**Charles University**

**Faculty of Social Sciences**

Institute of Economic Studies

DISSERTATION

# Credit Derivatives Market during Recent Financial Crisis

**Author:** PhDr. Petra Buzková

**Advisor:** doc. PhDr. Petr Teplý, PhD.

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## Declaration of Authorship

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Prague, June 28, 2018

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## Acknowledgements

I would like to express my gratitude to my supervisor doc. Petr Teplý for his guidance, doc. Miloš Kopa for his consultations and to my colleagues and best validators ever Jirka Poláček and Víťa Horák for their support before finishing the dissertation.

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This dissertation benefited from the European Union's Horizon 2000 Research and Innovation Staff Exchange programme under the Marie Sklodowska-Curie grand agreement No. 681228.

# Abstract


The dissertation is composed of three empirical research papers analyzing the development on credit derivatives markets in recent years characterized by the global financial crisis in 2007-2009 and subsequent European sovereign debt crisis. The basic motivation of the thesis is to contribute to the clarification of the turbulent development on credit derivatives markets. The first paper addresses main flaws of a collateralized debt obligation (CDO) market during the global financial crisis. The second paper examines the impact of the Greek debt crisis on sovereign credit default swap (CDS) reliability. The third paper analyzes whether a resulting change in CDS terms restored confidence in CDS contracts. An introductory chapter presents a common framework for the three papers.

In the first paper, we examine valuation of a Collateralized Debt Obligation (CDO) in 2007-2009. One Factor Gaussian Copula Model is presented and five hypotheses regarding CDO sensitivity to entry parameters are analyzed. Four main deficiencies of the CDO market are then articulated: i) an insufficient analysis of underlying assets by both investors and rating agencies; ii) investment decisions arising from the valuation model based on expected cash-flows and neglecting other factors such as mark-to-market losses; iii) mispriced correlation; iv) obligation of the mark-to-market valuation. Relevant recommendations for the renewal of the CDO market are then stated.

The second paper examines whether repeated questioning of reliability of a CDS contract during the EMU debt crisis 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. My 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.

The third paper investigates effects of new credit derivatives' definitions launched by International Swaps and Derivatives Association (ISDA) in October 2014. First, using a SUR model I observe whether the change increased the link between the CDS price as a hedging instrument and the bond spread as a hedged instrument. Second, using an ARFIMA-FIGARCH model I observe whether the extent of the long memory of CDS changes and their volatilities decreased. Data of liquid EU sovereigns and 3-year and 5-year maturities are analyzed. The first analysis reveals a limited positive impact on some countries – Belgium, France, Italy, Portugal and Spain – and only 5-year maturity. The second analysis concludes that the extent of long memory in the data did not decrease after the change, leading to the conclusion that the efficiency of the CDS market did not improve according to the efficient markets' hypotheses.

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# General Introduction

Credit derivatives, being invented in 1993, represent a relatively young category of financial instruments. However, their history is colorful regardless of the short existence. The dissertation covers three selected topics on credit derivatives' behavior during three chronologically ordered periods ranging from 2007 to 2015. All in all, it comprehensively contributes to the knowledge of these instruments illustrating the development of understanding to these instruments, the development of their use by market participants and the development of a regulatory approach. The dissertation represents an applied research contributing to the knowledge of credit derivatives' price behavior, their reliability and efficiency with conclusions aimed at regulators, market participants and risk managers.

After their inception credit derivatives were hailed as a wonder of modern finance. Discovery that a credit risk of any instrument can be transferred to another counterparty was liberating. Notional outstanding of credit default swaps soared from nearly zero in 1994 to USD 72 trillion in 2007 and the use of credit derivatives soon transferred from banks hedging their credit risks to speculating hedge funds (Barrett and Ewan, 2006). After this optimistic period markets experienced a hard hit with multiple defaults of large institutions such as several Icelandic banks, Fannie Mae, Freddie Mac, Washington Mutual Inc., Lehman Brothers Holdings Inc. or American International Group. These defaults caused a spiral of other defaults as their credit risk was widely spread via credit derivatives to other institutions around the world and resulted in a global financial crisis in 2007-2008. Saving troubled institutions then had a devastating impact on budgets of several governments and launched a so-called Eurozone debt crisis starting 2009. Credit derivatives were then blamed for triggering these crises and their volumes fell dramatically – in 2010 notional outstanding of credit default swaps was USD 18 trillion (Bank for International Settlements, 2013). Nonetheless, their existence was preserved with an increased demand for regulation to solve lack of transparency and standardization. Subsequent years can thus be characterized by finding the most appropriate extent of regulation of credit derivatives.

Credit default swap contracts (CDS) were internationally standardized during 2009 and U.S. and Europe launched their central clearing houses to settle CDS trades. In November, 2014, European regulators imposed a ban on naked CDS trading (i.e. buying credit protection is not possible without holding a long position in a debt instrument with the same reference entity). The purpose of this step was to address concerns about the spillover and contagion effects from CDS markets to bond markets pointed out in a paper of Delatte et al. (2012). The appropriateness of such a regulation has been criticized in e.g. the Global Financial Stability Report of the IMF (2013).

Even with increased standardization and restricted speculative use of CDSs, insufficient CDS contract definitions raised doubts about the efficiency of CDS contracts with Greek default in 2012 being the most visible example of CDS malfunctioning. In reaction, new 2014 ISDA Credit Derivatives Definitions were issued to offer a more comprehensive CDS definitions and increase CDS confidence (ISDA, 2014).

This dissertation essentially maps the abovementioned development by investigating several hypotheses in following three chapters each representing one empirical research article.

The first chapter analyses collateralized debt obligations (CDOs) and a period of the global financial crisis in 2007-2008. The origin of the global financial crisis lies in high volumes of subprime mortgages offered to households with a low credibility in the United States of America. The mortgages were securitized into mortgage backed securities (MBS) and then either directly sold to institutional investors or even combined with other MBS tranches and sold to institutional investors as a CDO. This way, the credit risk of the mortgages was spread to the whole financial sector. After some mortgage defaults, many institutions involved in this process were hit and some of them defaulted (such as Lehman Brothers or US mortgage agencies Fannie Mae and Freddie Mac). These involvements triggered a spiral of losses and downgrades exacerbated by diminishing liquidity: first settlements of CDO contracts, downgrades of MBS holders, consecutive downgrades of CDO holders and massive writedowns of many counterparties included in MBS or CDO business. This also resulted in CDS spreads widening and further mark-to-market losses. Some CDOs had to be terminated before maturity creating even higher losses. As a result of the high interdependence within a financial sector and its strong link to all business sectors, a series of problems of underlying companies led to a serious financial crisis.

To be more specific, Standard & Poors estimated that 3,000 CDO contracts were issued as of October, 2008 (Thomson Reuters, 2008), while 75% of synthetic CDOs sold swaps on Lehman Brothers. Moreover, 376 contracts included Kaupthing, Glitnir or Landsbanki and 1,500 contracts incorporated Washington Mutual and 1.200 contracts encompassed both Fannie Mae and Freddie Mac. In Europe 75% of all CDO deals contained at least one of the 7 large defaulted companies (Washington Mutual Inc., Lehman Brothers Holdings Inc., Fannie Mae, Freddie Mac, Glitnir. Kaupthing and Landsbanki). That implies that the CDO market lacked real diversification at that time. Non-diversified CDOs' portfolios, low cohesion of international financial markets together with the spiraling out of control mark-to-market losses and downgrades resulted in disastrous consequences.

The aim of the first paper is to contribute to the understanding of CDOs and shed light on CDO valuation based on data before and during the global financial crisis. Since CDOs rank among the most advanced structured products, the models used for their valuation are very complex. As a result, investors relied on the assessment of rating agencies without a proper understanding of the model. First, I explain a One Factor Gaussian Copula Model proposed by Li (2000) in context of the financial turmoil. It is a basic form of the CDO valuation model based on a principle of correlation of default times[1]. Then, I specify and demonstrate four main weaknesses of the CDO market and provide recommendations for the future existence and regulation of CDO markets.

The second chapter analyses credit default swaps and a period of the European debt crisis 2009-2013. Developments in Europe in this period have brought about discussions about sovereign default and financial markets witnessed a way of how European authorities act under the pressure of looming default. Also, terms and conditions of a CDS contract have been tested during the European debt crisis and did not pass. Elementary function of CDS was questioned. First, while

[1] The model values a CDO with plain vanilla underlying assets. However, undelying assets of a typical CDO before the crisis were structured bonds like MBS tranches (ESMA, 2012). These assets would make the valuation even more complex than the one presented in the first chapter.

Greece had been gradually heading towards default since 2009, the definition of the credit event that triggers CDS early settlement caused doubts. 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 the formulation of CDS terms.

There are two aspects that reflect proper functioning of the CDS markets:

1. A loss on an underlying asset truly triggers CDS settlement.
2. When the CDS settlement is triggered, investors are fully compensated for their losses.

Both of these aspects pointed to malfunctioning of the markets during the EU debt crisis. My aim is to evaluate the impact of this development on market prices of CDS.

Specifically, I analyse if and how recent developments in Europe influenced sovereign EMU CDSs market prices. I evaluate the CDS model price using the standard probabilistic CDS pricing model by Hull and White (2000) and compare it with the CDS market price using seemingly unrelated regression (SUR) model by Zellner (1962) to see whether there was any apparent change in this relationship between 2009 and 2013. My main hypothesis is that the relationship relaxed at the end of 2011 when first 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. In case it is confirmed, a more serious discussion about a CDS contract needs to be initiated. Not only the terms and conditions should be rephrased, but also the attitude of supranational organizations to sovereign default should be made more transparent.

The first version of the second chapter was finished before the end of 2013 (and first published in mid-2014 as an IES Working Paper No. 15/2014). It highlighted the deficiencies of the CDS contract and thereby called for its improved specification. In the last quarter of 2014 International Swaps and Derivatives Association (ISDA), which is responsible for the terms and conditions of standard CDS contract, actually updated them to account for these deficiencies.

The third chapter follows and extends the analysis performed in the second chapter. It investigates credit default swaps and a period around the change in the CDS terms and conditions by ISDA 2013 - 2015. The main question of interest of this chapter is whether this change in ISDA definitions lead to an increased trust in CDS instrument.

Specifically, two most important improvements relevant for sovereign default are:

1. Specification of credit event restructuring (and creation of a new credit event governmental intervention)
2. New asset package delivery provisions

The first improvement addressed the first aspect first mentioned in the second chapter, i.e. it clarified which action triggers the CDS early settlement. The second improvement addressed the second aspect mentioned above. If a bond holder receives a package of new bonds in a restructuring credit event, the settlement price of a CDS contract takes into account the new package structure.

There are two independent analyses performed in the chapter on a common data set of several Eurozone countries' CDS quotes and some other market variables ranging from October 2013 to October 2015. First, the link between the CDS price and bond price is observed using a break-point test and a SUR model. The principal use of sovereign CDSs is to hedge a sovereign default risk. The reasoning behind the analysis is that decreased trust in the CDS increases the deviation of CDS price changes from the bond price changes, because the CDS prices are driven by other factors than the bond prices. If there is a significantly increased link between the CDS price and the bond price after the change in the ISDA definitions, then it indicates increased trust in CDS instrument.

Second, long memory property of CDS quotes is analyzed using an autoregressive fractional integration moving average model combined with fractionally integrated generalized autoregressive conditional heteroscedasticity model (ARFIMA-FIGARCH). This model accounts for dual persistence of both CDS price changes and volatility of CDS price changes. The grounds for this analysis lie in the efficient market hypothesis by Fama (1970). In weak form efficient markets past development of prices cannot explain current prices. Transmitted to the long memory model application, if CDS price changes or volatilities of CDS price changes are predictable in long term, i.e. exhibit long memory, then the principal precondition for the validity of the weak form efficiency is not fulfilled. The observation period is divided by the effective date of the change in the ISDA definitions to compare the results of the model before and after the change. The reasoning behind the analysis is that increased trust in CDS restores efficiency of the market and decreases the extent of long memory that is present in the time series.

In the last chapter there is a short note on potential endogeneity issue with respect to models specified in Chapter 2 and Chapter 3. Chapter 4 thus complements results from the previous two chapters. Endogeneity in financial time series might be caused by simultaneity of variables and might result in inconsistent results. Some additional tests and calculations are performed that support the main findings of the thesis.

# 1. Collateralized Debt Obligation Valuation Using the One Factor Gaussian Copula Model

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*Abstract*

*The aim of this paper is to shed light on Collateralized Debt Obligation (CDO) valuation based on data before and during the 2007-2009 global turmoil. We present the One Factor Gaussian Copula Model and examine five hypotheses regarding CDO sensitivity to entry parameters. For our modeling we used data of the CDX NA IG 5Y V3 index from 20 September 2007 until 27 February 2009 and we appropriately transformed its quotes into CDO quotes. Based on the results we discovered four main deficiencies of the CDO market: i) an insufficient analysis of underlying assets by both investors and rating agencies; ii) investment decisions arise from the valuation model based on expected cash-flows, but they neglected other factors such as mark-to-market losses; iii) mispriced correlation; and finally iv) obligation of the mark-to-market valuation. Based on the mentioned recommendations we conclude that the CDO market has a chance to be regenerated but in smaller volumes compared to the pre-crisis period. However, it would then be more conscious, driven by smarter motives rather than by pure arbitrage and profit incentives.*

**Keywords:** collateralized debt obligations, copula function, valuation, securitization, One Factor Gaussian Copula Model

**JEL codes:** G01, G15, G17, C63

## 1.1. Introduction

By 2007, mounting defaults in the US sub-prime mortgage market led to US market instability, unleashing a global financial contagion that spread around the world, roiling markets and causing world economic upheaval. This contagion led to, for example, the nationalization of big financial institutions, bank failures, the end of an era in investment banking, increased federal insurance on banking deposits, government bailouts and opportunistic investments by sovereign wealth funds (Teplý, 2010a). Consequently, the world credit markets stalled significantly and raised the doubts of market participants and policymakers about the proper and fair valuation of financial derivatives and structured products such as collateralized debt obligations (CDOs).

The aim of the paper is to contribute to the understanding of CDOs and shed light on CDO valuation based on data before and during the current financial upheaval. Since CDOs rank among the more advanced structured products, the models used for their valuation are very complex and therefore investors often relied on assessment of rating agencies without a proper understanding of the model. After explaining the valuation model in context of the pending turmoil, we will be able to specify and demonstrate recent weaknesses of the CDO market and provide recommendations for the future existence and regulation of CDO markets.

This paper is organized as follows: after a brief introduction, we describe basic principles of CDOs. In Section 1.3 we present the One Factor Gaussian Copula Model. Although it is a relatively simple model, it suitably illustrates the main sensitivities and key features of CDO valuation. Moreover, it is more understandable. Section 1.4 develops the theoretical concept presented in the third section. In Section 1.5, we examine five hypotheses. Based on the outcomes, we detect main flaws of the CDO valuation and make relevant recommendations that should help to restore confidence of the CDO market. Finally, in conclusion we summarize the paper and state final remarks.

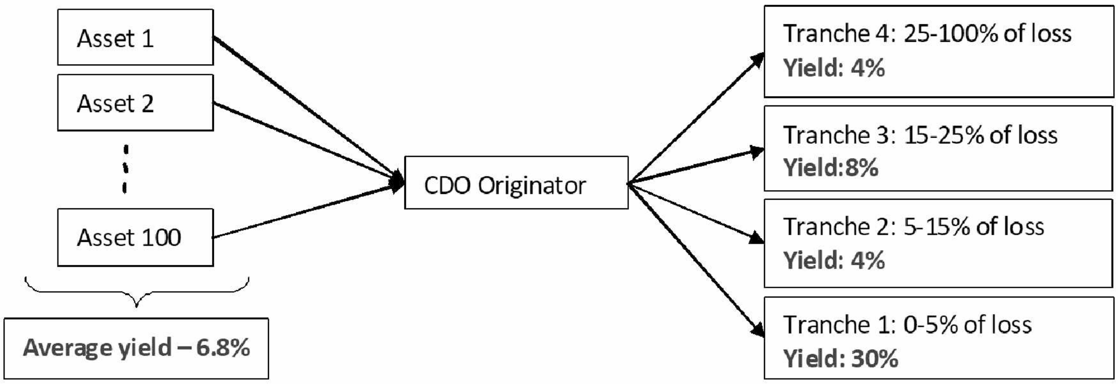
## 1.2. Basic principles of CDOs

### 1.2.1. CDO basics

IMF (2008) offers the following definition of a CDO: *"A structured credit security backed by a pool of securities, loans, or credit default swaps, where securitized interests in the security are divided into tranches with differing repayment and interest earning streams."* A CDO is a contract between an originator and an investor with specified maturity in which the originator commits to pay the investor regular premium payment until maturity. The investor in exchange promises to bear all the credit risk. In case of no default until maturity an originator continues to regularly pay the investor the premium. In case of default the investor compensates the originator the loss the originator suffered.

Moreover, CDO represents a product with a diverse risk structure. Through tranching it enables the investor to choose the amount of credit risk he would absorb based on his risk profile and appetite. The basic principle in a simplified form is sketched in the scheme below. An illustrative CDO is divided into four tranches, each absorbing a portion of the resulting cash flows or default impact; the first tranche holder compensates the issuer for the first 5% of defaults and the remainder flows are compensated by more senior tranches.

**Figure 1.1: Basic structure of a CDO**




**Source: Authors' calculations**

The paper analyses synthetic CDOs not only because they markedly outweighs cash CDOs in terms of volume but also its valuation is less complex. Synthetic CDO is an unfunded CDO where the underlying assets are not factually owned by an originator but they are acquired by selling CDS to chosen assets. The motive for a synthetic CDO originator is thus not a credit risk transfer but profit or capital relief. For more details about various types of CDOs see Fabozzi et al. (2008), Fabozzi and Kothari (2008) or Mejstřík et al. (2008).

### 1.2.2. CDO indices

CDOs are rank equivalent to an over the counter (OTC) products and hence no official exchange exists. CDO indices were established during times of high CDOs trade volume to achieve standardization in CDOs trading.

In our analysis we use the CDX index data. There are several advantages of using the CDX index compared to a single CDO for reasons such as diversification, transparency, or standardization. The main reason is its liquidity, i.e. reliable market quotes. Figure 1.2 shows an evolution of the CDX IG 5Y index Series 3 since 2004. It clearly reveals the main events on credit markets in the year 2008, i.e. Bear Stearns' bankruptcy in March 2008 and Lehman Brothers' collapse in September 2008. These events definitely confirmed serious troubles financial world went into.

**Figure 1.2: CDX IG 5Y index Series 3 (September 2004 – February 2009)**


**Source: Bloomberg**

### 1.2.3. CDO risks

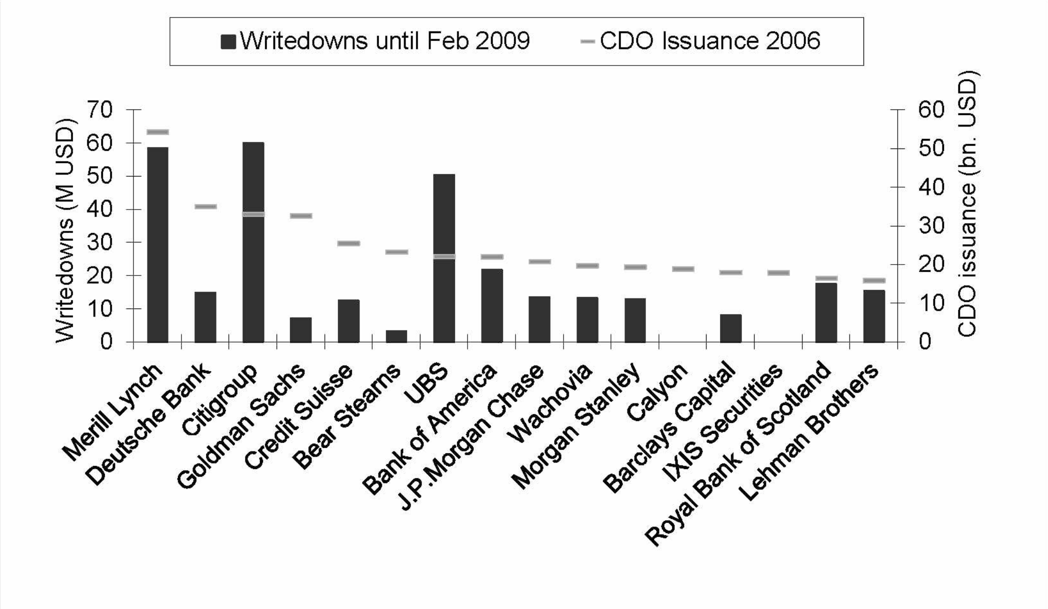
CDOs bear many risks for the investor such as interest rate risk, cross-currency risk, ramp-up risk and reinvestment risk (Fabozzi and Kothari, 2008); we will focus on the following two: i) correlation risk and ii) counterparty risk. By a correlation we mean the correlation between the defaults of underlying assets of a CDO. The higher the correlation the more fragile is the whole CDO structure. The importance of a correlation differs for different tranches' investors. Correlation also changes over time and depends on macroeconomic conditions. In times of a recession the correlation between assets tends to increase, whereas it is low in times of growth (Kakodkar et al., 2003). This is a very important feature which is essential to understand when investing in a CDO. Correlation will be discussed in more details in the following sections.

A CDO investor is subject to a counterparty risk of both a CDO issuer and all underlying assets' issuers. Usually, each CDO tranche is classified by a rating. This rating, however, can theoretically be reviewed and changed by a rating agency at any time. In previous years the rating agencies' assessment of risk was taken as gospel by all its users and they acted as if the rating was once given and irreversible. In fact, a default of one underlying asset can cause a downgrade of all tranches of a CDO. Consequently, not only a junior tranche investor is hit by the default but also a senior tranche investor suffers a loss – a mark-to-market loss – as the spread of the senior tranche soars. The threat of a downgrade of an asset and all its consequences based on numerical evidence will be further discussed in Section 1.5.

Figure 1.3 illustrates the above explained risks and their consequences. A right x-axis of the figure depicts institutions that issued more than USD 10 billion nominal value of CDOs in the most successful year 2006. The left x-axis shows the writedowns of the institutions since mid-2007 until February 2009. Citigroup with nearly USD 60 billion of writedowns was on the first place followed by Merrill Lynch and UBS. These writedowns have their roots in a high volume of subprime mortgages offered recklessly to households with a low credibility in the US. The mortgages were securitized into a mortgage backed securities (MBS) and then sold to institutional investors. In this way the credit risk of the mortgages was spread to the whole financial sector. After some mortgage defaults, many institutions involved in this process were hit and some of them even defaulted (such as Lehman Brothers or US mortgage agencies Fannie Mae and Freddie Mac).

These involvements triggered a spiral of losses and downgrades exacerbated by diminishing liquidity: first settlements of CDOs contracts, downgrades of MBS holders, consecutive downgrades of CDOs holders and massive writedowns of many counterparties included in MBS or CDOs business. This also resulted in CDS spreads widening and further mark-to-market losses. Some CDOs had to be terminated before maturity creating even higher losses. As a result of high interdependence within a financial sector and strong link of financial sector to all business sectors, a series of problems of underlying companies led to a serious financial crisis.

