six months and yearly maturities from one to ten years.

As a proxy for the risk-free rate, we used the benchmark German government bond yields from which we calculated zero coupon yields. Longstaff *et al.* (2005) extract the default component from bond yields using three types of discount curves: interest rate swaps, repo rates and government curve. Their finding is that all three curves yield robust results. The reason why we prefer the German bond curve over the swap curve is that low-risk government bonds often traded below swaps during our observation period and that would lead to negative default probabilities.[6] Although the swap curve is widely used as a benchmark in practice, the different liquidity profile of these two instruments would not provide reasonable results in this case. As Germany is used as a benchmark, the German CDS is not modeled and Germany is not included in our analysis.

The recovery rate value is set to 53% for all countries based on historical experience. It isan average sovereign issuer-weighted recovery rate from 1983 to 2010 according toan annual report of sovereign bond issuers' default issued by Moody's (2011). This assumption is restrictive, but it can be shown that the impact of the recovery rate assumption on the CDS model price is low. Duffie (1999) evaluates, explains and illustrates the robustness of recovery rate selection in CDS valuation. According to his study,an upward bias in LGD results in a downward bias in the risk-neutral hazard rate and these errors approximately cancel each other out. However, it is important to note that this property would not work for extreme values of the hazard rate (for credit spreads of several thousands of basis points). Based on that, Greece was excluded from our calculation because its model spread would not be reliable.

Howveling and Vorst (2005) and Longstaff *et al.* (2005) offer a similar argument and both use a fixed recovery rate, with the latter fixing its value at 50%.

A similar fixed level is also used by the regulatory authorities. For example, the Czech National Bank uses a fixed 45% LGD for estimation of the "sovereign risk indicator", which isan alternative to the probability of default and which is then used to set banks' limits on exposures to sovereigns. Regulation (EU) No. 575/2013 (Capital Requirements Regulation) sets the level of LGD for institutions using the foundation internal ratings-based (FIRB) approach to be applied at senior exposures at 45%. In addition to that, the Bank of England sets a "sovereign floor" of LGD at the level of 45% even for banks using the advanced internal ratings-based (AIRB) approach, arguing that the reliability of estimates of LGD of sovereign debtors is rather low (Bank of England, 2013).

As a result of using generic bond yield-to-maturity data which are not assigned a coupon, we expect that the bond trades at par and the coupon rate correspond to the yield every day. The cumulative default probability used in equation (4) was capped at 1. Although it is possible that after one default a country may default again, a second default would not have any impact on the CDS price, as the CDS would be settled right after the first default.

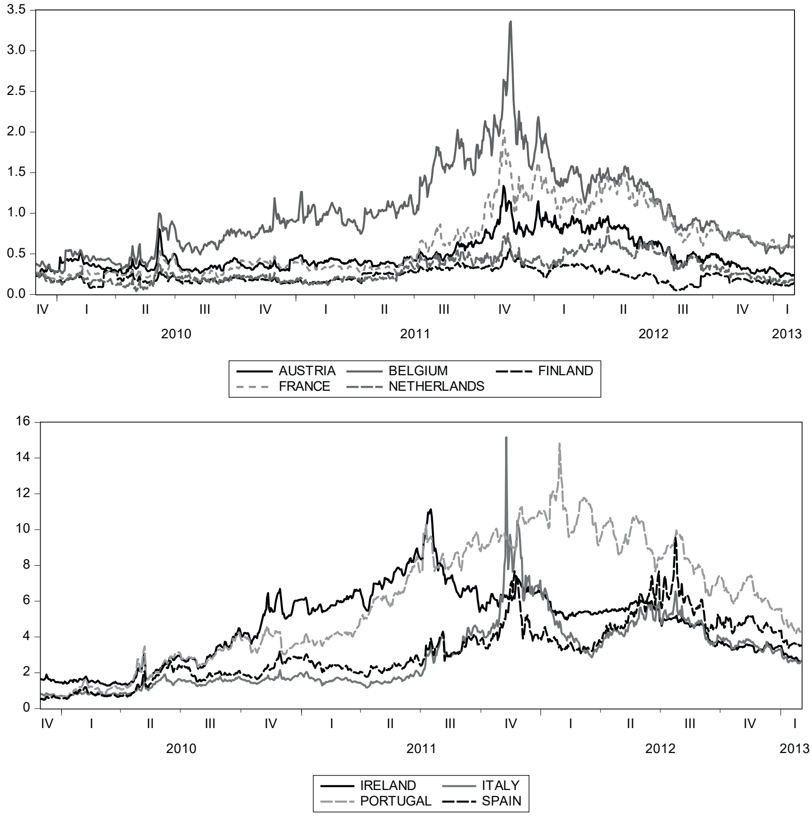
Computations were performed using Visual Basic in MS Excel.

5.4 CDS Valuation Results

We arrived at five- and ten-year CDS model prices. The development of the ten-year model CDS spreads is depicted in *Figure 1.* The modeled values of most of the countries peak at the end of November 2011 as a result of the escalating eurozone debt crisis. The development of the five-year maturity is similar.

[6] For example, the ten-year German government bond yield was lower than the ten-year EUR interest rate swap over the course of the whole observation period.

Figure 1 Results of CDS Valuation: Ten-year CDS Model Price (in percentage)



Source: Authors' calculations.

6. Single Equation Models

Our presumption is that if there are no uncertainties about the CDS contract conditions, its market price should be closely related to its modeled risk-neutral fair price. So, we regress the CDS market price on the CDS model price in a time series OLS regression. The selection of additional variables included in the regression is discussed in Section 4. To account for the default risk of the seller of a CDS, we include a proxy for counterparty risk derived from the CDS prices of top investment banks. To account for liquidity risk, a bid-ask spread of CDS quotes is included.