**Figure 1.3: Top CDO issuers and their writedowns as of February 2009 (in USD billions)**




**Source: Authors' calculations based on www.abalert.com**

### 1.2.4. CDO issuance

Although CDOs were first presented in 1980s, their issuance registered an outstanding growth since 2001 when most CDOs received a rating as the rating agencies became more familiar with CDOs (Fabozzi et al., 2008). In 2004 the worldwide CDOs issuance amounted to USD 157 billion and peaked in 2006 when totaled USD 521 billion. As a result of the financial turmoil, the CDOs issuance plummeted to mere USD 62 billion in 2008 (as of the end of 2008, total CDOs outstanding amounted to USD 870 billion) and to mere USD 4.3 billion in 2009. On other hand, in 1Q 2010 the CDOs issuance saw a year-on-year jump by 212% to USD 2.4 billion.

The high growth in CDOs activity in 2005 and 2006 was mainly due to arbitrage activity (i.e. profit motives) that replaced credit risk elimination (the initial motive of CDOs issuance). The highest tranches often obtained the highest possible score from rating agencies and therefore were wrongly considered a safe investment. However, as a result of the US mortgage crisis in 2007, the issuance of CDOs fell dramatically and the premiums the issuers were willing to pay for credit protection skyrocketed. As of October 2008 the CDO market was frozen and 67% of the CDOs issued since late 2005 to middle 2007 were in formal state of default (Thomson Reuters, 2008). Many institutional investors suffered massive write-downs (e.g. Citigroup, UBS or KBC), many of them were bailed-out (e.g. AIG, Royal Bank of Scotland or Northern Rock), while some were acquired by a stronger competitor (e.g. Bear Stearns, Merrill Lynch or Washington Mutual).

## 1.3. The One Factor Gaussian Copula model

The One Factor Gaussian Copula Model is a basic model of a CDO. Its basic form is based on a principle of correlation of default times firstly introduced by Li (2000). The main idea behind all CDO valuation models lies in determining such premium of a tranche that ensures the present value of premium payments equal to the present value of the loss payments implying that the total present value of the contract is zero. Both the loss payment and the premium payment depend on a number of defaults in the future and their timing, which further determines a time distribution of loss. As none of this is known, losses are random variables whose expected value should be computed within the model. First, we should determine the probability of default of an obligor by time $t$. Then, having this distribution for each obligor and combining it with a correlation structure among the obligors, we identify the joint distribution function. The factor model solves the problem with a correlation structure between obligors. The copula function approach introduces a quantitative way for coping with multidimensional distribution functions. After obtaining the joint distribution, it is straightforward to deduce the probability of number of defaults in each time period and the loss distribution.

The model can be extended either by using multiple factors instead of one (Hull and White, 2004), by assuming other than normal distribution of default times (Gregory and Laurent, 2004) or by modifying assumptions of entry parameters such as recovery rate or correlation (Wang et al., 2009). General theory of copulas can be found in Nelsen (2006), upgraded copulas theory and transformation of copulas is studied by Hájek and Mesiar (2008), Klement et al. (2005) or in Kybernetika (2008).

Suppose a CDO with $n$ underlying assets and denote $i$ an underlying asset, $i = 1, \dots, n$. Using One Factor Gaussian Copula Model our task is to set the premium payment $V$ for each tranche so that the present value of premium payments equals to the present value of loss payments. Such premium $V^*$ satisfies:

$$V^* = \frac{\sum_{k=1}^{T} B(t_0, t_k) \left[EL_{(K_A,K_D)}(t_k) - EL_{(K_A,K_D)}(t_{k-1})\right]}{\sum_{k=1}^{T} B(t_0, t_k)(t_k - t_{k-1})\left[1 - EL_{(K_A,K_D)}(t_k)\right]} \tag{1.1}$$

where $B(t_0, t_k)$ is a discount factor discounting from time $t_k$ , $k = 1, \dots, T$ to $t_0$ $(0 = t_0 < t_1 < \dots < t_T)$, thus $B(t_0, t_k) = exp\left(-\int_0^k f(0, s)ds\right)$, where $f(0, s)$ is a spot forward interest rate.

To determine optimal premium $V^*$ we need the expected loss function $EL_{(K_A,K_D)}(t_k)$ which is given by equation (1.2):

$$EL_{(K_A,K_D)}(t_k) = \frac{1}{K_D - K_A} \sum_{j=1}^{n} \left[ min\left( \frac{L_j(t_k)}{A \cdot n}; K_D \right) - K_A \right]^+ \cdot P(N(t_k) = j) \tag{1.2}$$

$K_A$ and $K_D$ define tranches, i.e. an attachment and detachment point (respectively) of a tranche expressed in percentage. We suppose the same volume of each underlying asset in the CDO pool and denote it $A$. $L_j(t_k)$ is a cumulative loss on the whole portfolio by time $t_k$ given $j$ defaults. To put it simply, to reach $EL_{(K_A,K_D)}(t_k)$ we count loss on a tranche for all cases of $j = 0,1,\dots,n$ defaults $\left[min\left(\frac{L_j(t_k)}{A \cdot n}; K_D\right) - K_A\right]^+$ and sum them weighted by their probability $P(N(t_k) = j)$. As other parameters of equation (1.2) are known, only the probability of $j$ defaults by time $t_k$, i.e. $P(N(t_k) = j)$ is to be determined.

Therefore, a random variable $\tau_i$ is introduced denoting a default time of $i$-th underlying asset, $i = 1,\dots,n$. It is essential for our calculation to deduce its properties.

The derivation is not straightforward; we divide it in two steps. In the first step we condition the probability on one factor $M$ which is supposed to be normally distributed:

$$X_i = \rho_i M + \sqrt{1 - \rho_i^2} \cdot \varepsilon_i \tag{1.3}$$

where $\varepsilon_i$ is a random variable with standard normal distribution, $i = 1,\dots,n$. In One factor model $\varepsilon_i$ and $M$ are independent. Therefore, also $X_i$ is a random variable with normal distribution. $\rho_i$ is a constant called loading factor, $|\rho_i| < 1$. Based on copula approach there is a link between $X_i$ and $\tau_i$. For a fixed $i$ suppose $\Phi(x)$ is a distribution function of $X_i$ and $F_i(t)$ is a distribution function of $\tau_i$. If $F_i$ is increasing, then there exists bilaterally unique correspondence between $t \in D_{F_i}$ and $x \in D_\Phi$[2] such that:

$$\begin{aligned} F_i(t) = P(\tau_i \le t) = P(X_i \le x) = \Phi(x) \quad or \\ t = F_i^{-1}(\Phi(x)) \quad resp. \quad x = \Phi^{-1}(\mathrm{F_i(t)}) \end{aligned} \tag{1.4}$$

i.e. $X_i$s are mapped to $\tau_i$ using a percentile-to-percentile transformation.

From now on we suppose a homogenous portfolio – i.e. the default times of all obligors have the same distribution - $\tau_i = \tau$ for all $i = 1,\dots,n$ and correlation among the default times is the same for each pair of obligors. That implies that also the loading factor is the same - $\rho_i = \rho$ for all $i = 1,\dots,n$. The number of defaults at time $t$ denoted $N(t)$ follows a binomial distribution, therefore:

$$\begin{aligned} & P(N(t) = j | M = m) \\ & \quad = \binom{n}{j} \cdot P^j(\tau \le t | M = m) \cdot \left(1 - P(\tau \le t | M = m)\right)^{n-j} \end{aligned} \tag{1.5}$$

where $P(\tau \le t | M = m)$ is derived from equation (1.6) using One Factor Gaussian Copula approach.

[2] $D$ is a standard notation of the definition scope

$$P(\tau \leq t|M = m) = \Phi\left(\frac{\Phi^{-1}(F(t) - \rho \cdot m)}{\sqrt{1-\rho^2}}\right) \quad (1.6)$$

The reason for conditioning in the first step is that based on the theory of copulas, the default times of obligors are mutually independent only conditionally on a factor value. Only having independent default times, the binomial distribution in equation (1.5) can be used.

In the second step we derive the unconditional probability using integral over $M$:

$$P(N(t) = j) = \int_{-\infty}^{\infty} \binom{n}{j} \cdot \left(\Phi\left(\frac{\Phi^{-1}(F(t) - \rho \cdot m)}{\sqrt{1-\rho^2}}\right)\right)^j \cdot \left(1 - \Phi\left(\frac{\Phi^{-1}(F(t) - \rho \cdot m)}{\sqrt{1-\rho^2}}\right)\right)^{n-j} \cdot \phi(m)dm \quad (1.7)$$

Given the mathematical background, in the following section we will present some practical aspects of the valuation. Consequently, parameters of the model will be chosen appropriately given recent improvements in CDO pricing. Finally, we will value the CDX index and its tranches before and during the financial crisis, implement comparative statistics and assess its sensitivity in context with the current financial crisis.

## 1.4. Implementation of CDO valuation

In this section we will show how to implement the valuation of a CDO contract following the theoretical concept introduced in the previous part. All market data were taken from Bloomberg. To implement the valuation it is necessary to adopt some assumptions about the entry parameters. The main is the distribution of $\tau$ and pairwise correlation $\rho$.

One useful measure of probability distribution of $\tau$ is hazard rate function $h(t)$ defined in Li (1998):

$$h(t) = \frac{f(t)}{1 - F(t)} \quad (1.8)$$

where $F(t)$ is the distribution function of $\tau$ and is $f(t)$ is the density of the default times. After some derivations we obtain:

$$f(t) = h(t)exp\left(-\int_0^t h(s)ds\right) \quad (1.9)$$

We suppose that the hazard rate function is constant at some level called hazard rate and denoted by λ. Based on this assumption the density of the default time simplifies to an exponential one:

$$f(t) = \lambda \cdot exp(-\lambda t) \quad (1.10)$$

Hazard rate of an asset is then deduced from the market quotes of credit default swap (CDS).

Concerning correlation, the correlation parameter is defined as a loading factor in the One factor model in equation (1.3). We suppose that correlation is the same for each pair of assets. There are two approaches to correlation determination: implied correlation and base correlation. In both approaches the correlation is determined endogenously. Implied correlation is defined as a correlation for which the net present value of a tranche equals zero. The base correlation approach is more complex. Suppose a CDX index with following tranching: (0-3)%, (3-7)%, (7-10)%, (10-15)% and (15-30)%. Now imagine a non-existing series of tranches (0-7)%, (0-10)%, (0-15)% and (0-30)%. Base correlation is a value of correlation that sets the non-existing tranches' values to zero.

Theoretically, the implied and base correlation should be the same for all tranches and subsets of tranches. The discussion of values of correlation in imperfect markets will follow. Generally, it is observed that it differs through tranches and even through time. For more discussion about correlation see Fabozzi and Kothari (2008) or Benešová and Teplý (2010).

## 1.5. Results of the model

The aim of this section is to illustrate CDO pricing using the model presented in Section 1.3 based on assumptions taken in Section 1.4. We run the calculation introduced above to show market risk of a CDO and to model the mark-to-market loss of a holder of senior tranches (i.e. we demonstrate what were the consequences of massive and naive investment in AAA rated tranches and why the CDO market nearly ceased to exist).

The section consists of three parts. At the beginning we briefly discuss the data used for our research. In the second part we determine a relation of each tranche's premium to correlation and hazard rate. We also analyze a loss after default and show the implications of three actual defaults on recent data. As we have examined data of an index instead of a CDO, we estimate how a real CDO would have behaved in two recent years, which were affected by the financial crisis. The last part deals with an overall assessment of the CDO market, its weaknesses and its role in the crisis and contribution to the crisis. The main flaws of the market are spotted and their correction is proposed.

### 1.5.1. Data used

As we discussed above, the volume of CDOs trades fell dramatically in 2008 after years of growth and the liquidity of the market disappeared. CDS index valuation will be implemented due to both difficulties to get market data and low level of liquidity of CDOs. We choose the most traded series of the main CDX index – 9 and maturity – 5 years (usually noted as CDX NA IG 5Y V3). This index originally counted 125 underlying bonds issued by North American companies. The effective date of the index was 20 September 2007. Since then there have been 3 defaults of underlying companies (Federal Home Loan Mortgage Corporation, Federal National Mortgage Association and Washington Mutual). After each event of default a new version of the index had to be launched so that new index investors had a starting position with no defaults and continuity of the index was sustained. First two defaults were settled at once; therefore a third version of this index was trading at the time of the valuation.

### 1.5.2. Examination of hypotheses

We examine five hypotheses about the entry parameters. Hypotheses 1, 2 and 3 are concerned with correlation within the CDO model, the Hypothesis 4 deals with the hazard rate and Hypothesis 5 raises the issue of mark-to-market valuation.

**Correlation evaluation (Hypotheses 1, 2 and 3)**

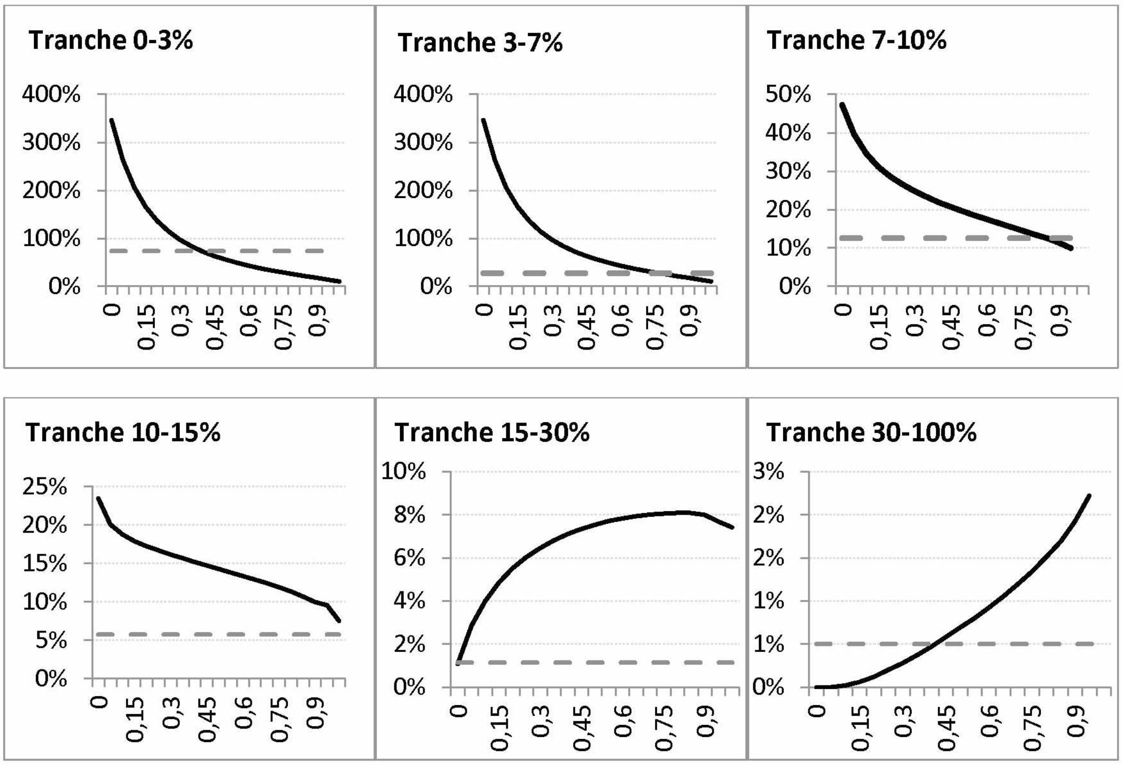
*Hypothesis 1: The higher the asset correlation, the lower the risk premium for a junior tranche and the higher the risk premium for a senior tranche.*

A correlation parameter shows the correlation between each pair of underlying assets. Figure 1.5 shows the role of correlation in each tranche. We fixed the hazard rate at 0.07 and calculated the premium of a tranche for a varying levels of correlation on vertical axis.

For the most junior tranche (0-3%) the premium is a decreasing function of correlation whereas for the most senior tranche the premium increases with correlation (see Figure 1.4). The mezzanine tranches are less sensitive to correlation. Moreover, the relation between correlation and premium does not always have to be monotonic (see results for the 15-30% tranche). Higher correlation has a lower value for an investor buying protection on the equity tranche as he is willing to pay less to the protection buyer. The opposite holds for the senior tranche investor for whom higher correlation has a higher value. To conclude, the model confirms Hypothesis 1.

For proper CDO valuation we need to determine the level of correlation. First, we will use the implied correlation. See Table 1.1 for the results of the valuation based on different values of correlation. In the first row there are market quotes of CDX tranches on 28 February 2009. For the three lowest tranches the values displayed are already recalculated to the upfront payment quotes. Market quote of the tranche is also incorporated in Figure 1.5 by a light grey line and its intersection point with the black line determines the implied correlation.

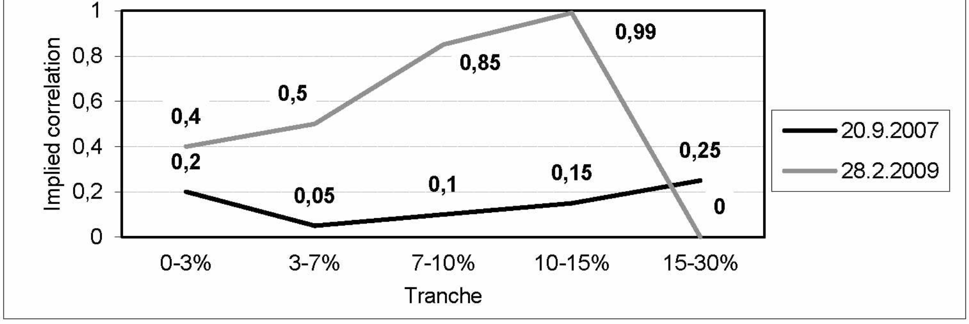
**Figure 1.4: Tranche premium for a given level of correlation (as of 28 February 2009)**




**Source: Authors' calculations**

Table 1.1 displays that the correlation differs substantially among tranches. The difference between implied correlations is a usual outcome of CDO valuation models (Hull and White, 2004 or Amato and Gyntelberg, 2005)). This is sometimes called "correlation smile" and points to both imperfection of the model and the fact that market quotes comprise other factors that are not included in the model. Figure 1.6 compares implied correlation of tranches on 28 February 2009 and 20 September 2007 and demonstrates that implied correlation was more stable through tranches in September 2007. Therefore, we conclude that distressed markets and inappropriate valuation of tranches caused current huge variations of implied correlation among tranches in February 2009.

**Figure 1.5: Implied correlation of tranches on 28 February 2009 and 20 September 2007**




**Source: Authors' calculations**

**Table 1.1: Results of valuation on 28 February 2009 with hazard rate of 0.07**

| | Tranche 0-3% | Tranche 3-7% | Tranche 7-10% | Tranche 10-15% | Tranche 15-30% | Tranche 30-100% |
|---|---|---|---|---|---|---|
| Market 28/2/2009 | 81.72% | 53.85% | 22.97% | 7.72% | 1.14% | 0.50% |
| correlation | | | | | | |
| 0.00 | 98.02% | 92.86% | 86.68% | 23.45% | **1.08%** | 0.00% |
| 0.05 | 97.46% | 90.37% | 75.91% | 20.07% | 2.85% | 0.00% |
| 0.10 | 96.59% | 85.87% | 67.40% | 18.76% | 4.00% | 2.00% |
| 0.15 | 95.21% | 80.89% | 61.18% | 17.91% | 4.85% | 0.06% |
| 0.20 | 93.28% | 76.01% | 56.34% | 17.24% | 5.51% | 0.12% |
| 0.25 | 90.88% | 71.39% | 52.34% | 16.67% | 6.03% | 0.20% |
| 0.30 | 88.08% | 67.03% | 44.91% | 16.15% | 6.45% | 0.28% |
| 0.35 | 84.95% | 62.98% | 45.88% | 15.66% | 6.80% | 0.37% |
| 0.40 | **81.54%** | 59.12% | 43.12% | 15.19% | 7.09% | **0.47%** |
| 0.45 | 77.87% | 55.44% | 40.56% | 14.73% | 7.33% | 0.58% |
| 0.50 | 73.98% | **51.89%** | 38.15% | 14.28% | 7.53% | 0.69% |
| 0.55 | 69.87% | 48.45% | 35.84% | 13.82% | 7.70% | 0.80% |
| 0.60 | 65.53% | 45.07% | 33.59% | 13.36% | 7.82% | 0.92% |
| 0.65 | 60.97% | 41.72% | 31.36% | 12.90% | 7.93% | 1.05% |
| 0.70 | 56.15% | 38.36% | 29.13% | 12.41% | 8.00% | 1.19% |
| 0.75 | 51.02% | 34.94% | 26.79% | 11.90% | 8.05% | 1.34% |
| 0.80 | 45.52% | 31.40% | 24.34% | 11.34% | 8.08% | 1.51% |
| 0.85 | 39.46% | 27.51% | **22.10%** | 10.66% | 8.07% | 1.69% |
| 0.90 | 32.68% | 22.44% | 18.82% | 9.99% | 7.98% | 1.92% |
| 0.95 | 24.52% | 17.62% | 15.12% | 9.54% | 7.67% | 2.22% |
| 0.99 | 15.30% | 12.67% | 8.71% | **7.51%** | 7.41% | 2.64% |
| **Implied correlation** | **0.40** | **0.50** | **0.85** | **0.99** | **0.00** | **0.40** |

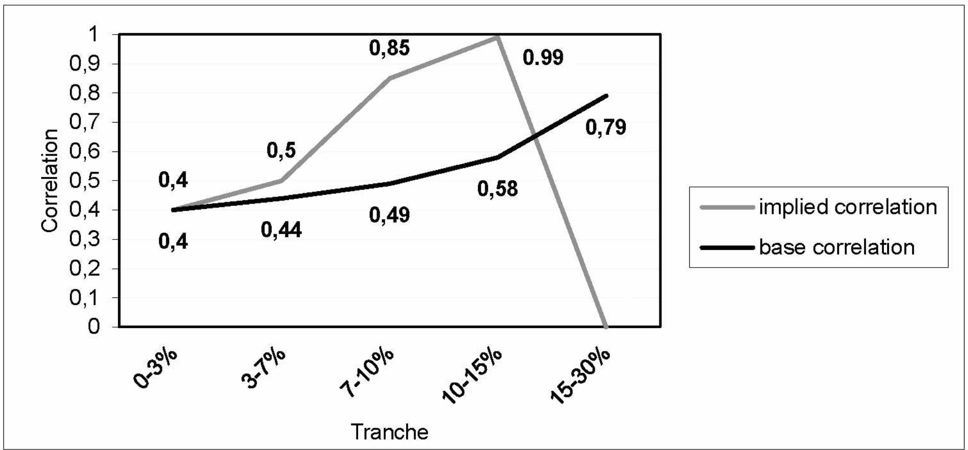
Note: The second row shows market CDX prices as of 28-Feb, 2009. Below, results of CDX valuation are shown for each correlation (rows) and tranche (columns). Bold values in the body of the table are the closest to the market price. Implied correlation is the value of correlation correspondent to the market price. It is then copied to the last row of the table.
**Source: Authors' calculations**

*Hypothesis 2: Base correlation is a more stable measure of correlation than implied correlation.*

As Figure 1.7 depicts, base correlation recorded less variance than the implied correlation as of 28 February 2009. To illustrate this, suppose an investment in all tranches of a CDO totaling USD 1 million. The distribution of the notional among tranches is given by their attachment and detachment points (e.g. we invest USD 30,000 in equity tranche, USD 40,000 in 3-7% tranche etc.).