In this section, we will estimate the model separately for five- and ten-year maturities and for each country. Our aim is to detect whether there was a break-point during the observation period and, if so, when such breakpoint occurred, and to estimate the model divided by the break point into two sub-periods. Based on the results of these regressions, we will conclude whether it is possible to estimate the model jointly for the five- and ten-year maturities for each country and arrive at more accurate results.

6.1 Model and Post-Estimation Analysis

The stationarity of all variables was tested using the augmented Dickey-Fuller unit root test (Wooldridge, 2009, Chapter 11). The alternative hypothesis of the test was that the variable is the best AR(p) model with p ranging from 1 to 20 selected according to the Schwarz Information Criterion. As the data is mostly non-stationary and highly persistent and there are visible trends, we used the initial differences of all variables instead of their absolute levels. As such, the null hypothesis of the test that the initial differences are non-stationary was rejected at the 5% significance level in all cases. The results of the test using both the absolute levels and initial differences of all variables are reported in *Appendix 1*.

We first separately estimated the following two regression equations for each of the nine countries listed in *Table 1* as reference entities—without Germany (Germany is considered to be a benchmark), i.e. we estimated 18 separate equations:

$$\begin{aligned} \Delta marketCDS\_5Y_{t_i,C} = \alpha_{1,C}\Delta modelCDS\_5Y_{t_i,C} + \alpha_{2,C}\Delta cpty\_5Y_{t_i,C} + \\ + \alpha_{3,C}\Delta liq\_5Y_{t_i,C} + \varepsilon_{t_i,C} \end{aligned} \tag{8}$$

and

$$\begin{aligned} \Delta marketCDS\_10Y_{t_i,C} = \beta_{1,C}\Delta modelCDS\_10Y_{t_i,C} + \beta_{2,C}\Delta cpty\_10Y_{t_i,C} + \\ + \beta_{3,C}\Delta liq\_10Y_{t_i,C} + \eta_{t_i,C} \end{aligned} \tag{9}$$

where $\Delta marketCDS_{t_i,C}$ denotes the daily change of the mid-market CDS spread, $\Delta modelCDS_{t_i,C}$ denotes the daily change of the model CDS calculated in Section 5, $\Delta cpty_{t_i,C}$ denotes counterparty risk (i.e. the daily change in the average CDS of top world investment banks) and $\Delta liq_{t_i,C}$ denotes liquidity risk (i.e. the daily change of the CDS bid-ask spread) for time t_i and country C. The *"_5Y"* ending of the variables in equation (8) denotes a five-year maturity and the *"_10Y"* ending of equation (9) denotes a ten-year maturity of the variables.

These 18 equations were estimated three times for three different periods (i = 3): t_1 = 1, 2, … 828; t_2 = 1, 2, …, T_C and $t_3 = T_C + 1, T_C + 2, \ldots, 828$. Hence, in the first stage we used the whole observation period of 828 days. In the next stage, we divided the whole period according to a breakpoint T_C specific for each country.

After estimating the model using the simple OLS method in the first stage (over the whole period), we performed a post-estimation analysis of residuals. The presence of heteroscedasticity was tested using the Breusch-Pagan test (Wooldridge, 2009, Chapter 8). As expected, the null hypothesis of the homoscedasticity of residuals was rejected in the vast majority of cases. For financial time series, it is common for volatility to change over time. In consequence, we used heteroscedasticity-robust statistics (White, 1980) to interpret the results.

Serial correlation of the residuals was tested using the Breusch-Godfrey test (Wooldridge, 2009, Chapter 12). The null hypothesis of no serial correlation was rejected in six out of 18 cases. However, the model is quite stable. We tried a different proxy for liquidity (the bid-ask spread on the bonds' market), but it did not have any significant impact on the results. Then, we re-estimated the model includingan autoregressive term of order one AR(1) in the residuals. This measure fixed the problem of serial correlation of residuals. Again, it did not substantially impact the value of other coefficients or their significance.

The correlation coefficient between the regressors is mostly between 0.3 and 0.5, which does not point to collinearity.

6.2 Chow Breakpoint Test

Having appropriately estimated the model in equations (8) and (9), we performed a Chow breakpoint test (Cipra, 2008). It divides the observation period into sub-periods and tests whether the regression coefficients of these sub-periods are different. Hence, it is able to detect a change either in the intercept or in any slope coefficient.

The breakpoint, i.e. the date on which we suspect a structural break occurred, needs to be known. For example, for the five-year maturity in the first sub-period, the model is the same as in equation (8), i.e. for $t_i = 1, \ldots, T_{C,5Y}$, the coefficients are $\alpha_{1,C}$, $\alpha_{2,C}$ and $\alpha_{3,C}$. $T_{C,5Y}$ denotes the break date for equation (8). In the second sub-period, i.e. for $t_i = T_{C,5Y} + 1, \ldots, 828$, the coefficients are $\left(\alpha_{1,C} + \alpha_{4,C}\right)$, $\left(\alpha_{2,C} + \alpha_{5,C}\right)$ and $\left(\alpha_{3,C} + \alpha_{6,C}\right)$. And the stability test isan F-test that tests the null hypothesis $H_0 : \alpha_{4,C} = 0, \alpha_{5,C} = 0, \alpha_{6,C} = 0$.