First, we start with the equity tranche where the base correlation equals the implied correlation, then we need to evaluate the base correlation for the two lowest tranches. Taking correlation of 0.4, the present value of the 0-3% tranche equals 0 and present value of the 3-7% tranche is negative. Both these tranches' premiums are decreasing in correlation (see Table 1.1). Therefore, we run the calculation with a higher value of correlation given market quotes which increases the present value of both tranches. Setting correlation to 0.44 we obtain the present value of the 0-3% tranche worth USD +3,200 and the present value of the 3-7% tranche worth USD -3,200. Therefore 0.44 is the base correlation for the two lowest tranches.

**Figure 1.6: Base and implied correlation for tranches on 28 February 2009**



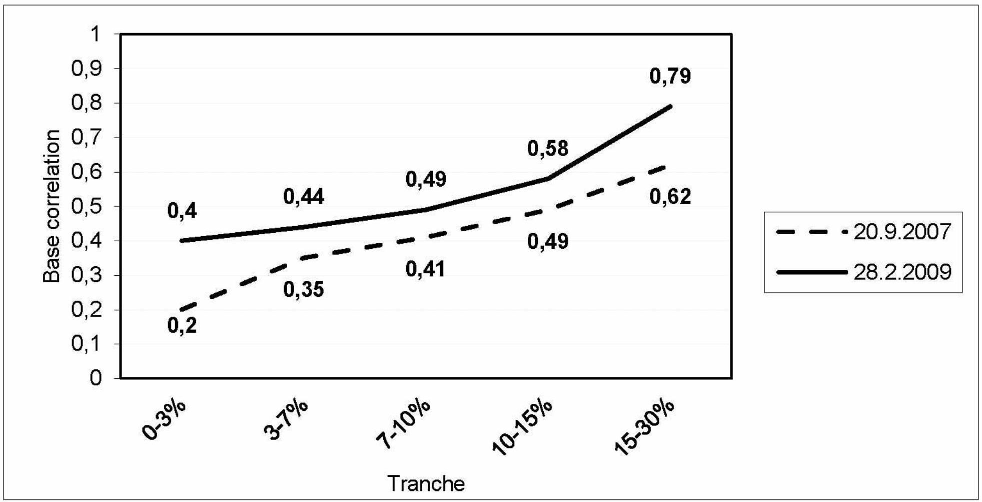

**Source: Authors' calculations**

We continue in this manner to determine the base correlation for all other tranches. The base correlation is, by definition, monotonically increasing in correlation and according to our calculations it is more stable than the implied correlation, which is in compliance with Hypothesis 2.

*Hypothesis 3: Correlation and hazard rate changed between 20 September 2007 and 28 February 2009*

In case of a standard CDO, the most senior tranche (30-100%) is not sold to protection sellers and is usually retained by the issuer and therefore not included into our calculations. Figure 1.7 shows the evolution of base correlation during the financial crisis and clearly demonstrates that the base correlation changed in the observed period. That approves the first part of Hypothesis 3. The second part of the hypothesis regarding the hazard rate is discussed in 1.5.2.

**Figure 1.7: Base correlation of tranches on 28 February 2009 and 20 September 2007**



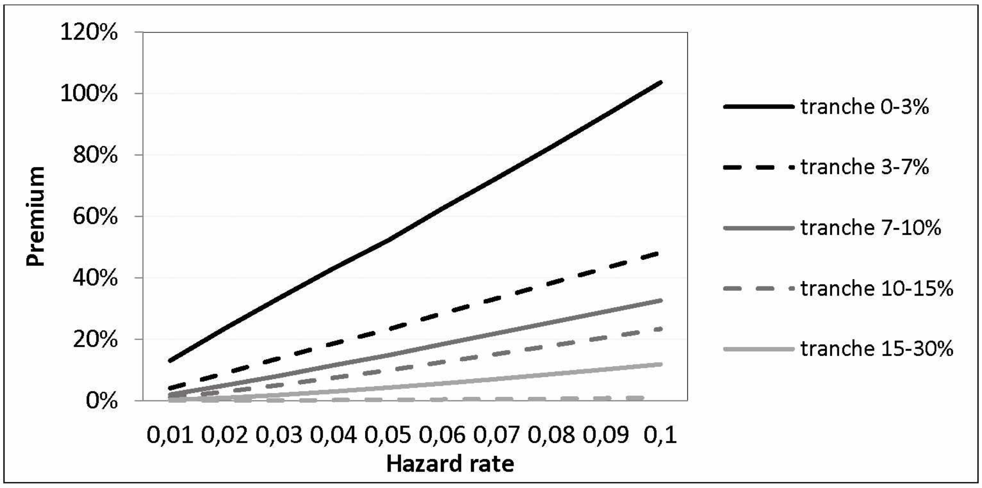

**Source: Authors' calculations**

## Hazard rate and tranche premium evaluation (Hypothesis 4)

*Hypothesis 4: Higher hazard rate increases the premium of all tranches more than proportionally*

Hazard rate for an asset is calculated from the credit default swap quote and recovery rate. Higher premium of a CDO implies a higher credit risk of an asset. The premium of any CDO tranche based on a pool of assets also increases. Higher recovery rate adverts to lower loss given default and therefore the premium of a CDO tranche would be lower (Figure 1.8). We assume a constant correlation of 0.4.

**Figure 1.8: Tranche's premium with respect to a hazard rate on 28 February 2009**




**Source: Authors' calculations**

Moreover, by zooming in Figure 1.8 we would see that the higher the seniority of the tranche, the more convex the relation between the premium and hazard rates. The higher the hazard rate, the higher the compensation in form of tranche's premium has to be to offset increased credit risk. Accordingly, the mark-to-market loss on the senior tranche in case of an increase of hazard rate has to be expected higher for higher starting level of the hazard rate. This is in line with Hypothesis 4.

**Loss evaluation (Hypothesis 5)**

*Hypothesis 5: There has been a substantial loss on the most senior tranche without a necessity to be hit directly by a default.*

We already mentioned an expressive increase of credit risk during the financial upheaval. The premiums of the tranches often multiplied in the crisis even despite the fact that after each default the index was recalculated. In this part, we will transform the CDX to a CDO, i.e. we will abolish the feature of the new version of the index following each default. The loss after a default can be separated to three parts according to a consequence: i) increased perception of credit risk; ii) new definition of tranche attachment and detachment point and iii) settlement of the defaulted asset. The first part points to a pure increase of fear on the market. Numerically it is expressed by an increase of hazard rate and correlation between assets. The second part of the loss is numerically expressed by a decrease of a number of underlying assets given fixed volume and decrease of attachment and detachment points' absolute values by the notional of the defaulted assets, both with fixed hazard rate and correlation. The third part of the loss bears only one tranche depending on sequences of the default.

**Table 1.2: Change of a premium and loss on a tranche after 1-3 defaults and hazard rate**

| | Tranche | 0-3% | | 3-7% | 7-10% | 10-15% | 15-30% |
|---|---|---|---|---|---|---|---|
| **NO DEFAULT** | **Premium** | **19.38%** | | **3.83%** | **1.12%** | **0.35%** | **0.03%** |
| | | | **Total loss** | | | | |
| 1 DEFAULT | Premium | 24.09% | | 5.2% | 1.42% | 0.43% | 0.04% |
| | Loss | -11.15% | -24.18% | -4.71% | -1.09% | -0.30% | -0.04% |
| 2 DEFAULTS | Premium | 32.17% | | 7.25% | 1.81% | 0.54% | 0.05% |
| | Loss | -26.34% | -44.29% | -11.29% | -2.53% | -0.69% | -0.08% |
| 3 DEFAULTS | Premium | 48.37% | | 10.66% | 2.36% | 0.67% | 0.06% |
| | Loss | -46.42% | -57.28% | -21.03% | -4.49% | -1.20% | -0.12% |

**Source: Authors' calculations**

Table 1.2 offers an illustration of the second and third part of a loss. Note that the premium for the highest tranche doubles (from 0.03% with no default to 0.06% after three defaults) with three defaults even if the change of correlation and hazard rate during time is not included. The total loss including the risk aversion increase and market mode is evaluated in further paragraphs.

In our calculation we suppose a CDO tranche buyer who entered the CDO contract on 20 September 2007 and held the CDO until 28 February 2009. This implies that his CDO suffered three defaults during its life. Our task is to evaluate his loss on 28 February 2009 based on the difference between the premium he agreed and the current fair premium based on expected cashflows. First, we evaluate the CDO as of the issue date. Consequently, we evaluate it on the valuation date with new parameters (Table 1.3).

**Table 1.3: Changes in parameters of the model between 28 Feb 2009 and 20 Sep 2007**

| | 20.9.2007 | 28.2.2009 |
|---|---|---|
| Correlation | 0.32 | 0.44 |
| Hazard rate | 0.01 | 0.07 |
| Number of assets | 125 | 122 |
| Notional invested | USD 100 mil. | USD 97.6 mil. |
| AP and DP | | -2.4 percentage points |

Note: AP = attachment point, DP = detachment point
**Source: Authors' calculations**

The hazard rate was deduced from the credit default swap spreads of the underlying assets based on 0.39 recovery rate and it has increased seven times since autumn 2008. That approves the second part of Hypothesis 3 and points to increased fear on the market. The correlation also increased. It is set as an average base correlation for the three lowest tranches (Figure 1.8). Compared to Table 1.2 in Table 1.4 the effect of an increase of correlation and hazard rate is included to determine the total loss of each tranche.

**Table 1.4: Mark-to-market loss on a CDO tranche on 28 Feb 2009**

**(using USD 10 million initial investment)**

| | | Tranche | | | | |
|---|---|---|---|---|---|---|
| | | **0-3%** | **3-7%** | **7-10%** | **10-15%** | **15-30%** |
| 20.9.2007 | Premium | **14.69%** | **4.21%** | **1.89%** | **0.88%** | **0.19%** |
| 28.2.2009 | Premium | **121.10%** | **46.94%** | **26.52%** | **17.76%** | **8.37%** |
| | % M-t-M Loss | -82.12% | -71.28% | -57.39% | -46.13% | -26.59% |
| | **M-t-M Loss** | **1 642 400** | **7 128 000** | **5 739 000** | **4 613 000** | **2 659 000** |

**Source: Authors' calculations**

We should note that what we call the mark-to-market loss is in fact the loss based on changed values of expected cash-flows (i.e. the loss based on mark-to-market change of entry parameters and the tranches are still valued by the model). The real mark-to-market loss would have to be derived from the market value of an instrument based on the fair value accounting principle. There are no available market data to a particular CDO but we can deduce from Figure 1.2 that this loss would be much higher. In fact, we might assume that such CDO contract would have to be terminated before our valuation date. The reason is that we did not fully included other risks, such as liquidity risk and market sentiment (despite that these factors being partly included in the hazard rate).

The outcomes of our model using the expected cashflows are alarming. The premium on the most senior tranche increased 44 times in the observed period, while the loss on this tranche amounted 26.50% of the notional amount. We should mention that these senior tranches usually got the highest possible rating scores indicating poor risk assessment of CDOs from rating agencies. As a consequence, the data confirm Hypothesis 5.

Even though only the equity tranche investors were factually hit by the defaults, all tranches were hit indirectly - in form of mark-to-market losses - regardless of their rating. Although it is improbable that more than 18 defaults occur resulting in a direct hit of the 15-30% tranche, its mark-to-market loss is high. Even if the investor decided to hold the tranche to maturity, as a financial institution it would have to report a significant loss in its accounting.

### 1.5.3. Four main flaws of the CDO market

As a consequence of the financial turmoil, financial institutions have suffered from massive writedowns of derivatives and financial instruments in their books (Figure 1.3). It is worthwhile to note that the majority of these writedowns resulted from only seven credit events (Washington Mutual Inc., Lehman Brothers Holdings Inc., Fannie Mae, Freddie Mac, Glitnir, Kaupthing and Landsbanki). These seven companies often represented either a counterparty or an issuer of an undelying asset in the credit derivative. After these credit events numerous downgrades by rating agencies followed. The agencies downgraded the tranches of CDOs with underlying assets issued by any of these seven companies (for example, Standard & Poor's downgraded 791 tranches of CDOs during one week in December 2008). As a result, the companies that held large positions in these CDOs had to be downgraded too (for instance. AIG, MBIA or Ambac were downgraded due to CDS hedging their CDOs positions losses). Frequently these companies were also included in CDOs and therefore caused further downgrades and mark-to-market losses. Thus the mortgage crisis was no doubt the trigger of the following complex credit crunch. What went wrong that the losses were so high and CDOs market collapsed after a couple of defaults?

Standard & Poors estimated that 3,000 CDOs contracts were issued as of September 2008 (Thomson Reuters, 2008), while 75% of synthetic CDOs sold swaps on Lehman Brothers. Moreover, 376 contracts included Kaupthing, Glitnir or Landsbanki and 1,500 contracts incorporated Washington Mutual and 1,200 contracts encompassed both Fannie Mae and Freddie Mac. In Europe, 75% of all CDOs deals contained at least one of the 7 defaulted companies. That implies that the CDO market lacked real diversification at that time. Non-diversified portfolios of CDOs, low cohesion of international financial markets together with the spiraling out of control of mark-to-market losses and downgrades resulted in disastrous consequences. We suggest four main weaknesses of the CDO market, their effects and lessons that should be learnt.

First, CDOs investors did not undertake a deeper analysis of CDOs underlying assets. It should have been alarming that in many cases the issued volume of a bond was much lower than the total volume included in CDOs contracts. Rating agencies should have also reflected low diversification and the threat of CDO market breakdown after even a few defaults (due to advanced complexity of the CDO market).

Second, the valuation model comprehension was often incomplete. Neither was the basic model introduced in Section 1.3 comprehended by the investors as they relied on ratings and did not concern themselves why a bond rated AAA by S&P yielded less than a CDO tranche with the same rating. The valuation model is a probability model which derives a price of a CDO based on a probability of default. The extreme case of multiple credit events is taken into account - it is priced in. Its probability is low but not zero, such that it can happen – and it happened. Moreover, the valuation models are based on future expected cash-flows and show the value for investors who hold a CDO to maturity and hence should not be valued on the mark-to-market principle. If an investor buys a senior tranche, after three defaults the chance of being hit is still very low and his cash-flow would remain unchanged and therefore the basic idea of the model was correct. However, the model doesn't take into account mark-to-market losses. This should have been understood by the majority of investors that have to disclose the mark-to-market value of their assets. Stress tests on changing input parameters – hazard rate and correlation – in combination with credit events should have been run (similar to Table 1.2 and Table 1.4). Last but not least, the resulting losses based on model quotes can be only considered as the lower bound of losses, because the market quotes tend to overreact in bad times. This complex analysis would lead to a better risk assessment of a CDO and higher premiums required from a CDO seller.

Third, the correlation was obviously mispriced in the model. As explained in Section 1.4, both the implied and base correlations are derived from CDO market quotes. In the previous paragraph we argued that the tranches were mispriced and therefore neither the correlation value was correct. Only after the market proper valuation of a CDO the actual value of correlation can be derived. Technically, market participants underestimated the possibility of an increase of correlation of the default times and the speed of the contagion.

Finally, the mark-to-market valuation principle according to the US law should be reconsidered. After the mentioned defaults the CDO market froze and the quotes of tranches plummeted. However, all financial institutions still had to value their assets according to these market quotes, in spite of their intention to hold CDOs until maturity. As a consequence, this obligation has induced multiple losses. In October 2008 the Emergency Economic Stabilization Act (often referred to as a bailout of the US financial system) was pronounced in the US. Primarily, the Act set apart USD 700 billion for a purchase of distressed assets and capital injection for the US banks. Additionally, it also allowed, in some cases suspending the mark-to-market accounting. Instead the value of a distressed asset can be derived from the expected value of cash-flows, i.e. it can be valued according to the model. As discussed in Section 1.5.2, such valuation would cause huge losses after the default and change of input parameters, but in a lesser extent compared to the use of distressed market quotes.

## 1.6. Conclusion

The world CDO market has undoubtedly experienced a serious shock since late 2007. In this paper we researched the main flaws of the CDO market that caused extensive writedowns from CDOs for many financial institutions worldwide. We presented the One Factor Model based on a Gaussian copula and developed a simple valuation program in VBA/MS Excel in which we run simulations to test five hypotheses. Based on the results we discovered four main deficiencies of the CDO market and made our recommendation for their elimination.

Specifically, for our modeling we used the CDX index data from 20 September 2007 until 27 February 2009 the quotes of which we appropriately transformed to CDOs quotes. Then we ran our valuation with varying entry parameters to show the sensitivities of all tranches. Finally, we compared a model value of a tranche before and during the crisis to value a loss of CDO investors based on changed expected cash-flows. We concluded that this loss constitutes a lower bound of real mark-to-market losses incurred by investors.

The first identified deficiency was an insufficient analysis of underlying assets by both investors and rating agencies. The fact that seven financial institutions that defaulted since September to December 2008 were included in 75% of all European synthetic CDOs should be alarming. Such a poor diversification has resulted in chain reaction of losses and downgrades of institutions and CDO tranches after these few defaults. Therefore, a deeper analysis of diversification effects and quality of underlying assets should be implemented in the future. Low understanding of the valuation model caused the second deficiency. Since the structure and the valuation of a CDO remains quite sophisticated, investors relied on a high rating of senior CDO tranches without understanding the main underlying risks. The model is based on expected cash-flows. The possibility of mark-to-market losses of the tranches should have been included in CDO investment decision. Results of stress-testing of tranches would have increased the expected premium payments and would better reflect higher credit risk involved. The third deficiency we found was the fact that also correlation was also mispriced. Both implied and base correlations derive from the market quotes which were artificially lowered by improper market optimism. Only after a deep understanding of the CDO valuation model the correlation should have been priced correctly. Also, market participants underestimated the possibility of an increase of correlation. Finally, as we numerically demonstrated, the mark-to-market valuation obligation for financial institutions should be reviewed and it should be possible to back out of it in cases of a frozen market when risk premiums explode. Accordingly, the expected cash-flows valuation should be considered, especially if the instrument is held to maturity. Otherwise a next set of writedowns and downgrades may be triggered.

Based on the mentioned recommendations we conclude that the CDO market has a chance to be regenerated but in much smaller volumes compared to the pre-crisis period. Securitization and credit market is needed but the trades have to be done rationally and deliberately which was not the case of past couple of years. The future CDO market would then be more conscious, driven by smarter motives and less extensive.

# 2. 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 chapter 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.*

**JEL classification:** C22, G01, G12

**Keywords:** credit default swap, debt crisis, Chow breakpoint test, reduced form valuation model, seemingly unrelated regression

## 2.1. 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 as an 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 chapter, 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.

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 chapter is divided into eight sections. Section 2.2 presents our motivation in detail, analyzing the historical context. Section 2.3 provides a review of the available literature in this field. In Section 2.4, we present all data needed for a consecutive analysis. Our empirical analysis is performed in the next three sections. In Section 2.5, we evaluate the CDS model price using a basic no-arbitrage model. In Section 2.6, we estimate single equation regressions and look for breakpoints in the regressions. In Section 2.7, the main model is estimated using seemingly unrelated regressions. Section 2.8 provides policy recommendations in the context of our results. Section 2.9 concludes the paper and discusses possibilities of further research.

## 2.2. Historical context and motivation

The European sovereign debt crisis brought forth an 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[3] 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. This situation was supported by European political authorities by saying that the interests of all key institutions are preserved by avoiding a fully fledged, recognized default and ignoring a trade off between write-offs and lending (The Guardian, 2011). 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.

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 of an 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.[4] 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

[3] 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.

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

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.[5] 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 settlement 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 on an 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.

## 2.3. 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 chapter, 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

[5] 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.

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 out an 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 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.

## 2.4. Data specification

The time series data downloaded from Bloomberg and used for the purposes of this chapter are summarized in Table 2.1.

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.

**Table 2.1: 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 | |
| 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 | 5Y, 10Y |
| cross-currency swap | bid and ask swap rate | | EUR/USD | EUBS5, EUBS10 Curncy | |

Government bond yields enable us to evaluate CDSs and reach the CDS model price in Section 2.5. The resulting model CDSs have a different denomination than market CDSs. Therefore, market CDSs are adjusted by the EUR/USD cross-currency swap value.[6]

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.

[6] 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.

Therefore, we included proxies of both of these factors in the regression analysis in Section 2.6 and Section 2.7.

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 2.1. 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.[7]

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. 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.

[7] 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.

## 2.5. 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 play an 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.

### 2.5.1. 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 chapter 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 $t_1 < t_2 < t_3 < ... < t_N$. 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, if an 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 $\alpha_{ij}$ is

$$\alpha_{ij} = v(t_i)\left[F_j(t_i) - RC_j(t_i)\right]. \tag{2.1}$$

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:

$$G_j - B_j = \sum_{i=1}^{j} q_i \beta_{ij}, \tag{2.2}$$

where $\beta_{ij} = \int_{t_{i-1}}^{t_i} v(t)\left[F_j(t) - RC_j(t)\right]dt$. From equation (2.2) we can deductively calculate $q$:

$$q_j = \frac{G_j - B_j - \sum_{i=1}^{j-1} q_i \beta_{ij}}{\beta_{jj}} \tag{2.3}$$

### 2.5.2. 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 $\pi$.

$$\pi = 1 - \int_0^T q(t)dt \tag{2.4}$$

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

$$w\int_0^T q(t)[u(t) + e(t)]dt + w\pi u(T), \tag{2.5}$$

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 of an 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 (2.5) 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 $R$: $1-[1+A(t)]R$. The expected present value of the CDS payoff is then

$$\int_0^T [1 - R - A(t)R]q(t)v(t)dt \tag{2.6}$$

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 (2.5) and (2.6) equal:

$$s = \frac{\int_0^T [1 - R - A(t)R]q(t)v(t)dt}{\int_0^T q(t)[u(t) + e(t)]dt + \pi u(T)} \tag{2.7}$$

The value of $s$ in equation (2.7) then shows the yearly CDS premium payment expressed as a percentage of the CDS nominal amount.

### 2.5.3. 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 2.4. For each country, we extracted the probability of default in equation (2.3) 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.[8] 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 is an average sovereign issuer-weighted recovery rate from 1983 to 2010 according to an 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-

[8] 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.

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 is an 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%. It 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).

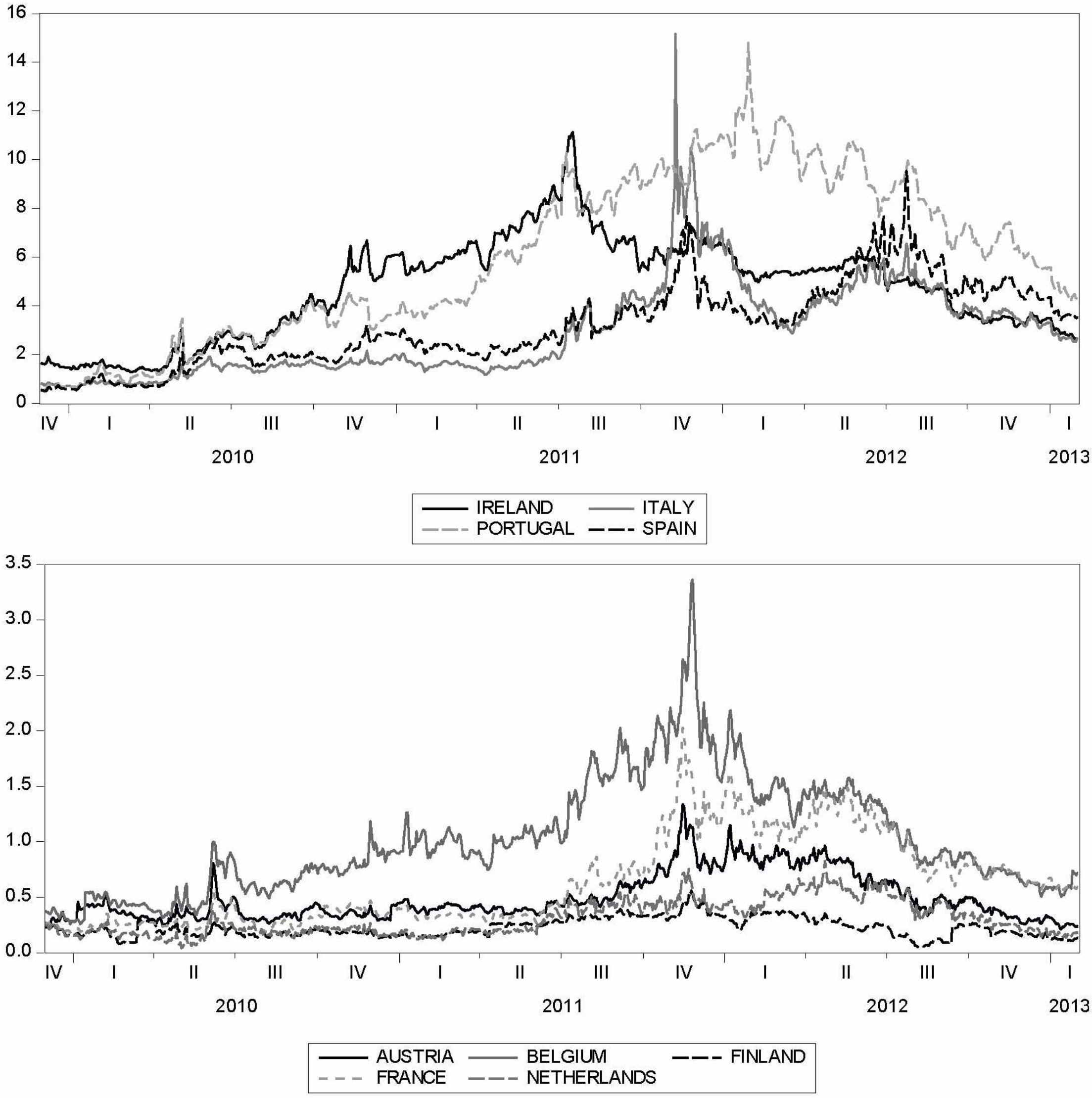
As a result of using generic bond yield-to-maturity data which are not assigned a coupon, we expect that the bond trades at par and the coupon rate correspond to the yield every day. The cumulative default probability used in equation (2.4) was capped at 1. Although it is possible that after one default 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.

### 2.5.4. 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 2.1. 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.

**Figure 2.1: Results of CDS valuation: 10-year CDS model price (in percentage)**




**Source: Authors' calculations**

## 2.6. 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 2.4. 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 breakpoint 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.

### 2.6.1. 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 the Appendix in Table 2.4.

We first separately estimated the following two regression equations for each of the nine countries listed in Table 2.1 as reference entities—without Germany (Germany is considered to be a benchmark), i.e. we estimated 18 separate equations:

$$\begin{aligned}\Delta marketCDS\_5Y_{t_i,C} &= \alpha_{1,C}\Delta modelCDS\_5Y_{t_i,C} + \alpha_{2,C}\Delta cpty\_5Y_{t_i,C} \\ &+ \alpha_{3,C}\Delta liq\_5Y_{t_i,C} + \varepsilon_{t_i,C}\end{aligned} \tag{2.8}$$

and

$$\begin{aligned}\Delta marketCDS\_10Y_{t_i,C} &= \beta_{1,C}\Delta modelCDS\_10Y_{t_i,C} + \beta_{2,C}\Delta cpty\_10Y_{t_i,C} \\ &+ \beta_{3,C}\Delta liq\_10Y_{t_i,C} + \eta_{t_i,C},\end{aligned} \tag{2.9}$$

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 2.5, $\Delta cpty_{t_i,C}$ 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 (2.8) denotes a five-year maturity and the *"_10Y"* ending of equation (2.9) denotes a ten-year maturity of the variables.

These 18 equations were estimated three times for three different periods ($i = 3$): $t_1 = 1, 2, \dots 828$; $t_2 = 1, 2, \dots, T_C$ and $t_3 = T_C + 1, T_C + 2, \dots, 828$. 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 including an 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.

### 2.6.2. Chow break point test

Having appropriately estimated the model in equations (2.8) and (2.9), 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 (2.8), i.e. for $t_i = 1, \dots, T_{C,5Y}$, the coefficients are $\alpha_{1,C}$, $\alpha_{2,C}$ and $\alpha_{3,C}$. $T_{C,5Y}$ denotes the break date for equation (2.8). In the second sub-period, i.e. for $t_i = T_{C,5Y} + 1, \dots, 828$, the coefficients are $(\alpha_{1,C} + \alpha_{4,C})$, $(\alpha_{2,C} + \alpha_{5,C})$ and $(\alpha_{3,C} + \alpha_{6,C})$. And the stability test is an 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.[9] 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:

$$\max\left\{\frac{F^1_{C,5Y}}{\max\{F^1_{C,5Y},\dots,F^{14}_{C,5Y}\}} + \frac{F^1_{C,10Y}}{\max\{F^1_{C,10Y},\dots,F^{14}_{C,10Y}\}},\dots,\frac{F^{14}_{C,5Y}}{\max\{F^1_{C,5Y},\dots,F^{14}_{C,5Y}\}} + \frac{F^{14}_{C,10Y}}{\max\{F^1_{C,10Y},\dots,F^{14}_{C,10Y}\}}\right\} \tag{2.10}$$

where $F^1_{C,5Y}$ 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 2.2.

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

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

countries—Italy, Portugal and Spain—is 1 October or 1 November 2011, which means that there was a change in the model between 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 2.2 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 (2.8) and (2.9) 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 (2.8) and equation (2.9).[10] 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.

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

**Table 2.2: Results of a Chow test for different break points**

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

| | Austria | | | Belgium | | | Finland | | | France | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 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 |

Note: 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 (2.10). 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**

## 2.7. 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):

$$\begin{aligned} \boldsymbol{\Delta marketCDS\_5Y_C} &= \alpha_1 \boldsymbol{\Delta modelCDS\_5Y_C} + \alpha_2 \boldsymbol{\Delta cpty\_5Y_C} + \alpha_3 \boldsymbol{\Delta liq\_5Y_C} + \boldsymbol{\varepsilon_1} \\ \boldsymbol{\Delta marketCDS\_10Y_C} &= \beta_1 \boldsymbol{\Delta modelCDS\_10Y_C} + \beta_2 \boldsymbol{\Delta cpty\_10Y_C} + \beta_3 \boldsymbol{\Delta liq\_10Y_C} + \boldsymbol{\varepsilon_2} \\ var\begin{pmatrix} \boldsymbol{\varepsilon_1} \\ \boldsymbol{\varepsilon_2} \end{pmatrix} &= \boldsymbol{\Omega} = \begin{pmatrix} \sigma_{11}\boldsymbol{I} & \sigma_{12}\boldsymbol{I} \\ \sigma_{21}\boldsymbol{I} & \sigma_{22}\boldsymbol{I} \end{pmatrix}, \end{aligned} \tag{2.11}$$

where $\Delta \boldsymbol{marketCDS}\_5\boldsymbol{Y}_C$ and $\Delta \boldsymbol{marketCDS}\_10\boldsymbol{Y}_C$ are ($T_{i,C}$ x 1) vectors of the dependent variable, $\Delta \boldsymbol{modelCDS}\_5\boldsymbol{Y}_C$, $\Delta \boldsymbol{cpty}\_5\boldsymbol{Y}_C$, $\Delta \boldsymbol{liq}\_5\boldsymbol{Y}_C$, $\Delta \boldsymbol{modelCDS}\_10\boldsymbol{Y}_C$, $\Delta \boldsymbol{cpty}\_10\boldsymbol{Y}_C$ and $\Delta \boldsymbol{liq}\_10\boldsymbol{Y}_C$ are ($T_{i,C}$ x 1) vectors of the independent variables. $\alpha_1$, $\alpha_2$, $\alpha_3$, $\beta_1$, $\beta_2$ and $\beta_3$ are scalar regression parameters. $\varepsilon_1$ and $\varepsilon_2$ are ($T_{i,C}$ x 1) vectors of residuals with zero expected value. The terms $\sigma_{jk}$, $j$ = 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 2.6.2 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 (2.11) 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 (2.11) are summarized in Table 2.3. 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 in Table 2.5.

**Table 2.3: SUR results**

| LESS RISKY COUNTRIES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **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 | |

| RISKIER COUNTRIES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **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 | |

Note: The table shows the results of model (2.11). 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**

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, 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 be an 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 shows an opposite relationship, i.e. increasing liquidity widens CDS spreads.

## 2.8. 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, Gűndűz 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 chapter 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.

## 2.9. Conclusion

Throughout this chapter, 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 chapter, 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 reach an 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 of an 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 chapter 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

**Table 2.4: Augmented Dickey-Fuller unit root test results**

**Levels of variables**

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

**First differences of variables**

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

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

**Table 2.5: 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 |

Note: 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 (2.11) 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**

# 3. Impact of the 2014 Change in ISDA Credit Derivatives Definitions on Sovereign CDS Market

*Abstract*

*In October 2014 International Swaps and Derivatives Association (ISDA) launched new credit derivatives' definitions as a response to a bad experience with early credit default swap (CDS) settlements. The positive effect of this change is assessed in two analyses. First, using a SUR model I observe whether the change increased the link between the CDS price as a hedging instrument and the bond spread as a hedged instrument. Second, using an ARFIMA-FIGARCH model I observe whether the extent of the long memory of CDS changes and their volatilities decreased. Data of liquid EU sovereigns and 3- and 5-year maturities are analyzed. First analysis reveals a limited positive impact on some countries – Belgium, France, Italy, Portugal and Spain – and only 5-year maturity. The second analysis concludes that the extent of long memory in the data did not decrease after the change, leading to the conclusion that the efficiency of the CDS market did not improve according to the efficient markets' hypothesis.*

**Key words:** ARFIMA-FIGARCH model, CDS, Chow test, long memory, SUR model

**JEL Classification:** C22, G01, G18

## 3.1. Introduction

After the world financial crisis in late 2000's, sovereign credit default swap (CDS) market grew significantly (DTCC, 2016). The increase of the volume was driven by subsequent financial difficulties of several developed economies and increasing perception of sovereign risk. Suddenly, sovereign default became a significant topic for the whole financial world and discussions about a default of a eurozone member state and subsequent contagion effects spread out (Longstaff, 2010). With this increasing awareness of a sovereign default, the role of CDSs mostly used as a hedging instrument for a sovereign risk (Fontana and Scheicher, 2016) increased as well. This paper represents an applied research contributing to the knowledge of CDS price behavior, its reliability and efficiency with conclusions aimed at regulators, market participants and risk managers.

Credit default swap (CDS) is a contract on financial markets in which the buyer commits to pay regular payments to the seller in exchange for a credit protection against a default of a reference entity. In case there is no credit event, the buyer keeps paying the regular payments until maturity of the CDS contract. In case the reference entity defaults, the seller compensates the buyer the losses caused by the default and the contract is terminated. The regular payments are based on the nominal of the contract agreed and CDS spread, which represents CDS market price and is quoted in basis points.

Recent experience with CDSs settlement has proven several deficiencies in standard terms and conditions of a CDS contract issued by an International Swaps and Derivatives Association (ISDA). In reaction, new 2014 ISDA Credit Derivatives Definitions were issued in October (ISDA, 2014). The main question of interest of this chapter is whether this change in ISDA definitions lead to an increased trust in CDS instrument.

There are two independent analyses in the chapter, performed on a common data set of several eurozone countries' CDS quotes and some other market variables ranging from October 2013 to October 2015. First, the link between the CDS price and bond price is observed using a break-point test and a seemingly unrelated regression (SUR) model by Zellner (1962). As mentioned above, the principal use of sovereign CDSs is to hedge a sovereign default risk. The reasoning behind the analysis is that decreased trust in the CDS increases the deviation of CDS price changes from the bond price changes, because the CDS prices are driven by other factors than the bond prices. If there is a significantly increased link between the CDS price and the bond price after the change in the ISDA definitions, then it indicates increased trust in CDS instrument.

Second, long memory property of CDS quotes is analyzed using an autoregressive fractional integration moving average model combined with fractionally integrated generalized autoregressive conditional heteroscedasticity model (ARFIMA-FIGARCH). This model accounts for dual persistence of both CDS price changes and volatility of CDS price changes. The grounds for this analysis lie in the efficient market hypothesis by Fama (1970). In weak form efficient markets past development of prices cannot explain current prices. Transmitted to the long memory model application, if CDS price changes or volatilities of CDS price changes are predictable in long term, i.e. exhibit long memory, then the principal precondition for the validity of the weak form efficiency is not fulfilled. The observation period is divided by the effective date of the change in the ISDA definitions to compare the results of the model before and after the change. The reasoning behind the analysis is that increased trust in CDS restores efficiency of the market and decreases the extent of long memory that is present in the time series.

The chapter is organized as follows. The motivation for the research in more detail is in Section 3.2. Literature overview is provided in Section 3.3 and overview of the data set in Section 3.4. The analysis follows in the new two sections - Section 3.5 looks at the relationship between the CDS spreads and bond spreads and Section 3.6 looks at the long memory properties of CDS spreads. Section 3.7 concludes.

## 3.2. Historical context and motivation

The popularity of sovereign CDS has grown rapidly with emerging problems of several European countries in late 2000's. Gross notional of euro-area member states' CDSs outstanding grew from about EUR 300 bn. at the end of 2009 to over EUR 800 bn. at the end of 2012 (DTCC, 2016).

However, coming examples of defaults and the way how the resolution of financial difficulties of several debtors was handled caused serious concerns about the reliability of the CDS contract (Reuters, 2011, Bloomberg, 2012). Investors realized that under existing conditions of a CDS contract it cannot provide them with an absolute certainty of no losses caused by worsened credit quality of the reference entity. Buzková and Kopa (2016) investigated the impact of these concerns on euro-zone CDS price discovery process by examining the relationship between the market CDS price and modelled risk neutral CDS price based on government yields. Their analysis showed that the link between these two variables significantly weakened in case of riskier euro-zone countries pointing to an increased role of other factors and uncertainty in CDS market quotes.

There are two aspects to assessing a correct functioning of a CDS contract terms: 1. Whether the contract terms enable a correct timing of the CDS early settlement. 2. After the early settlement is triggered, whether the CDS buyer is fully compensated for his losses. Practical examples of defaulted entities (represented mainly by Greece and SNS Bank NV) demonstrated that neither of these aspects can be warranted by the existing CDS terms and necessitated their change.

In February 2014, ISDA presented 2014 ISDA Credit Derivatives Definitions (the new definitions) as an update of insufficient 2003 ISDA Credit Derivatives Definitions (the old definitions in further text) (ISDA, 2014). Trading under the new definitions started on October 6, 2014. In case of sovereign entities analyzed in this paper, the new conditions apply to all new trades, i.e. they were not inserted in existing contracts agreed on prior to October 6, 2014.

Among others, two most important improvements relevant for sovereign default are:

1. Specification of credit event restructuring (and creation of a new credit event governmental intervention)
2. New asset package delivery provisions

The first improvement addressed the first aspect mentioned above, i.e. it clarified which action triggers the CDS early settlement.

Taking one of the most referenced examples – Greece, the period during which Greece was heading towards default was long (started with an update of Greek budget deficit from 8 to 15% of GDP in November 2009 and ended with a default in March 2012) and it is characteristic by several EU and IMF bailouts, discussions about voluntary debt restructuring and speculations about which action would finally trigger CDS early settlement. It was not clear whether a bond exchange represents a restructuring when the old bonds cease to exist or whether a redenomination out of euro represents a restructuring because subsequent depreciation will cause the bonds lose their value. Finally, the retroactive insertion of collective action clauses (CAC) in Greek bonds was perceived as a default by some market participants (e.g. Standard & Poor's, 2012) whereas it was not by ISDA. Only when CACs were activated, ISDA announced restructuring credit event. The new conditions should clarify ISDA stance with respect to all questions raised during the Greek crisis.

The second improvement addressed the second aspect mentioned above. If a bond holder receives a package of new bonds in a restructuring credit event, the settlement price of a CDS contract takes into account the new package structure. Thus, it is assured that not only a part of the new asset package can be delivered to settle the CDS early.

Illustrating this improvement on the Greek case, the fact is that in the Greek CDS settlement the investors were compensated for their losses was only a result of a lucky coincidence, but the losses of investors could have been immense. In the Greek restructuring, for each 100 nominal amount of defaulted domestic law Greek bonds the investor received 31.5 nominal of new domestic law Greek bonds, 31.5 nominal of gross domestic product-linked bonds and 15 nominal of low risk European Financial Stability Facility (EFSF) bonds. Only the new domestic law Greek bonds could constitute deliverable obligations in CDS settlement under the old conditions. Fortunately, their value was similar to the value of the whole package and Greek CDS investors did not suffer any significant loss.

The scope of the change of CDS terms was immense, it represented the biggest overhaul of credit derivatives in over a decade directly affecting USD 18 trillion credit derivatives (Bloomberg, 2014). E.g. Linklaters (2014) called the change not only the "big bang" but the "credit supernova". Also, it had been perceived positively by market participants before its launch, i.e. beneficial to liquidity, favoring CDS buyers and adding more transparency in CDS conditions (HSBC, 2014).

## 3.3. Literature overview

To the best of our knowledge, the impact of the 2014 change in the ISDA conditions on CDS spreads has not been examined in any other research paper. There are several papers dealing with recent development and changes on the eurozone CDS market.

Gunduz and Kaya (2013) investigate long memory in sovereign eurozone CDS data between 2007 and 2011. They conclude that despite the financial crisis and uncertainty on the financial markets, CDS price discovery process satisfies a minimum requirement for a weak form of efficiency. However, they discover that there is a strong evidence for a long memory in volatility patterns of CDS spread changes in case of 6 out of 10 countries. They also highlight an existence of co-movement of CDS spreads for all countries, which is more explicit for the riskier economies.

CDSs were suspected to drive bond prices and exacerbate the sovereign crisis. Several papers were devoted to this phenomenon. Coudert and Gex (2010) discovered that in the low-yield countries the price discovery process takes place in the bond market, whereas in the high-yield countries the direction changes and it is the CDS market that drives bond prices. Similar finding was reached by Bruneau et al. (2012) or Delatte et al. (2012) that found that the higher the distress, the more the CDS market dominates the information transmission between CDS and bond markets.

This discussion attracted lawmakers in the European Union and resulted in a regulation banning sovereign CDSs that do not hedge existing bond position (so called naked CDSs). Capponi and Larson (2014) evaluated this step claiming that regulators should prefer to consider other measures to reduce speculations. Other papers that look at the causality between the bond and CDS markets are O'Kane (2012) or Calice et al. (2013) who point to a role of liquidity in CDS prices.

Generally, quite many research papers focus on the decomposition of CDS quotes to different components attributable to different risks. Among others Longstaff et al. (2011) analyze selected world sovereign CDSs and find out that sovereign credit risk is much more correlated across countries than national equity indices, the result of which is higher dependence on a common set of global factors. These global factors represent about one third of sovereign CDS spread. Another important role in CDS price plays the liquidity risk (Chen et al., 2007, Badaoui et al., 2013) or counterparty risk (Hull and White, 2001, Arora et al., 2012).

In our paper I use two basic methods for the CDS price analysis. First, it is the seemingly unrelated regression (SUR) model developed by Zellner (1962), Zellner and Huang (1962) and Zellner (1963). Second, it is the analysis of long memory properties of time series. I first employ Geweke and Porter-Hudak (1983) log periodogram regression and modified log periodogram regression by Kim and Phillips (2006) and Phillips (2007). After that I perform a dual long memory ARFIMA-FIGARCH model. ARFIMA model was developed by Granger and Joyeux (1980) and a class of FIGARCH processes was developed by Baillie et al. (1996).

## 3.4. Data specification

In the first part of this section I will present the original data set and describe how this data were transformed to attain the variables used in the subsequent analysis. The second part provides the descriptive statistics of the variables.

### 3.4.1. Downloaded dataset

For my analysis I used daily time series data of several financial instruments and eurozone countries. All data were downloaded from Bloomberg. The summary of the data is provided in the table below.

Time period analyzed ranges from 1st October 2013 to 1st October 2015. The new conditions came into force on 6 October 2014, hence I am looking at the data approximately one year before and one year after the change. This leaves us with 522 observations for 3-year maturity and 516 observations for 5-year maturity for each time series.

**Table 3.1: Summary of downloadable data**

| Instrument | Data type | Maturity (years) | Currency | Rererence entity | Bloomberg ticker (5-year maturity) |
|---|---|---|---|---|---|
| credit default swap | bid spread<br>ask spread | 3 and 5 | USD | Austria, Belgium, France, Germany, Italy, the Netherlands, Portugal, Spain | AUST CDS USD SR, BELG CDS USD SR 5Y, FRTR CDS USD SR 5Y, GERMAN 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 |
| government bond yield | last yield | 3 and 5 | EUR | | GTATS5Y, GTBEF5Y, GTFRF5Y, GTDEM5Y, GTITL5Y, GTNL5Y, GTPTE5Y, GTESP5Y Gov |
| interest rate swap | bid price<br>ask price | 3 and 5 | EUR | | EUSA3, EUSA5 Curncy |
| credit default swap | mid spread | 3 and 5 | EUR or USD | Goldman Sachs, Morgan Stanley, JP Morgan, Credit Suisse, Bank of America Merrill Lynch, Barclay's Capital, Citigroup, Deutsche Bank, UBS, Wells Fargo | GS CDS USD SR 5Y D14, MS CDS USD SR 5Y D14, JPMCC CDS USD SR 5Y D14, CRDSUI CDS EUR SR 5Y D14, BOFA CDS USD SR 5Y D14, BACR CDS EUR SR 5Y D14, CINC CDS USD SR 5Y D14, DB CDS EUR SR 5Y D14, UBS CDS EUR SR 5Y D14, WELLFARGO CDS EUR SR 5Y D14 Corp |
| cross-currency swap | bid price<br>ask price | 3 and 5 | EUR/USD | | EUBS5 Curncy |

The calculation was performed for eight eurozone countries – Austria (AT), Belgium (BE), France (FR), Germany (GE), Italy (IT), the Netherlands (NE), Portugal (PT) and Spain (SP). The selection criterion for the countries was sufficient liquidity on 5-year CDS and bond market to avoid spurious results. I looked at the difference between each two subsequent observations. If the difference was zero in more than 5% of cases of either bond or CDS quotes, the country was excluded from the analysis. For example, from the old eurozone members I had to exclude Finland and Ireland because more that 5% of 5-year CDS quotes did not change inter-day.