According to our hypothesis, the change point should occur at the time we spotted the first articles and reactions of market participants speculating about the CDS trigger in the case of voluntary debt exchange, i.e. around October 2011.[7] To detect the most probable change point, we performed the test monthly 14 times for each equation with 14 different breakpoints starting on 1 January 2011 and ending on 1 February 2012. The most probable breakpoint is the date with the highest value of the F-statistics. Having two sets of F-statistics—for five- and ten-year maturities—we needed to reach a single breakpoint for each country. We selected the one with the highest sum of weighted F-statistics:

$$\max \left\{ \begin{array}{l} \dfrac{F_{C,5Y}^{1}}{\max\left\{F_{C,5Y}^{1},\ldots,F_{C,5Y}^{14}\right\}} + \dfrac{F_{C,10Y}^{1}}{\max\left\{F_{C,10Y}^{1},\ldots,F_{C,10Y}^{14}\right\}},\ldots, \\ \ldots,\dfrac{F_{C,5Y}^{14}}{\max\left\{F_{C,5Y}^{1},\ldots,F_{C,5Y}^{14}\right\}} + \dfrac{F_{C,10Y}^{14}}{\max\left\{F_{C,10Y}^{1},\ldots,F_{C,10Y}^{14}\right\}} \end{array} \right\} \tag{10}$$

where $F_{C,5Y}^{1}$ denotes the value of F-statistics for country C, maturity of five years with a change point at 1 January 2011 and so on. The results are summarized in *Table 2*. The presence of a change point was confirmed in all cases. Surprisingly, its location differs across countries according to their respective risk profiles. The breakpoint in the case of the riskier countries—Italy, Portugal and Spain—is 1 October or 1 November 2011, which means that there was a change in the model between

[7] See, for example, Reuters (2011) and NY Times Dealbook (2011).

Table 2 Results of the Chow Test for Different Breakpoints

RISKIER COUNTRIES

	Ireland			Italy			Portugal			Spain		
Breakpoint date	F-stat 5Y	F-stat 10Y	Weighted sum	F-stat 5Y	F-stat 10Y	Weighted sum	F-stat 5Y	F-stat 10Y	Weighted sum	F-stat 5Y	F-stat 10Y	Weighted sum
1.1.2011	1.865	1.019	0.34	13.749*	32.785*	0.53	1.482	4.467*	0.36	5.203*	28.653*	1.06
1.2.2011	2.687*	0.577	0.40	13.931*	32.791*	0.53	1.165	3.955*	0.30	5.29*	28.751*	1.07
1.3.2011	3.258*	0.376	0.46	14.402*	31.454*	0.53	1.079	3.805*	0.29	4.939*	29.39*	1.06
1.4.2011	4.08*	1.000	0.62	14.574*	32.055*	0.54	1.269	3.88*	0.31	5.212*	29.472*	1.08
1.5.2011	3.322*	2.166	0.63	17.573*	32.619*	0.59	1.250	5.789*	0.41	4.961*	29.086*	1.05
1.6.2011	3.322*	3.007	0.70	14.382*	32.289*	0.54	1.329	8.099*	0.53	5.597*	29.984*	1.12
1.7.2011	2.312	1.393	0.43	15.266*	33.746*	0.56	1.137	4.382*	0.32	6.084*	29.529*	1.14
1.8.2011	7.622*	11.237*	2.00	29.093*	47.582*	0.91	9.081*	10.39*	1.28	8.961*	31.449*	1.40
1.9.2011	2.922*	7.61*	1.06	52.947*	77.006*	1.56	9.436*	7.437*	1.15	10.18*	41.398*	1.72
1.10.2011	4.465*	9.122*	1.40	62.449*	91.957*	1.85	12.405*	8.537*	1.45	13.736*	41.846*	1.99
1.11.2011	4.467*	5.603*	1.08	67.061*	100.569*	2.00	11.692*	18.963*	1.94	12.938*	42.243*	1.94
1.12.2011	3.52*	2.789	0.71	5.185*	5.767*	0.13	9.511*	12.697*	1.44	9.326*	24.979*	1.27
1.1.2012	2.417*	2.637	0.55	14.64*	9.437*	0.31	5.418*	10.915*	1.01	6.932*	17.895*	0.93
1.2.2012	1.824	0.977	0.33	15.201*	10.769*	0.33	1.426	6.789*	0.47	5.29*	18.687*	0.83

LESS RISKY COUNTRIES

Breakpoint date	Austria F-stat 5Y	Austria F-stat 10Y	Austria Weighted sum	Belgium F-stat 5Y	Belgium F-stat 10Y	Belgium Weighted sum	Finland F-stat 5Y	Finland F-stat 10Y	Finland Weighted sum	France F-stat 5Y	France F-stat 10Y	France Weighted sum
1.1.2011	6.854*	2.026	1.40	13.859*	7.852*	1.92	6.987*	2.884*	1.76	10.729*	7.252*	1.07
1.2.2011	8.524*	2.180	1.64	13.26*	8.079*	1.90	7.961*	3.255*	2.00	25.753*	8.803*	1.79
1.3.2011	8.362*	2.593	1.74	11.755*	7.394*	1.72	7.587*	2.888*	1.84	24.288*	11.184*	1.94
1.4.2011	8.452*	2.508	1.72	11.369*	7.106*	1.65	7.625*	2.964*	1.87	24.291*	9.125*	1.76
1.5.2011	7.894*	2.334	1.61	10.739*	6.971*	1.59	7.474*	1.817	1.50	23.06*	7.863*	1.60
1.6.2011	8.076*	2.363	1.64	10.453*	6.769*	1.55	7.637*	1.730	1.49	23.009*	7.299*	1.55
1.7.2011	7.675*	2.615	1.66	8.551*	8.023*	1.56	7.41*	1.077	1.26	22.095*	7.794*	1.55
1.8.2011	5.698*	2.904*	1.52	5.384*	7.664*	1.29	6.575*	1.088	1.16	15.322*	6.826*	1.21
1.9.2011	4.849*	1.261	0.94	6.825*	6.409*	1.24	4.561*	0.673	0.78	8.59*	2.926*	0.60
1.10.2011	2.180	3.423*	1.26	3.192*	2.554	0.53	5.206*	2.324	1.37	4.608*	0.193	0.20
1.11.2011	2.105	2.345	0.93	3.939*	1.964	0.51	5.227*	1.199	1.02	4.274*	1.616	0.31
1.12.2011	0.154	1.858	0.56	3.768*	6.677*	1.05	1.198	0.522	0.31	2.697*	1.183	0.21
1.1.2012	0.457	1.525	0.50	5.833*	7.088*	1.25	0.127	0.602	0.20	2.486	2.898*	0.36
1.2.2012	3.63*	1.029	0.73	5.759*	8.529*	1.42	0.135	0.666	0.22	3.68*	3.274*	0.44

	Netherlands		
Breakpoint date	F-stat 5Y	F-stat 10Y	Weighted sum
1.1.2011	10.248*	2.213	1.16
1.2.2011	10.59*	2.328	1.21
1.3.2011	10.291*	2.012	1.12
1.4.2011	10.432*	2.378	1.21
1.5.2011	9.951*	2.004	1.10
1.6.2011	10.292*	1.609	1.04
1.7.2011	14.529*	2.061	1.42
1.8.2011	12.377*	3.68*	1.61
1.9.2011	11.226*	4.875*	1.77
1.10.2011	13.417*	3.267*	1.59
1.11.2011	10.537*	1.893	1.11
1.12.2011	1.487	1.986	0.51
1.1.2012	0.914	1.870	0.45
1.2.2012	1.464	2.328	0.58

Notes: For each country and date there are two values of the *F*-statistics—for five- and ten-year maturities. An asterisk denotes significance of the *F*-statistics at the 5% significance level. The third column shows the weighted sum of the first two columns according to equation (10). For a better illustration of the values and the nature of the change gray shading of the values in the third column is used. The higher the value, the darker the shade.

Source: Authors' calculations.

1 September and 1 November. This result is exactly in line with our expectations. The breakpoint in the case of the less risky countries—Austria, Belgium, France, Finland and the Netherlands—is apparent earlier in 2011. We believe that the motivation behind this change was different—in February 2011, the creation of a European bailout fund called the European Stability Mechanism was arranged. Member states have to contribute to the fund, which issues bonds and offers financial assistance to eurozone members if needed. As a result, interconnection between the eurozone countries increased.

The results for Ireland are rather unique due to one important piece of news specific for Irish markets. In July 2011, the EU leaders decided to relax the conditions of Irish loans from the EU under the EU/IMF financing program. The reaction of the markets to this act is evident from the data and 1 August was also unambiguously confirmed as the breakpoint date. However, the second highest value of the weighted *F*-statistics is on 1 October 2011, which is in line with the less risky countries.

In *Table 2* we can also observe the nature of the change. The data do not point to a one-off impact on the market; the change is rather gradual. There is not a single pattern and there are differences between countries. However, we can observe that the change in the case of the riskier countries is more distinct and the result is clearer.

Breakpoint T_C determined by the Chow test was then used to estimate the model in equations (8) and (9) divided into two sub-periods: $t_2 = 1, 2, \ldots, T_C$ and $t_3 = T_C + 1, T_C + 2, \ldots, 828$. The motivation behind this estimation was to calculate the correlation coefficient between the residuals from equation (8) and equation (9).[8] In the case of correlated residuals, the seemingly unrelated regressions (SUR) model achieves more appropriate results.

The correlation coefficient between five- and ten-year residuals ranges from 0.44 to 0.82. We tested its significance using a *t*-test with a null hypothesis of a zero correlation coefficient between the residuals. The null hypothesis was rejected with almost zero *p*-values in all cases.

There are two main conclusions of this chapter: 1. The SUR model is applicable in the case of all countries, and 2. the change point location is in line with our expectations in the case of the riskier countries and it occurred earlier in the case of the less risky countries.

7. Seemingly Unrelated Regressions

In the previous section, we mentioned that errors of the single equation model are contemporaneously correlated. As a result, the simple OLS estimator is no longer efficient. This result leads us to the SUR model (Cipra, 2008):

$$\begin{aligned} &\Delta \boldsymbol{marketCDS}\_5\boldsymbol{Y_C} = \alpha_1 \Delta \boldsymbol{modelCDS}\_5\boldsymbol{Y_C} + \alpha_2 \Delta \boldsymbol{cpty}\_5\boldsymbol{Y_C} + \alpha_3 \Delta \boldsymbol{liq}\_5\boldsymbol{Y_C} + \boldsymbol{\varepsilon}_1 \\ &\Delta \boldsymbol{marketCDS}\_10\boldsymbol{Y_C} = \beta_1 \Delta \boldsymbol{modelCDS}\_10\boldsymbol{Y_C} + \beta_2 \Delta \boldsymbol{cpty}\_10\boldsymbol{Y_C} + \beta_3 \Delta \boldsymbol{liq}\_10\boldsymbol{Y_C} + \boldsymbol{\varepsilon}_2 \\ &var\begin{pmatrix} \boldsymbol{\varepsilon}_1 \\ \boldsymbol{\varepsilon}_2 \end{pmatrix} = \boldsymbol{\Omega} = \begin{pmatrix} \sigma_{11}\mathbf{I} & \sigma_{12}\mathbf{I} \\ \sigma_{21}\mathbf{I} & \sigma_{22}\mathbf{I} \end{pmatrix} \end{aligned} \quad (11)$$

[8] We do not present the results of the regression because of limited scope of this paper.