Typically, 5-years maturity is the most liquid one. In addition, I use 3-year maturity that will complement our results and enable us to estimate the SUR model.

The currency of denomination of CDS quotes is USD whereas bond yields are quoted in EUR. The reason for using USD quotes is that on Bloomberg I had only access to USD denominated CDSs. De Santis (2015) points to an existence of a redenomination risk in EUR denominated CDSs. It is a risk that after a sovereign default either euro will devaluate or the new currency replacing euro will devaluate. Note that this risk is rather specific for sovereign CDSs. In this aspect, the difference between EUR and CDS quotes lies, among others, in the perception of a risk of devaluation of these currencies in case of default. Taking this into account, it is reasonable to expect that during and after the eurozone debt crisis the USD denominated CDS spreads represent a more stable measure encompassing lower redenomination risk.

The government bond spread was calculated as a difference between benchmark government bond mid yield and mid interest rate swap (IRS). In the SUR model our main aim is to observe the link between the bond spread and the CDS spread, which is by definition a hedging instrument, to the bond being a hedged instrument. However, there are several factors that cause that the price of these two instruments to differ. Recent literature points to the main two – liquidity risk and counterparty risk. Taking that into account the dataset from Table 3.1 was transformed to construct proxies for these two risks.

First, I calculated the bid-ask spread of CDS quotes as a proxy for liquidity risk of a CDS, which is the most heavily used proxy for liquidity risk in academic literature. Its use and the importance of liquidity risk for CDS price is illustrated by Calice et al. (2013) or Badaoui et al. (2013). The advantage of bid-ask spread is its availability on a daily basis. Alternative proxy would be the data about CDS volumes regularly published by the Depository Trust & Clearing Corporation (DTCC). However, these values are available only on a weekly basis.

Second, I needed a proxy for counterparty risk. Counterparty risk in a CDS contract is a risk that the CDS seller defaults and is not able to compensate potential losses. The importance of the role of counterparty risk is discussed in Hull and White (2001) or in Arora et al. (2012). As in Buzková and Kopa (2016) we used the average CDS of ten world's largest investment banks according to their revenues in 2015. These banks comprise the main dealers of CDS contracts. Namely, it is Goldman Sachs, Morgan Stanley, J. P. Morgan and Co., Credit Suisse, Bank of America Merrill Lynch, Barclays Capital, Citigroup, Deutsche Bank, UBS AG and Wells Fargo.[11] USD denominated CDS spreads were transformed using the EUR/USD cross-currency swap quotes.

### 3.4.2. Descriptive statistics

From the abovementioned transformation of the data I obtained three data series for each maturity and each country – CDS spread, bond spread and bid-ask spread. In addition, for each maturity we have an average banks' CDS spread. Charts of the data for a 5-year maturity are provided in the Appendix in Figure 3.1. Table 3.6 and Table 3.7 in the Appendix summarize the descriptive statistics of these variables for 3-year and 5-year maturities, respectively.

CDS spreads' means and averages are in all cases higher than bond spreads' means and averages. On the contrary, standard deviations of CDS spreads are in nearly all cases lower than standard deviations of bond spreads (except for France and Austria 3-years maturity). We can distinguish countries with higher volatility - Italy, Portugal and Spain - and countries with lower volatility – Germany and France. The data are mostly positively skewed with values of kurtosis higher that three which points to an asymmetric leptokurtic distribution with fatter of longer right tail. Jarque-Bera test statistic mostly rejects normal distribution of the quotes. I will use and extend these findings in the long-memory analysis in Section 3.6.

Stationarity of the levels of the data and of first differences of the data was tested using augmented Dickey-Fuller unit root test (Dickey and Fuller, 1981). The alternative of the test is that the time series follows an autoregressive process of order $p$ where the value of $p$ is selected according to

[11] Finance Maps of World (2016)

Table 3.8. The null hypothesis of non-stationarity cannot be rejected in case of levels of the data whereas it is clearly rejected in case of daily changes. Based on these results I will proceed to use changes of the data in the subsequent analysis.

## 3.5. Relationship between CDS and bond prices

As discussed in Section 3.2 the change of credit derivatives conditions was aimed at restoring trust at CDS. Before the launch of the change, investors could not be sure that buying a CDS as a hedging instrument would guarantee them timely and correct compensation for their losses.

My hypothesis is that before the change, the CDS price was more affected by external factors unrelated to the parameters of the reference bond because of this uncertainty. After the change the link between the bond spread and CDS spread restored and tightened. In this section I examine this hypothesis. First, I estimate single regression equations for each individual country and maturity to test for the most probable break-date and see whether it matches the date of the change of the conditions. Then, I calculate the system jointly for 3 and 5-years maturity divided into the two most probable sub-periods and compare the results between the sub-periods.

The analysis in this chapter follows the analysis performed in Buzkova and Kopa (2016) on different data.

### 3.5.1. Single equations model

I started my analysis by estimating the following regression using basic OLS method:

$$\Delta CDS_{M,C,t} = \beta_1 \Delta bond_{M,C,t} + \beta_2 \Delta liq_{M,C,t} + \beta_3 \Delta cpty_{M,C,t} + \varepsilon_t \qquad (3.1)$$

$t = 1, 2, \ldots, T_M$ , $C$ denotes country ($C = 1, 2, \ldots, 8$) and $M$ stands for maturity of the variables – either 3 or 5 years, i.e. $T_3 = 522$ and $T_5 = 516$. $\Delta$ denotes a difference of the variables between day $t$ and $t\text{-}1$. Hence, I estimated equation (3.1) sixteen times separately for each country and maturity.

*bond* denotes the bond spread as described in the previous section, *liq* the liquidity risk proxy – bid-ask spread of CDS quotes - and *cpty* the counterparty risk proxy – average CDS of top investment banks.

On the basis of the post-estimation analysis residuals exhibit conditional heteroscedasticity according to the Breusch-Pagan test (Breusch and Pagan, 1979) in 7 out of 16 cases. Heteroskedasticity is a typical property of many financial time series. Calm periods with low volatility are followed by periods with higher volatility and thus regression residuals are time dependent. To regain efficiency of the estimate, regressions with rejected hypothesis of homoscedasticity were re-estimated using White's method of robust standard errors (White, 1980).

The serial correlation was tested using the Breusch-Godfrey Lagrange Multiplier test (Cipra, 2008). The null hypothesis of no serial correlation was rejected in 6 out of 16 cases. Estimating the model with autoregressive term of order one AR(1) eliminated the serial correlation in residuals. The inclusion of the AR(1) term, however, did not have any major impact on the original results of values and significance of parameters.

Results of this section are used to test for the break-point, determination of which is described in the following section.

### 3.5.2. Chow break-point test

As a part of the post-estimation analysis of model (3.1), I tested for a presence of a break-point using a Chow test (Chow, 1960). This test requires a priori specification of a suspected break-point. The break-point is characterized as a change of either level parameter or any of the slope parameters of a regression.

Suppose a model in the first sub-period given by

$$y_t = \beta_1 + \beta_2 x_{t2} + \cdots + \beta_k x_{tk} + \varepsilon_t, \qquad t = 1, \ldots, T_1$$

A model in the second sub-period is

$$y_t = (\beta_1 + \beta_{k+1}) + (\beta_2 + \beta_{k+2})x_{t2} + \cdots + (\beta_k + \beta_{2k})x_{tk} + \varepsilon_t, \qquad t = T_1 + 1, \ldots, T_1 + T_2 = T$$

Chow test considers a null hypothesis that the parameters in the two models are equal.

$$H_0: \beta_{k+1} = 0, \ldots, \beta_{2k} = 0$$

Basically, the test estimates the regression equation divided by the specified break-point $T_1$ and compares the residual sum of squares of these regressions with the residual sum of squares of the regression estimated over the whole estimation period. Resulting test statistics follows an F-distribution.

The data range from October 2013 to October 2015 and I suspect a break-point in October 2014. I tested the presence of the break-point monthly 6 months before and 6 months after October 2014, i.e. I examined 13 dates for being the break-point. This extent leaves me with sufficient number of observations in each sub-period. Presence of a break-point elsewhere would be attributed to other factors that the change of the ISDA credit derivatives conditions.

Having two sets of maturities of the variables results in two sets of Chow tests for each country. In the subsequent analysis where the model is estimated jointly for 3 and 5 years I need a single break-point for each country. Thus, as in Buzkova and Kopa (2016), I calculated the sum of weighted F-statistics for each suspected break-point $b = 1, \ldots, 13$ as a joint statistics

$$\frac{F^b_{C,3Y}}{\max\{F^1_{C,3Y}, \ldots, F^{13}_{C,3Y}\}} + \frac{F^b_{C,5Y}}{\max\{F^1_{C,5Y}, \ldots, F^{13}_{C,5Y}\}} \tag{3.2}$$

where $F^1_{C,3Y}$ denotes the value of F-statistics for country $C$, maturity of 3-years and the first date analyzed for being a break-date out of 13. The date on which this joint statistic reaches its maximum is considered the most probable break-date.

Results of the test are presented in Table 3.2. The change of the ISDA credit derivatives conditions occurred on 6th October 2014. Thus, if the break-date is determined to be either 1st October or 1st November I can attribute it to the change of the conditions and this analysis concludes that the change of the conditions impacted the coefficients in the model in equation (3.1). Hence, I allow for a short conditioning of the markets before the change.

The highest value of the joint statistics on 1st October or 1st November is confirmed in case of France, Italy and the Netherlands. In case of Austria, Belgium, Portugal and Spain the joint statistics reach local maximum on either of these dates and the presence of a break-point is statistically significant in case of at least one maturity. As a result, I can confirm an existence of a break-point at the time of the change of the ISDA credit derivatives conditions in all countries except for Germany, where the break-date occurred two months earlier[12].

Specifically, in the following section I will use 1st October as a break-date connected to the change of the credit derivatives conditions in case of Belgium, France, Italy and the Netherlands and 1st November in case of Austria, Portugal and Spain. In case of Germany, 1st August will be used; however, the results cannot be attributed to the change of the credit derivatives conditions.

**Table 3.2: Chow break-point test results**

| | | 1 Apr 2014 | 1 May 2014 | 1 Jun 2014 | 1 Jul 2014 | 1 Aug 2014 | 1 Sept 2014 | 1 Oct 2014 | 1 Nov 2014 | 1 Dec 2014 | 1 Jan 2015 | 1 Feb 2015 | 1 Mar 2015 | 1 Apr 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AT** | 3-year | 3.078* | 2.961* | 3.040* | 2.013 | 0.291 | 0.255 | 0.347 | 0.321 | 0.237 | 0.170 | 1.036 | 2.006 | 2.009 |
| | 5-year | 3.87* | 3.991* | 3.039* | 3.026* | 2.605 | 2.609 | 3.562* | 3.939* | 3.487* | 1.795 | 2.155 | 1.765 | 2.493 |
| | joint | 1.970 | 1.962 | 1.749 | 1.412 | 0.747 | 0.737 | 1.005 | 1.091 | 0.951 | 0.505 | 0.877 | 1.094 | 1.277 |
| **BE** | 3-year | 3.111* | 1.567 | 1.201 | 0.823 | 0.785 | 1.353 | 2.353* | 3.001* | 2.994* | 2.711* | 15.567* | 14.678* | 14.681* |
| | 5-year | 1.140 | 0.962 | 0.361 | 0.137 | 0.241 | 1.302 | 2.046 | 1.111 | 0.869 | 0.487 | 0.983 | 0.951 | 1.101 |
| | joint | 0.684 | 0.510 | 0.231 | 0.111 | 0.153 | 0.640 | 1.144 | 0.665 | 0.562 | 0.381 | 1.418 | 1.347 | 1.411 |
| **FR** | 3-year | 2.232 | 1.992 | 1.934 | 2.144 | 2.858* | 4.011* | 4.316* | 1.422 | 1.214 | 2.120 | 0.615 | 0.217 | 0.186 |
| | 5-year | 5.427* | 4.559* | 4.041* | 4.477* | 4.248* | 5.412* | 5.970* | 4.210* | 3.349* | 1.827 | 1.354 | 1.233 | 2.019 |
| | joint | 1.426 | 1.225 | 1.125 | 1.247 | 1.374 | 1.836 | 2.000 | 1.035 | 0.842 | 0.797 | 0.369 | 0.257 | 0.381 |
| **GE** | 3-year | 0.323 | 0.637 | 1.966 | 4.482* | 14.345* | 14.293* | 13.554* | 1.361 | 2.258 | 2.816* | 4.774* | 3.494* | 3.222* |
| | 5-year | 4.187* | 4.812* | 4.312* | 3.587* | 3.328* | 0.602 | 0.481 | 1.848 | 7.439* | 10.438* | 3.482* | 3.881* | 3.973* |
| | joint | 0.424 | 0.505 | 0.550 | 0.656 | 1.319 | 1.054 | 0.991 | 0.272 | 0.870 | 1.196 | 0.666 | 0.615 | 0.605 |
| **IT** | 3-year | 3.651* | 3.536* | 2.935* | 2.997* | 3.072* | 3.950* | 2.832* | 2.279 | 1.078 | 0.440 | 1.199 | 1.382 | 1.714 |
| | 5-year | 1.053 | 1.205 | 2.625* | 2.194 | 2.634* | 3.460* | 5.102* | 0.696 | 0.634 | 0.838 | 0.937 | 0.553 | 1.053 |
| | joint | 1.131 | 1.131 | 1.258 | 1.189 | 1.294 | 1.678 | 1.717 | 0.713 | 0.397 | 0.276 | 0.487 | 0.458 | 0.640 |
| **NE** | 3-year | 0.401 | 0.517 | 0.528 | 1.351 | 6.549* | 20.937* | 30.047* | 30.068* | 27.248* | 26.233* | 26.775* | 23.970* | 23.703* |
| | 5-year | 0.417 | 0.389 | 0.284 | 1.158 | 1.101 | 1.106 | 2.685* | 1.562 | 1.591 | 1.178 | 0.996 | 1.127 | 1.114 |
| | joint | 0.169 | 0.162 | 0.123 | 0.476 | 0.628 | 1.108 | 1.999 | 1.582 | 1.499 | 1.311 | 1.261 | 1.217 | 1.203 |
| **PT** | 3-year | 5.099* | 3.173* | 3.264* | 3.139* | 3.681* | 2.682* | 2.754* | 2.207 | 2.009 | 2.246 | 1.497 | 0.436 | 0.168 |
| | 5-year | 2.877* | 3.280* | 3.698* | 3.736* | 1.573 | 1.438 | 1.593 | 2.331 | 1.926 | 1.973 | 0.198 | 0.173 | 0.561 |
| | joint | 1.855 | 1.446 | 1.551 | 1.527 | 1.240 | 0.961 | 1.009 | 1.016 | 0.886 | 0.955 | 0.418 | 0.144 | 0.152 |
| **SP** | 3-year | 1.920 | 2.113 | 2.483 | 3.341* | 3.255* | 3.187* | 3.025* | 3.661* | 2.993* | 1.964 | 2.413 | 5.221* | 3.493* |
| | 5-year | 1.148 | 1.407 | 1.839 | 2.137 | 3.015* | 3.569* | 3.266* | 5.146* | 3.463* | 2.350 | 2.116 | 2.435 | 5.433* |
| | joint | 0.579 | 0.664 | 0.814 | 1.033 | 1.178 | 1.267 | 1.181 | 1.648 | 1.211 | 0.809 | 0.852 | 1.448 | 1.669 |

Note: The table displays three rows for each country. In the first two rows are values of the F-statistics of the Chow test for 3-year and 5-year maturity, respectively. The third row shows a joint statistics calculated according to equation (3.2). Each column represents a different supposed break-date. A star by the value of the F-statistics denotes significance on 5% level. For a better legibility of the results a grey shading is used. The darker the shade the more probable it is, that the date is the break-date.
**Source: Author's calculations**

[12] As demonstrated in the subsequent analysis, our hypothesis was not confirmed in the case of Germany. New ISDA conditions did not have a significant positive impact on the link between bond and CDS prices. Therefore, the break-date is expected to be caused by different market movers than the new ISDA conditions.

### 3.5.3. Seemingly Unrelated Regression model

In this section I will estimate the SUR model for 3- and 5-years maturity divided into two sub-periods by the break-date determined in the previous section. I will then compare the results between the sub-periods and identify significant changes between the parameters.

The SUR model by Zellner (1962) enables us to estimate the single equation model in model (3.1) jointly for 3- and 5-years maturity of the variables for each country and reach more efficient estimator. The model assumes non-zero contemporaneous correlation of residuals among the regressions and exogeneity of all explanatory variables. The contemporaneous correlation of residuals in the model allows existence of other explanatory factors not included in the regression that may influence the dependent variable in both equations simultaneously.

To verify the existence of the correlation of residuals I computed the correlation coefficient between each two sets of residuals (for 3- and 5-years) from model (3.1) for each country and tested using a t-test whether it is significantly different from zero. The values of the correlation coefficient range from 12 to 23 and the null hypothesis of zero correlation was rejected in all cases.

The condition of orthogonality of all explanatory variables and the residual term is also clearly fulfilled, i.e. the null hypothesis of zero contemporaneous correlation between the residuals and all explanatory variables cannot be rejected in any case, which implies that all explanatory variables are exogenous.

Since the conditions for the use of SUR are met, I will estimate the following SUR model:

$$\begin{aligned} \Delta \boldsymbol{CDS}_{3Y,C} &= \alpha_1 \Delta \boldsymbol{bond}_{3Y,C} + \alpha_2 \Delta \boldsymbol{liq}_{3Y,C} + \alpha_3 \Delta \boldsymbol{cpty}_{3Y,C} + \boldsymbol{\varepsilon} \\ \Delta \boldsymbol{CDS}_{5Y,C} &= \beta_1 \Delta \boldsymbol{bond}_{5Y,C} + \beta_2 \Delta \boldsymbol{liq}_{5Y,C} + \beta_3 \Delta \boldsymbol{cpty}_{5Y,C} + \boldsymbol{\mu} \\ var\begin{pmatrix} \boldsymbol{\varepsilon_t} \\ \boldsymbol{\mu_t} \end{pmatrix} &= \boldsymbol{\Omega} = \begin{pmatrix} \sigma_{11}\boldsymbol{I} & \sigma_{12}\boldsymbol{I} \\ \sigma_{21}\boldsymbol{I} & \sigma_{22}\boldsymbol{I} \end{pmatrix} \end{aligned} \tag{3.3}$$

where $\mathbf{\Delta CDS}_{3Y,C}$ and $\mathbf{\Delta CDS}_{5Y,C}$ are ($T_{i,C}$ x 1) vectors of the dependent variable, $\boldsymbol{\Delta bond}_{3Y,C}$, $\boldsymbol{\Delta liq}_{3Y,C}$, $\boldsymbol{\Delta bond}_{3Y,C}$, $\boldsymbol{\Delta bond}_{5Y,C}$, $\boldsymbol{\Delta liq}_{5Y,C}$ and $\boldsymbol{\Delta bond}_{5Y,C}$ are ($T_{i,C}$ x 1) vectors of the independent variables. $\alpha_1, \alpha_2, \alpha_3, \beta_1, \beta_2$ and $\beta_3$ are scalar regression parameters. $\boldsymbol{\varepsilon}$ and $\boldsymbol{\mu}$ are ($T_{i,C}$ x 1) vectors of residuals with zero expected value. Terms $\sigma_{jk}$, $j$ = 1, 2 and $k$ = 1, 2 denote the covariance between the residual term of the $j$-th and the $k$-th equation. $\boldsymbol{I}$ is a unit ($T$ x $T$) matrix and $\boldsymbol{\Omega}$ is a ($2T$ x $2T$) variance matrix of the vector of residual terms. *3Y* and *5Y* denote the maturity of the variable and *C* denotes country.

The observation period with $T = 516$ observations is divided into two sub-periods by the break-point specified in the previous section. The model is estimated separately for each sub-period, i.e. $i = 1, 2$ and $T_{i,C}$ is the number of observations for country *C* in the i-th sub-period.

The estimation results are presented in Table 3.3. The equality of regression coefficients between the sub-periods was tested using a Wald test. Coefficients in the 2nd sub-period that are significant on 5% significance level and that significantly changed compared to the 1st sub-period (on 5% significance level) are highlighted by a grey color – light grey for a decrease and dark grey for an increase of the coefficient value after the change of the conditions. Results of the Wald test are in the Appendix in Table 3.9.

Generally, the change of the credit derivatives conditions had a limited impact on the relationship between the CDS and bond price only in case of some countries and only in case of 5-year maturity. If we take a look on the results for the 3-years maturity, we can see that the link between the bond and the CDS market changed significantly in only one case - Spain. In case of 5-years maturity there is a significant increase in the coefficient of the bond yield change in case of Belgium, France, Italy, Portugal and Spain. This result confirms my hypothesis that the change in the credit derivatives conditions improved the link between the CDS and the bond market. The hypothesis cannot be confirmed in case of Austria, Germany and the Netherlands where either the coefficients or the changes are insignificant.

The coefficient of determination in case of 5-year maturity increased after the change in case of Austria, Belgium, France, Italy, Portugal and Spain pointing to a better explanatory power of the model after the change and lower role of other factors not included in the regression in case of these countries. Except for liquidity risk in German 5-years maturity, no coefficient significantly decreased after the change. The role of counterparty risk in the CDS price did not change significantly in nearly any case (except for Spain, 3-years maturity). The coefficient of liquidity risk increased significantly in several cases.

Based on analysis in Section 3.5 I can make the following conclusions: 1. The presence of a break-point in model (3.1) at the time of the change of the credit derivatives conditions was confirmed in all examined countries except for Germany. 2. However, according to the SUR model the change is not substantial and the increased link between the bond and CDS market can be observed only in case of only some countries and 5-years maturity – Belgium, France, Italy, Portugal and Spain. Overall, the significance of these results does not improve if I change the frequency of the data.[13]

[13] Specifically, I used weekly data and the significance of parameters in the following table slightly increased in the case of France, Italy, Portugal and Spain and it slightly decreased in the case of other countries. Overall, the results were very similar.