where $\Delta \boldsymbol{marketCDS\_5Y_C}$ and $\Delta \boldsymbol{marketCDS\_10Y_C}$ are ($T_{i,C}$ x 1) vectors of the dependent variable, $\Delta \boldsymbol{modelCDS\_5Y_C}$, $\Delta \boldsymbol{cpty\_5Y_C}$, $\Delta \boldsymbol{liq\_5Y_C}$, $\Delta \boldsymbol{modelCDS\_10Y_C}$, $\Delta \boldsymbol{cpty\_10Y_C}$ and $\Delta \boldsymbol{liq\_10Y_C}$ are ($T_{i,C}$ x 1) vectors of the independent variables. α_1, α_2, α_3, β_1, β_2 and β_3 are scalar regression parameters. $\boldsymbol{\varepsilon_1}$ and $\boldsymbol{\varepsilon_2}$ are ($T_{i,C}$ x 1) vectors of residuals with zero expected value. The terms σ_{jk}, j = 1, 2 and k = 1, 2 stand for the covariance between the residual term of the j-th and the k-th equation, i.e. residual terms are contemporaneously correlated. **I** is a unit (T x T) matrix and $\boldsymbol{\Omega}$ is a (2T x 2T) variance matrix of the vector of residual terms.

We have T = 828 observations and the model is estimated separately for two sub-periods, i = 1, 2. The whole period is divided into sub-periods by breakpoint T_C, derived in Section 6.2 for each country C.

In the SUR model, all independent variables are expected to be exogenous. In the case of a linear regression model, the exogeneity means that the explanatory variables should not be contemporaneously correlated with the residuals. To verify this assumption, we calculated the correlation coefficient and tested the hypothesis that it equals zero. We could not reject the hypothesis in any case, meaning that all explanatory variables are exogenous.

To reach the best linear unbiased estimator of the parameters, the regression equations in model (11) cannot be estimated separately. Therefore, the Aitken generalized least squares estimator is applied. It is based on a non-diagonal property of the variance matrix $\boldsymbol{\Omega}$; see, for example, Cipra (2008) for more details.

The results of model (11) are summarized in *Table 3.* Additionally, after estimating the model, we tested whether the coefficients in the two sub-periods are equal using a Wald test, which mostly rejected the null hypothesis. The results of the Wald test are provided in *Appendix 2*.

Again, the results divide the countries into two groups according to their respective risk profiles. In the case of all riskier countries, such as Italy, Ireland, Portugal and Spain, the value of the coefficients of the CDS model price decreased after the breakpoint. Moreover, the adjusted R-squared coefficient also decreased after the breakpoint in the vast majority of cases. These facts confirm our hypothesis that the CDS market price in the second sub-period is not driven by the model CDS price to the extent that it was in the first sub-period. It also points to the fact that investors' trust in CDSs decreased. On the other hand, our hypothesis is not confirmed in the case of all less risky countries, such as Austria, Belgium, Finland, France and the Netherlands. This is a quite interesting finding, as it indicates that the creation of CDS market prices is not universal, but is rather more likely country specific.

In the case of the least risky countries in the first sub-periods (Finland, France and the Netherlands), the coefficient of determination is low and the CDS model price is not significant. This can be explained by the fact that the government bond spreads of these countries oscillated around German government bond spreads, which were used as a benchmark. In this case of low spreads, the CDS model calculation is very sensitive to benchmark selection and it might not offer reliable results. As soon as the spreads increase sufficiently above the benchmark, which happened later,

Table 3 SUR Model Results

		Austria		Belgium		Finland		France		Netherlands	
		Coeff	*P*-value	Coeff	*P*-value	Coeff	*P*-value	Coeff	*P*-value	Coeff	*P*-value
1st sub-period	ΔmodelCDS_5Y	0.125	0.001	0.173	0.000	-0.005	0.819	-0.018	0.691	0.007	0.789
	Δcpty_5Y	0.186	0.000	0.170	0.000	-0.001	0.951	0.199	0.000	0.111	0.000
	Δliq_5y	0.196	0.168	0.357	0.000	0.154	0.279	-0.050	0.572	-0.124	0.258
	ΔmodelCDS_10Y	0.209	0.000	0.240	0.000	-0.039	0.203	0.095	0.245	-0.041	0.253
	Δcpty_10Y	0.179	0.000	0.173	0.000	0.049	0.008	0.161	0.002	0.085	0.002
	Δliq_10y	0.389	0.000	0.209	0.003	0.267	0.026	0.473	0.000	0.333	0.000
	Adjusted *R*-squared 5y	0.100		0.201		-0.003		0.075		0.080	
	Adjusted *R*-squared 10y	0.200		0.237		0.031		0.111		0.172	
2nd sub-period	ΔmodelCDS_5Y	0.257	0.000	0.407	0.000	0.125	0.000	0.327	0.000	0.201	0.000
	Δcpty_5Y	0.404	0.000	0.568	0.000	0.093	0.000	0.422	0.000	0.203	0.000
	Δliq_5y	-0.047	0.692	0.148	0.150	0.143	0.165	0.361	0.013	-0.015	0.840
	ΔmodelCDS_10Y	0.250	0.000	0.389	0.000	0.044	0.410	0.247	0.000	-0.014	0.710
	Δcpty_10Y	0.343	0.000	0.523	0.000	0.104	0.000	0.402	0.000	0.247	0.000
	Δliq_10y	0.255	0.012	0.198	0.027	-0.056	0.657	0.133	0.041	0.299	0.000
	Adjusted *R*-squared 5y	0.503		0.605		0.136		0.563		0.330	
	Adjusted *R*-squared 10y	0.265		0.474		0.076		0.464		0.224	

		Ireland		Italy		Portugal		Spain	
		Coeff	*P*-value	Coeff	*P*-value	Coeff	*P*-value	Coeff	*P*-value
1st sub-period	ΔmodelCDS_5Y	0.502	0.000	0.503	0.000	0.487	0.000	0.437	0.000
	Δcpty_5Y	0.865	0.000	0.503	0.000	1.341	0.000	0.605	0.000
	Δliq_5y	-0.538	0.001	0.221	0.108	0.408	0.005	-0.298	0.001
	ΔmodelCDS_10Y	0.507	0.000	0.518	0.000	0.539	0.000	0.543	0.000
	Δcpty_10Y	0.720	0.003	0.507	0.000	0.870	0.000	0.469	0.000
	Δliq_10y	-0.162	0.000	0.021	0.764	-0.192	0.000	-0.090	0.178
	Adjusted *R*-squared 5y	0.581		0.625		0.574		0.538	
	Adjusted *R*-squared 10y	0.267		0.580		0.347		0.554	
2nd sub-period	ΔmodelCDS_5Y	0.283	0.000	0.129	0.000	0.304	0.000	0.301	0.000
	Δcpty_5Y	0.923	0.000	1.208	0.000	1.006	0.000	0.761	0.000
	Δliq_5y	0.027	0.814	0.393	0.021	0.099	0.102	0.692	0.000
	ΔmodelCDS_10Y	0.086	0.112	0.078	0.000	0.305	0.000	0.197	0.000
	Δcpty_10Y	0.680	0.000	1.082	0.000	0.724	0.000	0.745	0.000
	Δliq_10y	-0.158	0.001	0.333	0.000	0.039	0.191	0.189	0.028
	Adjusted *R*-squared 5y	0.354		0.555		0.426		0.644	
	Adjusted *R*-squared 10y	0.147		0.476		0.350		0.497	

Notes: The table shows the results of model (11). Cases where the values of the regression parameters are higher in the second period are highlighted in dark gray and the opposite cases are highlighted in light gray. Cases where the Wald test revealed that the change of the regression parameter between the two sub-periods is not significant are not highlighted. The value of *R*-squared in the second sub-period is highlighted in a dark gray in the case that it is higher compared to the first sub-period and in light gray color in the case that it is lower.

Source: Authors' calculations.

mainly during the second sub-period, the model works well (almost all regressors proved to be significant).

Counterparty risk is significant in all cases. In almost all cases, its role became more important in the second sub-period.

The results for liquidity risk are not that uniform. Generally, the role of liquidity risk in the CDS market determination seems to have decreased in the case of the less risky countries and increased in the case of the riskier countries, i.e. the parameters changed between the two sub-periods in the opposite direction than in the case of the parameters of the model CDS price. However, in several cases the change was not confirmed to be significant. In combination with lower significance of the liquidity proxy (it is significant in 58% of the equations), we cannot come to a plausible conclusion. Such a finding is not incompatible with other researchers' results. The current findings show that the role of liquidity is not so definite. For example, Collin-Dufresne *et al.* (2001) analyze credit spreads of plain-vanilla corporate bonds and arrive at the conclusion that commonly used variables including liquidity cannot explain the variation in credit spread changes. They stress the importance of supply and demand shocks, which might bean important determinant of credit spread changes. Although several studies conclude that lowering liquidity increases the CDS premium payment (e.g. Badaoui, 2013 and Pan and Singleton, (2008), Fabozzi *et al.* (2007) numerically reach the conclusion that the impact of liquidity proxies on the CDS spread is not as obvious as in case of a bond market. The penalty for liquidity should be accounted for in both the premium payments and the compensation payment in the case of a default. As a result, the impact of liquidity on CDS spreads might be both positive and negative depending on the risk-free discount factors and the survivor probabilities. In addition to that, their regression analysis of CDS quotes from the financial, corporate and telecom sectors showsan opposite relationship, i.e. increasing liquidity widens CDS spreads.

8. Market Context and Policy Impacts

The correctness of the CDS quotes is of high importance. During the recent crisis in the eurozone, several member states were unable to refinance their government debt or to bail out their banks and therefore they needed to be rescued by external resources from other eurozone states, the European Central Bank or the International Monetary Fund. Countries' debt-to-GDP ratios have been watched closely since the eurozone debt crisis. Similarly, Gũndũz and Kaya (2014) stress that eurozone CDSs, indicating market perception of indebtedness, are in the spotlight as they have never been before.

As a result, the behavior of CDSs needs to be examined and subsequent policy decisions should be taken to avoid malfunctioning of the markets. Unlike the debt-to-GDP ratio, the CDS quote is influenced by factors other than indebtedness alone. Policy makers are responsible for minimizing the impacts of factors such as doubts about CDS terms and conditions and uncertainty about the ability of a CDS to protect its buyers. It is very importance to set the conditions of this instrument so that they are a reliable source//resource for financial markets.

This article contributes to the knowledge of sovereign CDS behavior. Based on our analysis, we conclude that there has been a need for a change in the setting of the CDS terms since 2011. We showed that the link between the CDS market price and the arbitrage-free model CDS weakened in the case of riskier countries. There may be various reasons for this change. But the timing of the change corresponds to the timing of the increasing uncertainty about the CDS settlement. In our opinion and based on our discussion with various CDS market participants, it is very probable that these uncertainties were behind the weakened link.

In October 2014, the terms and conditions of CDS contracts were changed towards greater protection. Some trades were upgraded automatically, while trades linked to governments, banks and some companies needed to be exited and re-agreed upon under the improved terms and conditions. This action was aimed at rebuilding trust in CDSs. This is a matter for further research aim at assessing its effects.