**Table 3.3: SUR model results**

| | | AT | | BE | | FR | | GE | | IT | | NE | | PT | | SP | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| maturity | | coeff | *P-val* | coeff | *P-val* | coeff | *P-val* | coeff | *P-val* | coeff | *P-val* | coeff | *P-val* | coeff | *P-val* | coeff | *P-val* |
| 1st sub-period | | | | | | | | | | | | | | | | | |
| 3 | d.bond | -0.088 | *0.200* | -0.035 | *0.554* | 0.069 | *0.121* | -0.010 | *0.875* | 0.516 | *0.000* | -0.028 | *0.503* | 0.519 | *0.000* | 0.382 | *0.000* |
| | d.cpty | 0.019 | *0.778* | 0.177 | *0.007* | 0.178 | *0.000* | 0.070 | *0.077* | 0.892 | *0.012* | 0.045 | *0.416* | 1.558 | *0.000* | 0.651 | *0.000* |
| | d.liq | -0.346 | *0.000* | -0.171 | *0.013* | -0.589 | *0.000* | -0.233 | *0.010* | 0.067 | *0.769* | -0.413 | *0.000* | 0.089 | *0.437* | 0.043 | *0.654* |
| 5 | d.bond | 0.016 | *0.631* | -0.005 | *0.918* | 0.014 | *0.676* | -0.021 | *0.436* | 0.434 | *0.000* | -0.065 | *0.083* | 0.401 | *0.000* | 0.350 | *0.000* |
| | d.cpty | 0.043 | *0.331* | 0.138 | *0.041* | 0.198 | *0.000* | 0.067 | *0.004* | 0.801 | *0.000* | 0.135 | *0.000* | 1.233 | *0.000* | 0.608 | *0.000* |
| | d.liq | -0.006 | *0.845* | -0.005 | *0.897* | 0.134 | *0.042* | -0.389 | *0.000* | 0.241 | *0.014* | 0.013 | *0.705* | -0.335 | *0.000* | 0.006 | *0.521* |
| 3 | adj. R-sq | 9.98% | | 4.34% | | 17.34% | | 3.74% | | 11.84% | | 10.11% | | 46.29% | | 39.93% | |
| 5 | adj. R-sq | -0.29% | | 0.71% | | 8.83% | | 37.17% | | 48.61% | | 3.14% | | 48.12% | | 39.78% | |
| 2nd sub-period | | | | | | | | | | | | | | | | | |
| 3 | d.bond | -0.188 | *0.109* | -0.032 | *0.763* | 0.163 | *0.070* | -0.092 | *0.035* | 0.511 | *0.000* | -0.016 | *0.823* | 0.555 | *0.000* | 0.569 | *0.000* |
| | d.cpty | 0.048 | *0.528* | 0.272 | *0.000* | 0.142 | *0.006* | 0.065 | *0.013* | 1.021 | *0.000* | 0.014 | *0.741* | 1.555 | *0.000* | 0.709 | *0.000* |
| | d.liq | -0.257 | *0.022* | 0.080 | *0.264* | -0.137 | *0.072* | 0.473 | *0.000* | 0.890 | *0.000* | 0.563 | *0.000* | -0.324 | *0.091* | 0.019 | *0.867* |
| 5 | d.bond | -0.024 | *0.477* | 0.174 | *0.000* | 0.156 | *0.000* | -0.015 | *0.613* | 0.631 | *0.000* | -0.003 | *0.935* | 0.510 | *0.000* | 0.440 | *0.000* |
| | d.cpty | 0.084 | *0.017* | 0.041 | *0.401* | 0.151 | *0.002* | 0.053 | *0.008* | 0.973 | *0.000* | -0.010 | *0.779* | 1.229 | *0.000* | 0.896 | *0.000* |
| | d.liq | 0.360 | *0.000* | -0.014 | *0.727* | 0.639 | *0.000* | -0.300 | *0.000* | -0.163 | *0.379* | 0.035 | *0.161* | -0.520 | *0.000* | -0.375 | *0.016* |
| 3 | adj. R-sq | 2.39% | | 4.69% | | 4.48% | | 16.21% | | 34.27% | | 22.17% | | 27.64% | | 39.24% | |
| 5 | adj. R-sq | 9.56% | | 5.53% | | 16.29% | | 10.67% | | 49.49% | | -0.11% | | 72.70% | | 51.65% | |

Note: For each regression the regression coefficients, p-values and adjusted R-squared are displayed. In the upper half of the table are results before the change of the credit derivatives conditions (1st sub-period) and in the lower half of the table are results after the change. In the first column maturity of the variables is displayed. Coefficients in the 2nd sub-period that are significant on 5% significance level and that significantly changed compared to the 1st sub-period (on 5% significance level according to the Wald test) are highlighted by a grey color – light grey for a decrease and dark grey for an increase of the coefficient value after the change of the conditions. Also, adjusted R-squared values are highlighted by a light grey and dark grey color in case of decrease and increase of its value, respectively.

**Source: Author's calculations**

### 3.6. Long memory of CDS quotes

In this section the behavior of CDS quotes alone is analyzed in more detail. We will see if the new ISDA credit derivatives definitions improved the efficiency of the CDS prices. According to the controversial efficient market hypothesis (EMH) by Fama (1965), asset prices fully reflect all available information and as a result it should not be possible to outperform the market. In his later research Fama (1970) identified three main forms of market efficiency – weak, semi-strong and strong. In this paper I will concentrate on the weak form of efficiency. Under the weak form of efficiency future asset prices cannot be derived from the past asset prices. In other words, in the long run it is not possible to achieve abnormal return based on an analysis of historical price movements.

In this section long-range dependence or long memory in the CDS data is quantified and the dependence of current CDS price changes on the CDS price changes in the distant past is observed. If the evidence of the presence of the long memory is observed, then CDS prices are not weak form efficient (Assaf, 2015).

In the analysis, I will use a recent specification of an autoregressive conditional heteroscedasticity (ARCH) model, the autoregressive fractionally integrated moving average model combined with fractionally integrated generalized autoregressive conditional heteroscedasticity model (ARFIMA-FIGARCH). This model represents a dual model for long memory. First, in the ARFIMA specification the long memory of the CDS changes is observed. Second, in the FIGARCH specification the long memory of volatility of the CDS changes is observed. As demonstrated by Gűndűz and Kaya (2014) or Al-Shboul and Anwar (2016) some asset's returns do not exhibit a long-memory, whereas the volatility of the returns does, i.e. asset price volatility or riskiness of the asset is persistent and it may be predicted based on past volatilities. Investors may then adjust their investment strategy to reflect this property of prices. Proper modelling of volatility is important for the risk management purposes, volatility is used for value-at-risk calculation, derivatives pricing or for national regulation purposes.

Long-memory properties of time-series data have been investigated in many papers. For example, Lo (1991), Ding et al. (1993), Cheung and Lai (1995), Barros et al. (2012) or Charfeddine and Ajmi (2013) test for long memory properties of asset prices' returns. Especially after the financial crisis in late 2000's the interest in long memory of stock returns grew. However, vast majority of the papers is aimed at stock prices or stock indices. According to Gűndűz and Kaya (2014) and to the best of my recent knowledge, their paper is the only study so far that has been devoted to the long memory of CDS prices. They observe sovereign CDSs of selected European countries after the collapse of Lehman Brothers and find no evidence of long memory in CDS returns and a presence of long memory in CDS volatilities in some countries.

In the subsequent analysis, I will first look in more detail on the order of integration of the data and perform additional stationarity and unit-root test. Second, the model is presented and third, the results are displayed and commented with respect to the post-estimation analysis.

The 5-years maturity of the CDS data is used because it is the most traded maturity and 5-year quotes are the most reliable. The long memory of both CDS changes as well as conditional volatilities of CDS changes are analyzed. The observation period is the same as in the previous analysis, it starts one year before the launch of the new definitions and ends one year after. The results are reported separately for two sub-periods divided by the new conditions' starting date – 6 October, 2014.

### 3.6.1. Stationarity and unit root test

Long memory in time series data relates to the time of decay of the statistical significance between two observations with increasing time interval between the observations. Empirically, long memory can be uncovered from an observed autocorrelation function. Long memory is present if an autocorrelation function of a stationary time series decays at slow hyperbolic rate. This property of the data was observed by Hurst (1951 and 1957). Contrary, if an autocorrelation function of a time series decays rapidly, then the data may show a short memory.

As a result, the extent of persistence of time series with long memory is not consistent with neither processes integrated of order one, I(1), nor processes integrated of order zero, I(0). The sharp division of time series data to either I(0) or I(1) is too restrictive and the order of integration may be fractional.

Two additional tests to assess stationarity respectively unit root behavior of CDS data are performed. First is the Phillips-Perron (1988) unit root test (P-P test) with a null hypothesis that a time series is integrated of order one. It is robust to unspecified autocorrelation and heteroscedasticity of the disturbances in the test equation. Second is the Kwiatkowski–Phillips–Schmidt–Shin (1992) stationarity test (KPSS test). The null hypothesis is that the series is stationary. Combination of these two tests with alternate hypotheses may point to the existence of long memory - if the Phillips-Perron test rejects the unit root behavior and the KPSS rejects stationarity at the same time.

Results of the tests are displayed in Table 3.4. As a proxy for CDS volatility patterns, squared changes of CDS are tested. The unit root is clearly rejected in all cases. However, there are several cases where the stationarity is rejected as well. For example, in case of 5-year CDS changes in Italy, Portugal and Spain the stationarity is rejected on 10% significance level in the first sub-period and it is not rejected in the second sub-period.

**Table 3.4: Unit root and stationarity tests for CDS changes and squared changes**

| | 3-years maturity | | | | 5-years maturity | | | |
|---|---|---|---|---|---|---|---|---|
| | 1.10.2013 - 5.10.2014 | | 6.10.2014 - 30.9.2015 | | 1.10.2013 - 5.10.2014 | | 6.10.2014 - 30.9.2015 | |
| | KPSS | P-P | KPSS | P-P | KPSS | P-P | KPSS | P-P |
| Changes of CDS | | | | | | | | |
| AT | 0.039 | -52.113*** | 0.210 | -36.421*** | 0.266 | -18.141*** | 0.06 | -36.238*** |
| BE | 0.068 | -27.067*** | 0.066 | -22.508*** | 0.329 | -29.775*** | 0.048 | -36.36*** |
| FR | 0.161 | -20.373*** | 0.060 | -20.121*** | 0.219 | -17.603*** | 0.128 | -17.489*** |
| GE | 0.172 | -25.171*** | 0.072 | -27.656*** | 0.053 | -21.691*** | 0.062 | -23.368*** |
| IT | 0.331 | -27.983*** | 0.024 | -18.549*** | 0.402* | -13.612*** | 0.041 | -16.417*** |
| NE | 0.089 | -23.465*** | 0.115 | -26.052*** | 0.135 | -19.072*** | 0.053 | -36.814*** |
| PT | 0.503** | -13.611*** | 0.035 | -15.486*** | 0.38* | -13.133*** | 0.07 | -25.512*** |
| SP | 0.397 | -15.458*** | 0.098 | -5.980*** | 0.384* | -52.173*** | 0.031 | -15.248*** |
| Squared changes of CDS | | | | | | | | |
| AT | 0.068 | -12.795*** | 0.291 | -9.261*** | 0.524** | -139.318*** | 0.054 | -45.138*** |
| BE | 0.456 | -15.176*** | 0.472** | -11.889*** | 0.039 | -27.101*** | 0.051 | -37.501*** |
| FR | 0.129 | -14.480*** | 0.294 | -15.385*** | 0.2 | -38.94*** | 0.25 | -165.509*** |
| GE | 0.178 | -12.692*** | 0.345 | -14.760*** | 0.31 | -77.149*** | 0.027 | -46.966*** |
| IT | 0.254 | -9.152*** | 0.123 | -10.577*** | 0.175 | -101.458*** | 0.275 | -104.254*** |
| NE | 0.981*** | -12.434*** | 0.530** | -12.135*** | 0.083 | -79.2*** | 0.051 | -38.55*** |
| PT | 0.482** | -13.774*** | 0.101 | -15.447*** | 0.071 | -65.647*** | 1.13*** | -92.268*** |
| SP | 0.223 | -16.059*** | 0.192 | -16.078*** | 0.109 | -57.857*** | 0.167 | -96.182*** |

Note: The table displays values of the test statistics for each country and period. *, ** and *** denote significance at 10%, 5% and 1% level, respectively.

**Source: Authors' calculations**

### 3.6.2. The dual persistence model

In this section I will use an ARFIMA-FIGARCH model of CDS changes which is the most advanced method for estimating long memory of time series. ARFIMA specification of the mean equation by Granger and Joyeux (1980) captures the long memory, i.e. the fractional integration parameter, in the CDS changes. Compared to semi-parametric methods that might be biased if the data generating process exhibits short memory properties (Agiakloglou et al., 1993), it is convenient that ARFIMA distinguishes both short and long memory properties of the process. The conditional variance is estimated using a FIGARCH model by Baillie et al. (1996) that estimates fractional integration of conditional variance of the process. This specification captures data properties typical for many financial time series, above all volatility clustering, but also leptokurtic distribution or leverage effect of the data. The whole model is estimated jointly using the full maximum likelihood information.

The ARFIMA($p$, $d$, $q$) model for $\{y_t\}$ is specified as follows:

$$\rho(L)(1-L)^d y_t = \theta(L)\varepsilon_t$$
$$\varepsilon_t = z_t\sigma_t \tag{3.4}$$

$L$ is the lag operator, hence $Ly_t = y_{t-1}$. $\rho(L)$ is the AR operator of order $p$, $\rho(L) = (1-\rho_1 L - \cdots - \rho_p L^p)$, $\theta(L)$ is the MA operator of order $q$, $\theta(L) = (1+\theta_1 L + \cdots + \theta_q L^q)$. All unit roots of $\rho(L)$ and $\theta(L)$ lie outside the unit root circle. $\varepsilon_t$ is the i.i.d. innovation term, $E_{t-1}(z_t) = 0$, $var_{t-1}(z_t) = 1$ and $\sigma_t^2$ is the conditional variance of process $\varepsilon_t$. The key parameter is the fractional integration parameter $d$ which denotes the integer number of differences required to make the time series stationary. If *d = 0*, the model simplifies to ARMA (*p*, *q*). $(1-L)^d$ is the fractional differencing operator defined by

$$(1-L)^d = \sum_{k=0}^{\infty} \frac{\Gamma(k-d)L^k}{\Gamma(-d)\Gamma(k+1)}$$

where $\Gamma(.)$ denotes the gama (generalized factorial) function and parameter *d* is allowed to take any value.

The FIGARCH(*r*, *ξ*, *s*) model for $\{\varepsilon_t\}$ is specified as follows:

$$\phi(L)(1-L)^{\xi}\varepsilon_t^2 = \omega + [1-\beta(L)]\upsilon_t \quad (3.5)$$

where $\upsilon_t = \varepsilon_t^2 - \sigma_t^2$ and $\phi(L) = [1-\alpha(L)-\beta(L)](1-L)^{-1}$, $\alpha(L)$ being the lag operator of order *s*, $\beta(L)$ being the lag operator of order *r*. All unit roots of $\phi(L)$ and $[1-\beta(L)]$ lie outside the unit root circle. The fractional differencing parameter is denoted *ξ*. If *ξ* equals 0, the model simplifies to GARCH(*r*, *s*) and if *ξ* equals 1, it becomes IGARCH(*r*, *s*).

Financial time series during the crisis experienced increased volatility and more extreme values. Horváth and Šopov (2016) demonstrate on recent stock market returns that GARCH models with Student's *t* conditional distribution capture the tail shape more accurately than Gaussian GARCH. It is thus assumed that conditional variance of disturbances follows a Student's *t* distribution with $\nu$ degrees of freedom

$$\varepsilon_t|\Omega_{t-1} \sim t(0, \sigma_t^2, \nu) \quad (3.6)$$

where $\Omega_{t-1}$ is an information set of all information through time *t-1*.

### 3.6.3. Results and post-estimation analysis

When estimating the model, I first needed to determine the correct values of parameters *p* and *q* in the ARFIMA model. Misspecification of the model could lead to substitution of the short memory effect by the long memory effect. Hence I first estimated simple ARMA(*p*, *q*) model with all possible combinations of $p \leq 2$ and $q \leq 2$ for each country and sub-period and selected the best specification according to the Akaike information criterion. Mostly, AR(1) model was selected. E.g. in case of 5-year maturity, lag of two was selected only in one case – France - in the second sub-period. Conservatively, the ARFIMA model was estimated using *p = 2* and *q = 2* not to confuse the short and long memory effects. In several cases where the results of the iterations did not converge using these lag orders the lag order was decreased to reach convergence (as seen in Table 3.5). However, the final lag order is not lower that the lag order determined by the Akaike information criterion in any case.

For the specification of FIGARCH model parameters it is common to use one lag for each ARCH and GARCH component (Brunetti and Gilbert, 2000).

The results of the model are displayed in Table 3.5.

**Table 3.5: Dual memory model results: ARFIMA(p, d, q)–FIGARCH (r, ξ, s)**

| 3-YEAR MATURITY | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1st sub-period (1.10.2013 - 5.10.2014) | | | | | | | | | | |
| | *v^(1/2)* | *d* | *AR(1)* | *AR(2)* | *MA(1)* | *MA(2)* | *ω^(1/2)* | *ξ* | *ARCH(1)* | *GARCH(1)* |
| AT | 1.414 | -0.084 | 0.133 | -0.554*** | 0.337 | -0.547*** | 2.097** | -0.063 | 0.454*** | 0.274 |
| | *(0.000)* | *(0.108)* | *(0.311)* | *(0.179)* | *(0.241)* | *(0.265)* | *(0.950)* | *(0.071)* | *(0.162)* | *(0.188)* |
| BE | 3.995 | -0.425** | -0.696*** | 0.622*** | -0.942*** | 0.31*** | 0.011 | 0.116 | -0.100 | 0.029 |
| | *(2.401)* | *(0.290)* | *(0.139)* | *(0.153)* | *(0.249)* | *(0.268)* | *(0.011)* | *(0.176)* | *(0.180)* | *(1.589)* |
| FR | 3.756 | -0.111 | 1.285*** | -0.807** | 1.356*** | -0.922*** | 0.010** | -0.189** | 0.245** | 0.453** |
| | *(2.401)* | *(0.103)* | *(0.350)* | *(0.320)* | *(0.233)* | *(0.242)* | *(0.004)* | *(0.092)* | *(0.097)* | *(0.206)* |
| GE | 1.937 | -0.103*** | 1.034*** | 0.856*** | 0.431** | 0.891*** | 0.006** | -0.024 | 0.304 | 0.261 |
| | *(0.715)* | *(0.043)* | *(0.097)* | *(0.154)* | *(0.205)* | *(0.142)* | *(0.003)* | *(0.131)* | *(0.282)* | *(0.360)* |
| IT | 1.572 | 0.258 | 0.709*** | | 0.924 | | 0.036*** | -0.517*** | 1.027*** | -0.095 |
| | *(0.107)* | *(0.266)* | *(0.151)* | | *(0.092)* | | *(0.006)* | *(0.089)* | *(0.071)* | *(0.130)* |
| NE | 1.789 | -0.022 | -0.217 | 0.086 | -0.020 | 0.152 | 0.007*** | 0.250 | 0.106 | 0.492** |
| | *(0.182)* | *(0.117)* | *(0.432)* | *(0.166)* | *(0.420)* | *(0.231)* | *(0.002)* | *(0.191)* | *(0.237)* | *(0.219)* |
| PT | 2.123 | 0.265 | 0.252 | 0.445 | 0.385 | 0.527 | 0.081*** | -0.293** | 0.627 | 0.126 |
| | *(0.369)* | *(0.206)* | *(0.340)* | *(0.318)* | *(0.453)* | *(0.406)* | *(0.019)* | *(0.137)* | *(0.419)* | *(0.291)* |
| SP | 4.229 | 0.278* | -0.367*** | 0.591*** | -0.092 | 0.814*** | 0.234*** | -0.195*** | 0.580 | 0.351** |
| | *(2.525)* | *(0.152)* | *(0.104)* | *(0.104)* | *(0.080)* | *(0.074)* | *(0.056)* | *(0.075)* | *(0.109)* | *(0.115)* |
| 2nd sub-period (6.10.2014 - 30.9.2015) | | | | | | | | | | |
| | *v^(1/2)* | *d* | *AR(1)* | *AR(2)* | *MA(1)* | *MA(2)* | *ω^(1/2)* | *ξ* | *ARCH(1)* | *GARCH(1)* |
| AT | 1.925 | -0.398*** | 0.440 | 0.526 | 0.074 | 0.301 | 0.003** | 0.650*** | -1.193*** | 0.878*** |
| | *(0.192)* | *(0.136)* | *(0.688)* | *(0.673)* | *(0.714)* | *(0.414)* | *(0.001)* | *(0.327)* | *(0.332)* | *(0.102)* |
| BE | 1.418 | 0.349*** | -0.018 | -0.079 | 1.222*** | -0.231 | 0.228*** | -0.948*** | 1.575*** | -0.940*** |
| | *(0.002)* | *(0.143)* | *(0.330)* | *(0.110)* | *(0.431)* | *(0.429)* | *(0.061)* | *(0.115)* | *(0.412)* | *(0.117)* |
| FR | 1.530 | -0.413*** | 2.599*** | -2.491*** | 2.42*** | -2.212*** | 0.007*** | 0.922*** | -0.706*** | 0.754*** |
| | *(0.091)* | *(0.158)* | *(0.064)* | *(0.113)* | *(0.108)* | *(0.213)* | *(0.003)* | *(0.294)* | *(0.374)* | *(0.132)* |
| GE | 1.531 | 0.491*** | -1.191*** | -1.139*** | -0.857*** | 0.079*** | 0.001 | 0.639*** | 0.270 | 0.990*** |
| | *(0.126)* | *(0.089)* | *(0.112)* | *(0.116)* | *(0.012)* | *(0.008)* | *(0.001)* | *(0.209)* | *(0.606)* | *(0.011)* |
| IT | 1.522 | -0.098 | 0.753*** | 0.768*** | 0.756*** | 0.765*** | 0.006 | 0.994*** | -1.293*** | 0.992*** |
| | *(0.074)* | *(0.067)* | *(0.015)* | *(0.011)* | *(0.016)* | *(0.006)* | *(0.005)* | *(0.088)* | *(0.195)* | *(0.013)* |
| NE | 1.768 | -0.030 | 0.021 | | 0.382*** | | 0.002** | 0.846*** | -0.731*** | 0.756*** |
| | *(0.100)* | *(0.084)* | *(0.142)* | | *(0.138)* | | *(0.001)* | *(0.138)* | *(0.154)* | *(0.063)* |
| PT | 2.208 | -0.039 | 0.065 | -0.862*** | 0.101* | -0.956*** | 0.048*** | 0.287*** | 0.06** | -0.991*** |
| | *(0.347)* | *(0.077)* | *(0.085)* | *(0.105)* | *(0.055)* | *(0.043)* | *(0.015)* | *(0.113)* | *(0.026)* | *(0.003)* |
| SP | 1.636 | -0.037 | 0.915 | -0.865*** | 0.821*** | -0.918*** | 0.005 | 0.842** | -1.355 | 0.963*** |
| | *(0.442)* | *(0.145)* | *(0.623)* | *(0.250)* | *(0.209)* | *(0.125)* | *(0.025)* | *(0.417)* | *(0.856)* | *(0.335)* |