Another example of how policymakers react to the development on the sovereign CDS market and to recent findings of researchers in this field is the naked CDS ban in the EU starting in November 2012. The purpose of the ban was to address concerns about the spillover and contagion effects from CDS markets to bond markets pointed out in a paper by Delatte *et al.* (2012). The appropriateness of such a regulation has been criticized. For example, the Global Financial Stability Report of the IMF (2013) analyzed the effects of the ban and discovered that the evidence does not support the necessity of the ban and that the negatives of this regulation outweigh the positives. The report was published shortly after the start of the ban, so the observation period was quite brief. Hence, analysis of the longer-term effect of the ban in a broader context could be another topic of research.

9. Summary

Throughout this article, the relationship between the probability-neutral market price of a credit default swap contract and its model value was examined. We focused on the most liquid EMU countries except for Greece and the period of the European sovereign debt crisis starting with the sudden reassessment of Greece's budget deficit.

In the first part of the article, we calculated the fair price of a CDS using the basic and commonly used the reduced form model, which extracts the default probability function from bond prices with different maturities. Using any kind of a model price is a source of model risk, which needs to be taken into account when interpreting the results. Our presumption was that if there are no uncertainties about a CDS contract, the market price of CDS should be closely related to the model price. Therefore, we regressed the CDS market price on the CDS model price in econometric models, individually for each country and maturity.

We verified the presence of a breakpoint around the time we first spotted articles doubting the presence of a CDS trigger, i.e. October 2011. Interestingly, the change happened in line with our expectations only in the case of countries with a riskier credit profile (Italy, Portugal and Spain). In the case of less risky countries (Austria, Belgium, Finland, France and the Netherlands), it occurred earlier in 2011, so there must have been a different reason for the change, namely the fact that in February 2011, European authorities agreed on the creation of the European Stability Mechanism. We believe that the establishment of such a bailout fund increased the interconnection between the countries and caused the change. The case of Ireland is rather specific. Relaxation of the conditions of the EU/IMF loan to Ireland had a greater effect on our model and pointed to a change point in August 2011. Other eurozone members (Cyprus, Luxembourg, Malta, Slovakia and Slovenia) were not included in the analysis because of insufficient liquidity and missing market data.

After obtaining the change point, which divided the estimation period into two sub-periods, we used a two-equation SUR model for five- and ten-year maturities of the variables to reachan efficient estimate of the parameters in each sub-period. The weakened relationship between the CDS market and the model price was confirmed only in the case of the riskier countries—Ireland, Italy, Portugal and Spain. The regression coefficient decreased and the adjusted coefficient of determination mostly decreased between the two sub-periods as well.

Based on these findings and in accordance with our line of reasoning, it seems that investors' trust in CDSs did not decrease generally, but rather decreased only in the case of the riskier countries. In the case of the less risky countries, the dependence between the market and CDS model price increased, which points to the conclusion that trust might have increased, but it definitely did not decrease. This contributes to the fact that since the EU debt crisis, investors have better distinguished between individual member states. Conversely, this result is quite surprising because the attitude of the EU, the IMF and national governments to a country's insolvency and the treatment ofan early CDS settlement should be similar no matter which EMU member state is defaulting, i.e. one might expect a uniform result.

The development commented upon in this article started discussions about the correct functioning of CDSs as a hedging instrument and it resulted in some reactions of international authorities aimed at improving the CDS market. Thus, there is room for further research in this field. At the end of 2012, the EU banned naked CDSs to prevent speculation. In October 2014, the ISDA changed the terms and conditions of CDS contracts, thus expanding the list of events that trigger a CDS payout in order to increase the reliability of CDSs. The impact of these measures should be further examined. Sovereign CDS volumes increased substantially during the EU debt crisis. Research in this field is important to help increase investors' confidence in CDSs and to learn lessons from the unprecedented case of Greece.

Appendix 1 Augmented Dickey-Fuller Unit Root Test Results

	AT	BE	FI	FR	IR	IT	NE	PT	SP
marketCDS_5Y	-1.62 (0.47)	1.60 (0.48)	-2.15 (0.23)	-1.88 (0.34)	-1.52 (0.52)	-1.86 (0.35)	-2.09 (0.25)	-1.61 (0.48)	-2.03 (0.28)
modelCDS_5Y	-2.74 (0.07)	-1.99 (0.29)	1.75 (0.40)	-2.20 (0.21)	-1.69 (0.44)	-2.15 (0.23)	-1.94 (0.31)	-1.60 (0.48)	-2.41 (0.14)
cpty_5Y					-1.99 (0.29)				
liq_5y	-2.59 (0.10)	-2.74 (0.07)	-2.37 (0.15)	-3.63 (0.01)	-2.37 (0.15)	-2.76 (0.07)	-2.16 (0.22)	-2.21 (0.20)	-3.99 (0.00)
marketCDS_10Y	-1.83 (0.37)	-1.98 (0.30)	1.80 (0.38)	-1.87 (0.35)	-1.74 (0.41)	-1.98 (0.30)	-1.69 (0.44)	-2.01 (0.28)	-2.18 (0.21)
modelCDS_10Y	-2.61 (0.09)	-2.45 (0.13)	-2.87 (0.05)	-1.86 (0.34)	-1.66 (0.45)	-1.96 (0.30)	-2.50 (0.11)	-1.63 (0.47)	-2.13 (0.23)
cpty_10Y					-2.04 (0.27)				
liq_10y	-2.15 (0.23)	-1.88 (0.34)	-2.37 (0.15)	-3.55 (0.01)	-2.53 (0.11)	-1.28 (0.64)	-3.66 (0.01)	-3.72 (0.00)	-2.10 (0.25)