| 5-YEAR MATURITY | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1st sub-period (1.10.2013 - 5.10.2014) | | | | | | | | | | |
| | *v^(1/2)* | *d* | *AR(1)* | *AR(2)* | *MA(1)* | *MA(2)* | *ω^(1/2)* | *ξ* | *ARCH(1)* | *GARCH(1)* |
| AT | 1.729 | 0.439*** | -0.934*** | -0.062 | 0.114 | 0.859*** | 0.012*** | -0.060 | 0.135 | 0.084 |
| | *(0.210)* | *(0.086)* | *(0.144)* | *(0.106)* | *(0.070)* | *(0.075)* | *(0.002)* | *(0.115)* | *(0.265)* | *(0.212)* |
| BE | 1.705 | 0.067 | -0.472*** | -0.267 | -0.321 | -0.079 | 0.004** | -0.114 | 0.592* | 0.514*** |
| | *(0.203)* | *(0.115)* | *(0.087)* | *(0.265)* | *(0.761)* | *(0.518)* | *(0.002)* | *(0.164)* | *(0.220)* | *(0.174)* |
| FR | 2.141 | 0.068 | -1.269*** | -0.799** | -1.133*** | -0.728 | 0.008*** | 0.138 | 3.880 | 18.198 |
| | *(0.304)* | *(0.087)* | *(0.185)* | *(0.390)* | *(0.336)* | *(0.539)* | *(0.002)* | *(0.149)* | *(0.868)* | *(0.110)* |
| GE | 1.417 | -0.041 | 0.043 | 0.194 | | | 0.071 | -1.031*** | 0.585 | 0.421 |
| | *(0.011)* | *(0.091)* | *(0.180)* | *(0.201)* | | | *(0.054)* | *(0.336)* | *(1.178)* | *(1.179)* |
| IT | 2.231 | 0.036 | 0.308 | -0.269 | 0.215 | -0.174 | 0.037*** | -0.157* | 0.292** | 0.303** |
| | *(0.408)* | *(0.055)* | *(0.253)* | *(0.266)* | *(0.188)* | *(0.197)* | *(0.008)* | *(0.072)* | *(0.115)* | *(0.141)* |
| NE | 2.131 | 0.122 | -0.777 | 0.065 | -0.538 | 0.234 | 0.002*** | 0.871*** | -1.154*** | 0.873*** |
| | *(0.327)* | *(0.210)* | *(1.307)* | *(1.479)* | *(1.095)* | *(0.872)* | *(0.001)* | *(0.262)* | *(0.279)* | *(0.087)* |
| PT | 1.827 | -0.441*** | -0.941 | 0.533*** | -1.249*** | -0.662*** | 0.007 | 0.435*** | -0.120 | 0.949*** |
| | *(0.259)* | *(0.074)* | *(0.074)* | *(0.115)* | *(0.179)* | *(0.179)* | *(0.007)* | *(0.162)* | *(0.074)* | *(0.056)* |
| SP | 1.420 | 0.09*** | -0.818*** | 0.003 | 0.196 | 0.834*** | 0.241 | -0.449 | 0.790*** | 0.169 |
| | *(0.006)* | *(0.041)* | *(0.238)* | *(0.048)* | *(0.211)* | *(0.231)* | *(0.158)* | *(0.726)* | *(0.290)* | *(0.264)* |
| 2nd sub-period (6.10.2014 - 30.9.2015) | | | | | | | | | | |
| | *v^(1/2)* | *d* | *AR(1)* | *AR(2)* | *MA(1)* | *MA(2)* | *ω^(1/2)* | *ξ* | *ARCH(1)* | *GARCH(1)* |
| AT | 1.280 | -0.008 | 0.725*** | | 0.866*** | | 0.006*** | 0.936*** | -0.809*** | 0.622*** |
| | *(0.145)* | *(0.103)* | *(0.207)* | | *(0.069)* | | *(0.001)* | *(0.020)* | *(0.179)* | *(0.034)* |
| BE | 1.453 | -0.008 | 0.442 | | 0.493 | | 0.021 | 1.008*** | -0.791 | 0.106 |
| | *(0.122)* | *(0.103)* | *(0.817)* | | *(0.595)* | | *(0.037)* | *(0.022)* | *(0.736)* | *(0.086)* |
| FR | 1.796 | 0.041 | -0.877*** | -0.937*** | -0.885*** | -0.967*** | 0.002*** | 0.935*** | -0.484*** | 0.874*** |
| | *(0.104)* | *(0.051)* | *(0.064)* | *(0.048)* | *(0.040)* | *(0.027)* | *(0.001)* | *(0.155)* | *(0.062)* | *(0.040)* |
| GE | 1.560 | -0.143*** | -0.876*** | -0.049 | -0.756*** | | 0.007** | 0.668*** | 0.033 | -0.941*** |
| | *(0.090)* | *(0.045)* | *(0.128)* | *(0.084)* | *(0.089)* | | *(0.003)* | *(0.225)* | *(0.031)* | *(0.054)* |
| IT | 1.869 | 0.161** | -0.144 | 0.833*** | 0.020 | 0.972*** | 0.033*** | 0.358*** | 0.141*** | -0.515 |
| | *(0.231)* | *(0.079)* | *(0.105)* | *(0.069)* | *(0.031)* | *(0.030)* | *(0.011)* | *(0.120)* | *(0.034)* | *(0.163)* |
| NE | 1.463 | -0.135*** | 0.128*** | 0.131*** | 0.135*** | 0.137*** | 0.016 | 0.902*** | 0.001 | -0.999*** |
| | *(0.056)* | *(0.048)* | *(0.005)* | *(0.008)* | *(0.004)* | *(0.007)* | *(0.011)* | *(0.085)* | *(0.001)* | *(0.002)* |
| PT | 1.616 | -0.126** | 1.336*** | -0.657** | 1.338*** | -0.709** | 0.138** | -0.577*** | 1.13*** | -0.151 |
| | *(0.093)* | *(0.056)* | *(0.223)* | *(0.312)* | *(0.224)* | *(0.289)* | *(0.054)* | *(0.184)* | *(0.081)* | *(0.078)* |
| SP | 1.626 | 0.088 | 0.002 | 0.84*** | 0.085 | 0.901*** | 0.001 | 0.447*** | 0.139** | -0.533** |
| | *(0.088)* | *(0.068)* | *(0.096)* | *(0.084)* | *(0.093)* | *(0.092)* | *(0.781)* | *(0.137)* | *(0.056)* | *(0.222)* |

Note: The table displays results of the model in equations (3.4) and (3.5). In the first row for each country the value of the parameter is displayed together with its significance (*, **, *** for 10%, 5% and 1% significance level, respectively). In the second row the robust standard error is displayed. *AR(p)* and *MA(q)*, *p = 1, 2* and *q = 1, 2* denote the autoregressive resp. moving average parameters of equation (3.4), *ω* denotes constant for the variance equation, *ARCH(r)* and *GARCH(s), r = s = 1,* denote parameters in equation (3.5). *d* and *ξ* denote fractional integration parameters of mean resp. variance equation. Where the values are missing the model was estimated at lower lag orders to reach convergence. v denote degrees of freedom of Student's t distribution.
**Source: Author's calculations**

In the spotlight are the results for parameters $d$ and $\xi$. The fractional integration parameter for the mean equation $d$ is mostly not significant. In the first sub-period it is significant in case of three countries and in the second sub-period it is significant in case of four countries. These results are the same for the 3- and 5-year maturity. The absolute value of $d$ is below 0.5 in all significant cases, i.e. the series is stationary, $d$ takes both positive and negative values. The autocorrelation function with negative $d$ also decays at slow hyperbolic rate. The situation where $d$ is negative is sometimes called intermediate memory (Hosking, 1981; Bailie, 1996) and sometimes long memory (Box et al., 2008). The result can be interpreted that in most cases there is no evidence for the long memory in CDS spread changes. With regards to the hypothesis analyzed in this chapter there is no evidence that in general the extent of the long memory in CDS spread changes decreased after the launch of the new ISDA definitions.

The significance of parameter $\xi$ points to the existence of persistence in volatility of CDS changes in most countries. More importantly, the significance increased in the second sub-period which again contradicts our hypothesis, that the new ISDA definitions increased the efficiency of the CDS contract. We can also observe that AR and MA terms are significant in some cases, which points to the existence of a short term predictability of CDS changes. Again, the significance of the parameters rather increases than decreases in the second sub-period. The significance of GARCH and ARCH terms confirms expected existence of volatility clustering in the time series.

To test for model misspecification I calculated the values of Box-Pierce Q statistics of residuals and squared residuals. The results are reported in the Appendix in Table 3.10. The null hypothesis that the data are independently distributed was not rejected in any case.

The robustness of the model was checked by estimating the model by assuming first the normal conditional distribution of disturbances in equation, second by assuming Student's *t* distribution as defined in equation (3.6) and third by assuming generalized error distribution (GED). In the third case an ARIMA-FIGARCH model was estimated instead of ARFIMA-FIGARCH for a better convergence. The results in all three cases point to the same result – after the launch of the new ISDA definitions the extent of long memory in the changes and volatility of CDS spreads did not decrease. The Student's *t* distribution was selected based on GED results and the results of Box-Pierce test in case of normal distribution which rejected the hypothesis of no serial correlation in some cases.[14]

## 3.7. Conclusion

Throughout the chapter the effect of the introduction the new ISDA credit derivatives' definitions in October 2014 was observed. The purpose of change was to restore trust in CDS after recent bad experiences. Hence the main hypothesis set up in the chapter is that the launch of the new conditions had a positive impact on the CDS market. The chapter describes two ways of how to assess the hypothesis in two separate analyses. Data on EU sovereign CDS spreads, bond spreads and proxies for liquidity and counterparty risk starting one calendar year before the launch and ending one calendar year after the launch have been analyzed asking the following questions: 1. Did the launch increase the link between CDS prices and bond prices – bonds being the hedged item and CDS being the hedging item? 2. Did the launch increase the efficiency of CDS spreads?

The first analysis is aimed at answering the first question. The dependence of CDS market prices on bond spreads, counterparty risk and liquidity risk is analyzed using the SUR model with two equations for 3- and 5-year maturity of the variables for each country. Before estimating the model, the existence and location of a break-point is tested using a Chow break-point test. The test reveals the presence of the break-point around the date of the launch in case of all analyzed countries (Austria, Belgium, France, Italy, the Netherlands, Portugal and Spain) except for

[14] The results of these estimates are not presented because of the lenght of the chapter.

Germany. The SUR model is estimated dividing the observation period by the break-point into two sub-periods and the significance of the change of the parameters between the sub-periods is tested. The results point to several significant and unambiguous changes in favor of the main hypothesis. The relationship between the CDS price and bond spread, in which I am interested the most, significantly increased in case of 5-years maturity in Belgium, France, Italy, Portugal and Spain. The coefficient of determination increased in case of Austria, Belgium, France, Italy, Portugal and Spain pointing to a better explanatory power of the model after the change and lower role of uncertainty or other factors not included in the regression in case of these countries and 5-year maturity. Results for the 3-year maturity of variables are much less distinctive. The conclusion from this analysis is that we can observe some positive effect of the launch of the new conditions, i.e. the link between the CDS and bond spread increased, however this effect is not substantial and the increased link between the bond and CDS market can be observed in case of limited number of countries and only in case of 5-years maturity.

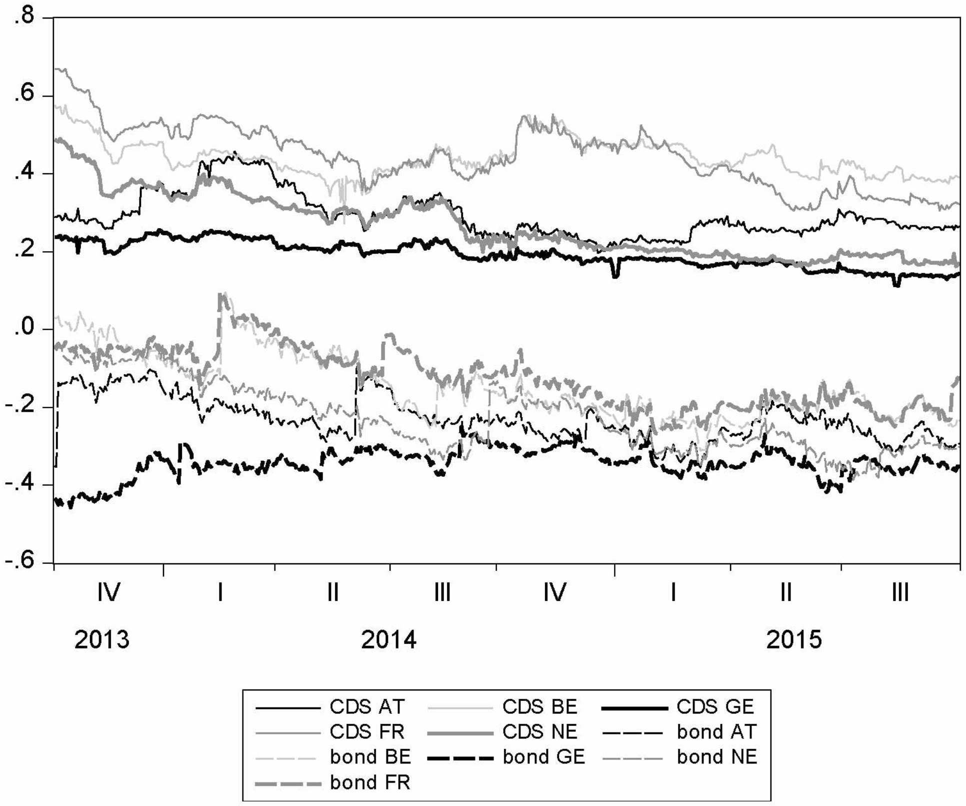
To analyze the second question, the efficient market hypothesis is used and I focus purely on EU sovereign CDS data during the same observation period. The presumption of the analysis is following: if the existence of the long memory is observed, then CDS prices are not weak form efficient, because under the weak form of market efficiency, it should not be possible to predict future changes of market variables from their past changes. Moreover, the ARFIMA-FIGARCH model enables us to analyze dual persistence in the time series data – in CDS changes and in the volatility of CDS changes. Generally, the results of the model do not support the main hypothesis. The existence of a long memory in spread changes is limited and there is an evidence of a long memory in the volatility of CDS changes. More importantly, the significance of the long memory parameters did not decrease overall; by contrast it increased in most cases.

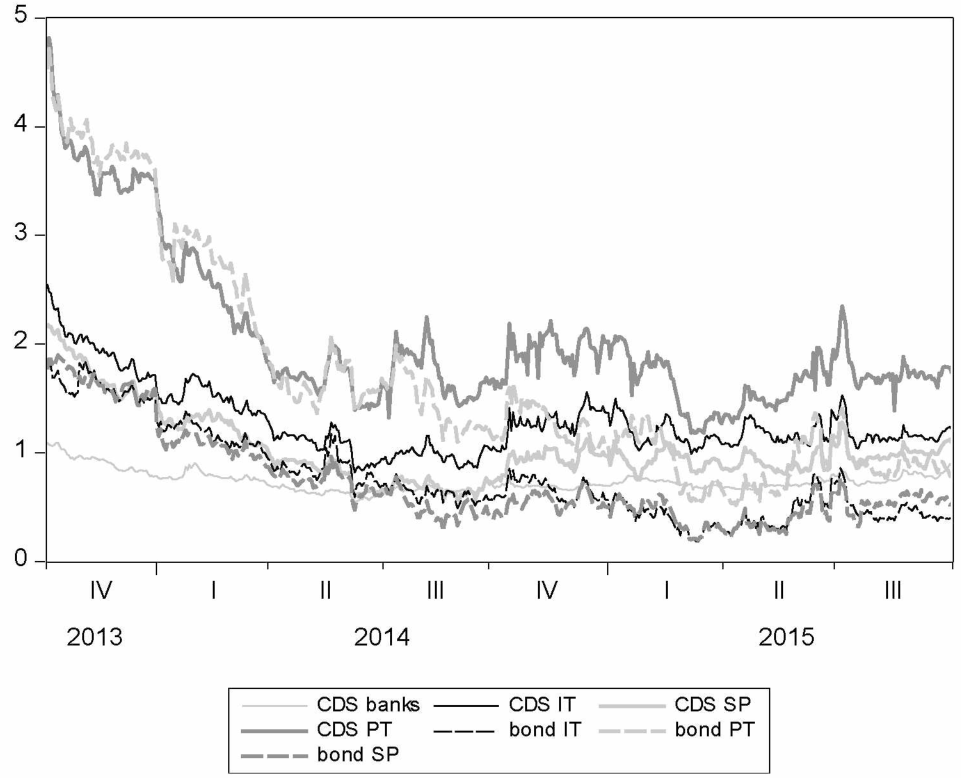
In conclusion, analysis performed in this chapter shows that the positive effect of the launch of the new ISDA credit derivatives' definitions is either not observed or very limited. It is important for policy makers and regulators to analyze efficiency of markets and observe the effect of new policies on market participants and subsequently on market prices. Findings presented in this chapter concerning the predictability of CDS market prices and their volatility are in turn beneficial for market participants or risk managers.

## Appendix

**Figure 3.1: CDS and bond spreads, 5-year maturity, from Oct-2013 to Oct-2015**

(in percentage points)




**Source: Bloomberg and author's calculations**

**Table 3.6: Descriptive statistics of the levels of the data, 3-years maturity**
(from Oct-2013 to Oct-2015)

| | Min | Max | Mean | Median | SD | Skewness | Kurtosis | J-B |
|---|---|---|---|---|---|---|---|---|
| CDS | | | | | | | | |
| AT | 0.055 | 0.295 | 0.164 | 0.156 | 0.042 | 0.657 | 3.012 | 37.5 |
| BE | 0.155 | 0.378 | 0.234 | 0.230 | 0.043 | 0.911 | 3.672 | 67.0 |
| FR | 0.129 | 0.384 | 0.234 | 0.235 | 0.055 | 0.196 | 2.721 | 5.0 |
| GE | 0.040 | 0.150 | 0.094 | 0.090 | 0.024 | 0.118 | 2.155 | 16.8 |
| IT | 0.485 | 1.945 | 0.951 | 0.872 | 0.242 | 1.330 | 4.865 | 229.6 |
| NE | 0.073 | 0.253 | 0.136 | 0.125 | 0.045 | 0.402 | 1.956 | 37.8 |
| PT | 0.770 | 4.450 | 1.575 | 1.335 | 0.664 | 1.806 | 5.858 | 461.5 |
| SP | 0.330 | 1.650 | 0.743 | 0.690 | 0.249 | 1.364 | 4.900 | 232.1 |
| Bond | | | | | | | | |
| AT | -0.367 | -0.146 | -0.273 | -0.271 | 0.046 | 0.211 | 2.775 | 5.0 |
| BE | -0.312 | -0.078 | -0.229 | -0.237 | 0.044 | 0.684 | 3.120 | 41.0 |
| FR | -0.322 | -0.137 | -0.238 | -0.238 | 0.031 | 0.052 | 3.347 | 2.9 |
| GE | -0.499 | -0.274 | -0.356 | -0.353 | 0.043 | -0.609 | 3.381 | 35.4 |
| IT | 0.059 | 1.459 | 0.486 | 0.409 | 0.332 | 1.026 | 3.196 | 92.3 |
| NE | -0.418 | -0.106 | -0.269 | -0.268 | 0.052 | 0.130 | 3.500 | 6.9 |
| PT | 0.103 | 4.900 | 1.111 | 0.735 | 1.046 | 1.700 | 4.830 | 324.2 |
| SP | -0.023 | 1.383 | 0.468 | 0.359 | 0.379 | 0.917 | 2.654 | 73.1 |
| Bid-ask | | | | | | | | |
| AT | 0.020 | 0.187 | 0.045 | 0.050 | 0.012 | 3.069 | 34.622 | 22,568.5 |
| BE | 0.018 | 0.178 | 0.048 | 0.050 | 0.016 | 1.469 | 11.506 | 1,761.7 |
| FR | 0.015 | 0.094 | 0.042 | 0.010 | 0.010 | 0.694 | 3.698 | 52.5 |
| GE | 0.014 | 0.076 | 0.033 | 0.030 | 0.007 | 0.923 | 6.719 | 359.8 |
| IT | 0.008 | 0.209 | 0.089 | 0.087 | 0.022 | 0.942 | 6.212 | 301.7 |
| NE | 0.004 | 0.071 | 0.040 | 0.040 | 0.011 | 0.228 | 2.513 | 9.7 |
| PT | 0.080 | 0.300 | 0.170 | 0.162 | 0.035 | 0.322 | 3.189 | 9.8 |
| SP | 0.050 | 0.175 | 0.091 | 0.086 | 0.020 | 1.317 | 5.600 | 287.8 |
| CDS banks | | | | | | | | |
| | 0.406 | 0.960 | 0.647 | 0.659 | 0.127 | 0.153 | 2.177 | 16.8 |
| Number of observations | | | | | | | | 522 |

Note: Values are in percentage points. CDS is the market CDS quote, bond is a difference between government bond mid-yield and mid interest rate swap, bid-ask is a difference between bid and ask market price of a CDS and CDS banks is average CDS of top 10 investment banks. SD denotes standard deviation and J-B Jarque-Bera test statistic.