	AT	BE	FI	FR	IR	IT	NE	PT	SP
ΔmarketCDS_5Y	-24.68 (0.00)	-18.04 (0.00)	-27.22 (0.00)	-18.07 (0.00)	-21.38 (0.00)	-20.22 (0.00)	-25.51 (0.00)	-17.15 (0.00)	-17.18 (0.00)
ΔmodelCDS_5Y	-25.07 (0.00)	-17.71 (0.00)	-26.99 (0.00)	-26.62 (0.00)	-23.20 (0.00)	-19.59 (0.00)	-27.47 (0.00)	-22.68 (0.00)	-18.31 (0.00)
Δcpty_5Y					-16.80 (0.00)				
Δliq_5Y	-21.04 (0.00)	-22.68 (0.00)	-16.58 (0.00)	-21.85 (0.00)	-28.81 (0.00)	-24.04 (0.00)	-15.55 (0.00)	-25.79 (0.00)	-24.97 (0.00)
ΔmarketCDS_10Y	-25.30 (0.00)	-23.02 (0.00)	-30.09 (0.00)	-25.45 (0.00)	-25.86 (0.00)	-22.15 (0.00)	-29.43 (0.00)	-24.48 (0.00)	-18.33 (0.00)
ΔmodelCDS_10Y	-25.40 (0.00)	-22.95 (0.00)	-27.91 (0.00)	-29.11 (0.00)	-22.29 (0.00)	-22.11 (0.00)	-36.47 (0.00)	-16.36 (0.00)	-19.00 (0.00)
Δcpty_10Y					-16.69 (0.00)				
Δliq_10Y	-16.54 (0.00)	-17.92 (0.00)	-16.58 (0.00)	-24.56 (0.00)	-16.28 (0.00)	-16.58 (0.00)	-19.40 (0.00)	-32.29 (0.00)	-16.86 (0.00)

Notes: The stationarity of each variable was tested over the whole period for each country. In each case, two values are reported. The top number is the value of the test statistic and its *p*-value is in the brackets below. The upper table shows the results for levels and the lower table shows the results for initial differences of the variables. In the upper table, the nonstationarity of nearly all time series cannot be rejected at the 5% significance level. The lower table shows that all time series are stationary, i.e. nonstationarity is rejected in all cases.

Source: Authors' calculations.

Appendix 2 Wald Test for Equality of Coefficients

	Austria		Belgium		Finland		France		Netherlands	
Hypothesis	chi-sq	p-value	chi-sq	*p*-value	chi-sq	*p*-value	chi-sq	*p*-value	chi-sq	*p*-value
$\alpha_1^{1st}=\alpha_1^{2nd}$	12.200	0.001	66.167	0.000	37.795	0.000	56.561	0.000	52.906	0.000
$\alpha_2^{1st}=\alpha_2^{2nd}$	33.943	0.000	98.142	0.000	19.672	0.000	29.305	0.000	23.541	0.000
$\alpha_3^{1st}=\alpha_3^{2nd}$	4.271	0.039	8.042	0.005	0.007	0.936	21.747	0.000	0.990	0.320
$\beta_1^{1st}=\beta_1^{2nd}$	0.780	0.377	20.190	0.000	7.283	0.007	29.372	0.000	0.562	0.454
$\beta_2^{1st}=\beta_2^{2nd}$	16.919	0.000	80.307	0.000	8.706	0.003	22.646	0.000	37.073	0.000
$\beta_3^{1st}=\beta_3^{2nd}$	3.574	0.059	0.024	0.877	7.336	0.007	18.044	0.000	0.940	0.332
$\alpha_1^{1st}=\alpha_1^{2nd}$ and $\alpha_2^{1st}=\alpha_2^{2nd}$ and $\alpha_3^{1st}=\alpha_3^{2nd}$	56.645	0.000	215.347	0.000	65.185	0.000	158.760	0.000	90.112	0.000
$\beta_1^{1st}=\beta_1^{2nd}$ and $\beta_2^{1st}=\beta_2^{2nd}$ and $\beta_3^{1st}=\beta_3^{2nd}$	23.687	0.000	126.216	0.000	24.219	0.000	54.740	0.000	43.267	0.000

	Ireland		Italy		Portugal		Spain	
Hypothesis	chi-sq	*p*-value	chi-sq	*p*-value	chi-sq	*p*-value	chi-sq	*p*-value
$\alpha_1^{1st}=\alpha_1^{2nd}$	85.399	0.000	262.257	0.000	50.983	0.000	34.566	0.000
$\alpha_2^{1st}=\alpha_2^{2nd}$	0.120	0.167	185.478	0.000	6.193	0.013	3.682	0.055
$\alpha_3^{1st}=\alpha_3^{2nd}$	12.335	0.000	1.578	0.209	4.617	0.032	123.844	0.000
$\beta_1^{1st}=\beta_1^{2nd}$	75.662	0.000	289.654	0.000	25.421	0.000	177.139	0.000

$\beta_2^{1st} = \beta_2^{2nd}$	0.027	0.870	132.095	0.000	0.707	0.400	15.222	0.000
$\beta_3^{1st} = \beta_3^{2nd}$	0.010	0.920	19.210	0.000	37.092	0.000	17.408	0.000
$\alpha_1^{1st} = \alpha_1^{2nd}$ and $\alpha_2^{1st} = \alpha_2^{2nd}$ and $\alpha_3^{1st} = \alpha_3^{2nd}$	95.472	0.000	351.734	0.000	81.823	0.000	153.837	0.000
$\beta_1^{1st} = \beta_1^{2nd}$ and $\beta_2^{1st} = \beta_2^{2nd}$ and $\beta_3^{1st} = \beta_3^{2nd}$	87.412	0.000	355.129	0.000	63.637	0.000	197.340	0.000

Notes: In the first column, there is a null hypothesis to be tested. We tested whether the change of the values of the coefficients from model (11) between the first and the second sub-period is significant. The test was performed on the level of individual coefficients (the first six rows) and on the level of whole equations (the seventh and eighth rows). The results reveal that the change is significant in the majority of cases.

Source: Authors' calculations.

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