**Source: Author's calculations**

**Table 3.7: Descriptive statistics of the levels of the data, 5-years maturity**
(from Oct-2013 to Oct-2015)

| | Min | Max | Mean | Median | SD | Skewness | Kurtosis | J-B |
|---|---|---|---|---|---|---|---|---|
| CDS | | | | | | | | |
| AT | 0.000 | 0.458 | 0.292 | 0.279 | 0.061 | 0.273 | 5.765 | 170.8 |
| BE | 0.000 | 0.577 | 0.432 | 0.433 | 0.078 | -3.356 | 20.195 | 7,325.1 |
| FR | 0.306 | 0.670 | 0.446 | 0.448 | 0.080 | 0.212 | 2.694 | 5.9 |
| GE | 0.112 | 0.255 | 0.194 | 0.193 | 0.034 | -0.089 | 2.032 | 20.8 |
| IT | 0.818 | 2.555 | 1.285 | 1.177 | 0.315 | 1.381 | 4.811 | 234.5 |
| NE | 0.000 | 0.490 | 0.262 | 0.239 | 0.089 | 0.026 | 3.340 | 2.5 |
| PT | 0.000 | 4.818 | 2.051 | 1.797 | 0.733 | 1.426 | 4.651 | 233.6 |
| SP | 0.000 | 2.188 | 1.009 | 0.950 | 0.356 | 0.689 | 5.148 | 140.0 |
| Bond | | | | | | | | |
| AT | -0.354 | 0.000 | -0.228 | -0.237 | 0.058 | 0.623 | 3.495 | 38.7 |
| BE | -0.311 | 1.000 | -0.119 | -0.165 | 0.185 | 4.703 | 28.738 | 16,144.9 |
| FR | -0.269 | 0.094 | -0.123 | -0.125 | 0.077 | 0.236 | 2.255 | 16.7 |
| GE | -0.457 | -0.251 | -0.344 | -0.341 | 0.038 | -0.738 | 3.740 | 58.6 |
| IT | 0.182 | 1.856 | 0.776 | 0.653 | 0.407 | 0.927 | 2.886 | 74.2 |
| NE | -0.386 | 0.000 | -0.220 | -0.235 | 0.094 | 0.491 | 2.203 | 34.4 |
| PT | 0.000 | 4.745 | 1.690 | 1.322 | 1.021 | 1.143 | 3.185 | 113.0 |
| SP | 0.000 | 3.733 | 0.711 | 0.576 | 0.421 | 1.168 | 3.686 | 127.4 |
| Bid-ask | | | | | | | | |
| AT | -0.024 | 0.204 | 0.045 | 0.046 | 0.015 | 5.447 | 59.996 | 72,393.6 |
| BE | 0.000 | 1.094 | 0.721 | 0.712 | 0.143 | -2.255 | 15.237 | 3,656.4 |
| FR | 0.013 | 0.090 | 0.037 | 0.037 | 0.009 | 0.217 | 4.647 | 62.6 |
| GE | 0.007 | 0.083 | 0.030 | 0.030 | 0.009 | 0.932 | 7.766 | 563.2 |
| IT | 0.015 | 0.117 | 0.072 | 0.073 | 0.018 | -0.351 | 3.124 | 10.9 |
| NE | 0.013 | 0.243 | 0.043 | 0.040 | 0.021 | 7.139 | 65.125 | 85,499.6 |
| PT | -0.018 | 0.869 | 0.142 | 0.134 | 0.081 | 6.415 | 51.996 | 54,938.1 |
| SP | -0.018 | 1.440 | 0.083 | 0.075 | 0.102 | 12.419 | 159.517 | 527,404.8 |
| CDS banks | | | | | | | | |
| | 0.000 | 1.094 | 0.732 | 0.712 | 0.110 | -0.806 | 14.307 | 2,804.5 |
| Number of observations | | | | | | | | 516 |

Note: Values are in percentage points. CDS is the market CDS quote, bond is a difference between government bond mid-yield and mid interest rate swap, bid-ask is a difference between bid and ask market price of a CDS and CDS banks is average CDS of top 10 investment banks. SD denotes standard deviation and J-B Jarque-Bera test statistic.
**Source: Author's calculations**

**Table 3.8: Results of Augmented Dickey-Fuller unit root test**

**Levels of the variables, 3-years maturity**

| | CDS | | Bond | | Bid-ask | | CDS banks | |
|---|---|---|---|---|---|---|---|---|
| AT | -2.555 | | -3.204 | ** | -7.435 | *** | | |
| BE | -2.253 | | -3.625 | *** | -3.271 | ** | | |
| FR | -1.978 | | -4.113 | *** | -2.464 | | | |
| GE | -1.880 | | -3.106 | ** | -4.271 | ** | -1.959 | |
| IT | -3.825 | *** | -2.346 | | -5.575 | *** | | |
| NE | -2.584 | * | -3.529 | *** | -4.748 | *** | | |
| PT | -4.564 | *** | -3.874 | *** | -4.296 | *** | | |
| SP | -3.756 | *** | -2.347 | | -6.410 | *** | | |

**Levels of the variables, 5-years maturity**

| | CDS | | Bond | | Bid-ask | | CDS banks | |
|---|---|---|---|---|---|---|---|---|
| AT | -1.526 | | -2.732 | *** | -12.71 | *** | | |
| BE | -10.784 | *** | -5.503 | *** | -8.404 | *** | | |
| FR | -2.442 | | -2.383 | | | | | |
| GE | -1.632 | | -3.648 | *** | | | -3.429 | ** |
| IT | -3.904 | *** | -2.368 | | | | | |
| NE | -2.51 | | -2.342 | | | | | |
| PT | -3.912 | *** | -2.661 | *** | | | | |
| SP | -3.794 | *** | -2.922 | ** | | | | |

**First differences of the variables, 3-years maturity**

| | CDS | | Bond | | Bid-ask | | CDS banks | |
|---|---|---|---|---|---|---|---|---|
| AT | -14.375 | *** | -17.363 | *** | -12.618 | *** | | |
| BE | -16.295 | *** | -9.556 | *** | -11.837 | *** | | |
| FR | -18.972 | *** | -16.860 | *** | -11.951 | *** | | |
| GE | -14.475 | *** | -16.038 | *** | -14.677 | *** | -13.906 | *** |
| IT | -13.647 | *** | -16.273 | *** | -13.845 | *** | | |
| NE | -14.513 | *** | -15.998 | *** | -15.076 | *** | | |
| PT | -10.358 | *** | -8.611 | *** | -15.618 | *** | | |
| SP | -20.103 | *** | -19.951 | *** | -16.450 | *** | | |

**First differences of the variables, 5-years maturity**

| | CDS | | Bond | | Bid-ask | | CDS banks | |
|---|---|---|---|---|---|---|---|---|
| AT | -17.401 | *** | -9.429 | *** | -15.473 | *** | | |
| BE | -13.828 | *** | -14.116 | *** | -11.206 | *** | | |
| FR | -15.789 | *** | -17.561 | *** | -14.937 | *** | | |
| GE | -18.388 | *** | -18.303 | *** | -11.824 | *** | -11.206 | *** |
| IT | -15.689 | *** | -16.500 | *** | -13.959 | *** | | |
| NE | -11.824 | *** | -13.657 | *** | -15.913 | *** | | |
| PT | -12.522 | *** | -10.070 | *** | -11.661 | *** | | |
| SP | -16.128 | *** | -12.443 | *** | -16.000 | *** | | |

Note: Values of the test statistic are reported. Stars denote significance on 10% (*), 5% (**) and 1% (***) level, respectively. The number of lags was selected according to the Akaike Information Criterion. In case of levels, the null hypothesis of non-stationarity cannot be rejected in some cases whereas in case of daily changes, the non-stationarity is unambiguously rejected in all cases.

**Source: Author's calculations**

**Table 3.9: Wald test results**

| | AT | | BE | | FR | | GE | | IT | | NE | | PT | | SP | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Break-date | 1.11.2014 | | 1.10.2014 | | 1.10.2014 | | 1.8.2014 | | 1.10.2014 | | 1.10.2014 | | 1.11.2014 | | 1.10.2014 | |
| Hypothesis | Chi-sq | P-val | Chi-sq | P-val | Chi-sq | P-val | Chi-sq | P-val | Chi-sq | P-val | Chi-sq | P-val | Chi-sq | P-val | Chi-sq | P-val |
| $\alpha_1^{1st} = \alpha_1^{2nd}$ | 2.110 | *0.146* | 0.002 | *0.961* | 4.429 | *0.035* | 1.847 | *0.174* | 0.002 | *0.962* | 0.084 | *0.772* | 0.662 | *0.416* | 22.553 | *0.000* |
| $\alpha_2^{1st} = \alpha_2^{2nd}$ | 0.170 | *0.680* | 2.139 | *0.144* | 0.751 | *0.386* | 0.011 | *0.915* | 0.132 | *0.717* | 0.314 | *0.575* | 0.000 | *0.987* | 0.284 | *0.594* |
| $\alpha_3^{1st} = \alpha_3^{2nd}$ | 1.959 | *0.161* | 0.000 | *0.986* | 22.457 | *0.000* | 61.389 | *0.000* | 12.887 | *0.000* | 170.828 | *0.000* | 13.015 | *0.000* | 0.063 | *0.802* |
| $\beta_1^{1st} = \beta_1^{2nd}$ | 1.493 | *0.222* | 14.139 | *0.000* | 18.395 | *0.000* | 0.053 | *0.817* | 26.584 | *0.000* | 2.737 | *0.098* | 3.986 | *0.046* | 6.606 | *0.010* |
| $\beta_2^{1st} = \beta_2^{2nd}$ | 0.857 | *0.355* | 2.081 | *0.149* | 1.384 | *0.240* | 0.352 | *0.553* | 1.869 | *0.172* | 13.446 | *0.000* | 0.000 | *0.985* | 6.345 | *0.012* |
| $\beta_3^{1st} = \beta_3^{2nd}$ | 155.492 | *0.000* | 0.041 | *0.839* | 58.561 | *0.000* | 6.432 | *0.011* | 17.051 | *0.000* | 0.438 | *0.508* | 12.200 | *0.000* | 1,552.6 | *0.000* |
| $\alpha_1^{1st} = \alpha_1^{2nd}$<br>$\alpha_2^{1st} = \alpha_2^{2nd}$<br>$\alpha_3^{1st} = \alpha_3^{2nd}$ | 3.783 | *0.286* | 15.501 | *0.001* | 28.068 | *0.000* | 62.076 | *0.000* | 13.381 | *0.004* | 171.341 | *0.000* | 13.403 | *0.004* | 27.399 | *0.000* |
| $\beta_1^{1st} = \beta_1^{2nd}$<br>$\beta_2^{1st} = \beta_2^{2nd}$<br>$\beta_3^{1st} = \beta_3^{2nd}$ | 163.906 | *0.000* | 16.333 | *0.000* | 84.806 | *0.000* | 7.040 | *0.071* | 55.367 | *0.000* | 12.780 | *0.010* | 12.808 | *0.010* | 1,640.76 | *0.000* |

Note: Results for model (3.3). The null hypothesis is in the first column. The test was performed on the level of individual coefficients (first six rows) and on the level of the whole equations (seventh and eighth row). The results reveal that the change is significant on the level of whole equations whereas it is often not significant on the level of individual coefficients.

**Source: Author's calculations**

**Table 3.10: Box-Pierce Statistics for residuals of ARFIMA-FIGARCH model**

| | 1.10.2013 - 5.10.2014 | | 6.10.2014 - 30.9.2015 | |
|---|---|---|---|---|
| | *Q* | *Q*$^2$ | *Q* | *Q*$^2$ |
| *3-year maturity* | | | | |
| AT | 8.675 | 4.259 | 7.993 | 2.504 |
| BE | 9.995 | 9.751 | 8.312 | 8.074 |
| FR | 4.604 | 5.045 | 2.959 | 3.870 |
| GE | 9.352 | 8.198 | 10.021 | 7.256 |
| IT | 10.179 | 20.952 | 6.162 | 0.892 |
| NE | 12.020 | 3.068 | 5.135 | 11.149 |
| PT | 4.097 | 12.331 | 7.458 | 7.918 |
| SP | 7.364 | 5.057 | 3.656 | 13.134 |
| *5-year maturity* | | | | |
| AT | 6.404 | 7.481 | 5.699 | 7.330 |
| BE | 10.945 | 13.212 | 5.656 | 0.323 |
| FR | 3.880 | 18.198 | 8.289 | 7.491 |
| GE | 8.013 | 10.969 | 11.732 | 6.467 |
| IT | 7.790 | 15.026 | 8.688 | 8.519 |
| NE | 6.599 | 9.056 | 7.587 | 1.073 |
| PT | 10.119 | 9.463 | 10.019 | 18.266 |
| SP | 6.399 | 4.684 | 7.874 | 7.382 |

Note: Values of Q statistics for residuals (denoted Q) and squared residuals (denoted $Q^2$) are reported. Significance on 95% level would be denoted by a *, however the null hypothesis of serially correlated residuals is rejected in all cases. The presence of serial correlation was tested up to 12 lags.
**Source: Author's calculations**

# 4. Note on Endogeneity

This note provides several alternative calculations to complement models provided in the previous three chapters. The calculations do not change the main findings; however they offer the full picture of the modelling problems, point to some modelling difficulties and address opponents comments of a computational nature.

This chapter elaborates the topic of potential endogeneity of dependent variables in the models in Chapters 2 and 3. Important assumption for the application of an OLS estimate is that explanatory variable is not contemporaneously correlated with the error term of the regression. The subsequent estimation is based on this assumption and it assures consistency of OLS estimate.

There are multiple causes of endogeneity, the one relevant for my research is simultaneity because financial time series may react simultaneously to the new information or there might be a reverse causality. More specifically, in Chapter 2 we might suspect that model CDS is endogenous variable and in Chapter 3 we might suspect that bond spread is endogenous variable. Government bond spreads, model CDS spreads derived from government bond spreads and government CDS spreads are closely related to each other and there is no clear one-sided causality between bond market and CDS market (Delatte et al. (2012)), even though the original purpose of a CDSs was to hedge credit risk of bonds. Endogeneity of other variables included in the models is less likely, because they either come from different markets or have a different nature.

In this subchapter I will follow the procedure proposed by Sande and Ghosh (2018) in their article devoted to endogeneity problems in research articles. First, I will find theoretically justified relevant instrumental variable (IV) and use a two stage least squares (2SLS) estimator as an alternative model to the model (2.11), respectively (3.3). Second, I will empirically evaluate orthogonality condition of selected instrument using Eichenbaum, Hansen and Singleton (1988) test (EHS test). Third, I will test for endogeneity of regressors using Durbin-Wu-Hausman test. Fourth, I will calculate 3SLS estimates and compare them with original estimates provided in Chapter 2 and 3.

Final part of this chapter is dedicated to a topic of selection of lagged variables as instruments as discussed in Reed (2013). The selection of instrumental variables is problematic, so I have decided to additionally perform a very simple analysis independent of the endogeneity issues and IV selection issues to validate the original findings. I simply observe a time series of differences of model CDS price and market CDS in Chapter 2 and CDS price and government bond spread in Chapter 3 both cleaned from the effect of liquidity and counterparty risk and compare the distribution of this time series before and after the change.

First, an instrument for model CDS resp. government spread needs to be selected. Selection of a correct instrument is a problematic issue. One may either arrive at misleading results by choosing a poor-quality instrument or not solve the endogeneity problem by choosing another endogenous variable as an instrument. The instrument needs to be orthogonal to the dependent variable and closely correlated to the potentially endogenous explanatory variable. Potential solution is to select a lagged explanatory variable as suggested by Cipra (2008) or applied by Aschoff and Schmidt (2008), Bania, Gray and Stone (2007) or Bansak, Morin and Starr (2007). The explanation for such a choice is that a variable created by the system in the past should not be correlated with residuals originated in the future. In model (2.11) I use the following instruments: ΔmodelCDS_5Y(-1), ΔmodelCDS_10Y(-1), Δcpty_5Y, Δliq_5Y, Δcpty_10Y and Δliq_10Y. In model (3.3) the instruments are as follows: Δbond_3Y(-1), Δbond_5Y(-1), Δcpty_3Y, Δliq_3Y, Δcpty_5Y and Δliq_5Y.

Second, I performed an EHS test separately for each equation in model (2.11) and (3.3) where the null hypothesis is that ΔmodelCDS_5Y(-1) resp. ΔmodelCDS_10Y(-1) (Chapter 2) and Δbond_3Y(-1) resp. Δbond_5Y(-1) (Chapter 3) are valid instruments, i.e. the instrument is orthogonal to a function of the parameters of the model. The test statistics is the difference between J-statistics of the original 2SLS model (with all instruments) with a model estimated with all instruments except for the one being tested. The results of the test are in Table 4.1 and Table 4.2 below. Low values of J-statistics lead me not to reject the null hypothesis in both cases.

**Table 4.1: Results of EHS orthogonality test (Chapter 2)**

| | | Difference J-stat | Prob | | | Difference J-stat | Prob | | | Difference J-stat | Prob |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AT | 5y1 | 0.031 | 0.860 | FR | 5y1 | 0.006 | 0.934 | NE | 5y1 | 1.423 | 0.233 |
| | 5y2 | 0.101 | 0.750 | | 5y2 | 0.012 | 0.912 | | 5y2 | 0.122 | 0.727 |
| | 10y1 | 0.018 | 0.893 | | 10y1 | 0.341 | 0.559 | | 10y1 | 0.662 | 0.416 |
| | 10y2 | 0.002 | 0.965 | | 10y2 | 0.049 | 0.825 | | 10y2 | 0.034 | 0.855 |
| BE | 5y1 | 0.483 | 0.487 | IR | 5y1 | 0.003 | 0.955 | PT | 5y1 | 0.069 | 0.793 |
| | 5y2 | 0.104 | 0.747 | | 5y2 | 0.082 | 0.775 | | 5y2 | 0.129 | 0.720 |
| | 10y1 | 0.287 | 0.592 | | 10y1 | 0.208 | 0.648 | | 10y1 | 1.738 | 0.187 |
| | 10y2 | 0.007 | 0.935 | | 10y2 | 7.148 | 0.008 | | 10y2 | 0.071 | 0.789 |
| FI | 5y1 | 0.028 | 0.868 | IT | 5y1 | 0.047 | 0.829 | SP | 5y1 | 0.016 | 0.898 |
| | 5y2 | 0.011 | 0.917 | | 5y2 | 0.017 | 0.896 | | 5y2 | 0.002 | 0.962 |
| | 10y1 | 0.026 | 0.871 | | 10y1 | 1.144 | 0.285 | | 10y1 | 0.241 | 0.624 |
| | 10y2 | 0.024 | 0.878 | | 10y2 | 0.041 | 0.840 | | 10y2 | 0.048 | 0.827 |

Note: The test was performed separately for each country, maturity and subperiod (5y1 in the second column point to a 5-year maturity and 1st sub-period).

**Source: Author's calculations**

**Table 4.2: Results of EHS orthogonality test (Chapter 3)**

| | | Difference J-stat | Prob | | | Difference J-stat | Prob | | | Difference J-stat | Prob |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AT | 3y1 | 0.000 | 0.989 | GE | 3y1 | 0.004 | 0.947 | PT | 3y1 | 1.028 | 0.311 |
| | 3y2 | 0.000 | 0.985 | | 3y2 | 0.310 | 0.577 | | 3y2 | 0.341 | 0.559 |
| | 5y1 | 0.024 | 0.876 | | 5y1 | 0.011 | 0.918 | | 5y1 | 2.014 | 0.156 |
| | 5y2 | 0.127 | 0.721 | | 5y2 | 0.802 | 0.371 | | 5y2 | 1.043 | 0.307 |
| BE | 3y1 | 0.000 | 0.988 | IT | 3y1 | 0.060 | 0.806 | SP | 3y1 | 0.032 | 0.859 |
| | 3y2 | 0.004 | 0.952 | | 3y2 | 0.321 | 0.571 | | 3y2 | 1.905 | 0.168 |
| | 5y1 | 0.027 | 0.871 | | 5y1 | 3.863 | 0.049 | | 5y1 | 14.463 | 0.000 |
| | 5y2 | 0.471 | 0.493 | | 5y2 | 0.183 | 0.669 | | 5y2 | 0.426 | 0.514 |
| FR | 3y1 | 0.005 | 0.958 | NE | 3y1 | 0.068 | 0.795 | | | | |
| | 3y2 | 0.148 | 0.700 | | 3y2 | 0.117 | 0.732 | | | | |
| | 5y1 | 0.537 | 0.464 | | 5y1 | 0.196 | 0.658 | | | | |
| | 5y2 | 0.742 | 0.389 | | 5y2 | 0.460 | 0.500 | | | | |

Note: The test was performed separately for each country, maturity and subperiod (3y1 in the second column point to a 3-year maturity and 1st sub-period).

**Source: Author's calculations**

Third, a Durbin-Wu-Hausman specification test was performed separately for each equation in model (2.11) and (3.3) where the null hypothesis is that ΔmodelCDS_5Y resp. ΔmodelCDS_10Y (Chapter 2) and Δbond_3Y resp. Δbond_5Y (Chapter 3) are exogenous. The exogeneity was not rejected in 19 cases out of 36 in Chapter 2 case and in only 4 cases out of 32 in Chapter 3 case at a 5% significance level (see Table 4.3 and Table 4.4). I conclude that endogeneity might be present in Chapter 2 model and I will estimate the model using 3SLS. However, in the case of Austria, the Netherlands and Finland we could not reject endogeneity of model CDS in any equation. For these countries I will not estimate the 3SLS because these results points to the fact the original SUR model results are sufficient. In Chapter 3 model SUR results are sufficient and 3SLS needs not be estimated.

**Table 4.3: Results of Durbin-Wu-Hausman specification test (Chapter 2)**

| | | Difference J-stat | Prob | | | Difference J-stat | Prob | | | Difference J-stat | Prob |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AT | 5y1 | 0.135 | 0.713 | FR | 5y1 | 5.301 | 0.021 | NE | 5y1 | 0.001 | 0.971 |
| | 5y2 | 0.006 | 0.941 | | 5y2 | 0.126 | 0.723 | | 5y2 | 0.946 | 0.331 |
| | 10y1 | 0.487 | 0.485 | | 10y1 | 8.247 | 0.004 | | 10y1 | 0.745 | 0.388 |
| | 10y2 | 0.009 | 0.924 | | 10y2 | 8.127 | 0.004 | | 10y2 | 1.145 | 0.285 |
| BE | 5y1 | 5.044 | 0.025 | IR | 5y1 | 7.830 | 0.005 | PT | 5y1 | 5.331 | 0.021 |
| | 5y2 | 4.103 | 0.043 | | 5y2 | 12.446 | 0.000 | | 5y2 | 10.660 | 0.001 |
| | 10y1 | 5.117 | 0.024 | | 10y1 | 16.361 | 0.000 | | 10y1 | 13.847 | 0.000 |
| | 10y2 | 6.437 | 0.012 | | 10y2 | 3.791 | 0.052 | | 10y2 | 8.757 | 0.003 |
| FI | 5y1 | 0.022 | 0.882 | IT | 5y1 | 0.066 | 0.797 | SP | 5y1 | 0.000 | 0.992 |
| | 5y2 | 0.160 | 0.689 | | 5y2 | 11.802 | 0.001 | | 5y2 | 0.367 | 0.544 |
| | 10y1 | 0.978 | 0.323 | | 10y1 | 3.961 | 0.047 | | 10y1 | 3.827 | 0.050 |
| | 10y2 | 0.046 | 0.831 | | 10y2 | 0.820 | 0.365 | | 10y2 | 3.041 | 0.081 |

Note: The test was performed separately for each country, maturity and subperiod (5y1 in the second column point to a 5-year maturity and 1st sub-period).

**Source: Author's calculations**

**Table 4.4: Results of Durbin-Wu-Hausman specification test (Chapter 3)**

| | | Difference J-stat | Prob | | | Difference J-stat | Prob | | | Difference J-stat | Prob |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AT | 3y1 | 0.677 | 0.411 | GE | 3y1 | 1.298 | 0.255 | PT | 3y1 | 1.651 | 0.199 |
| | 3y2 | 1.013 | 0.314 | | 3y2 | 0.125 | 0.724 | | 3y2 | 1.251 | 0.263 |
| | 5y1 | 0.098 | 0.754 | | 5y1 | 1.248 | 0.264 | | 5y1 | 7.341 | 0.007 |
| | 5y2 | 0.974 | 0.324 | | 5y2 | 0.091 | 0.763 | | 5y2 | 3.142 | 0.076 |
| BE | 3y1 | 0.050 | 0.823 | IT | 3y1 | 1.128 | 0.288 | SP | 3y1 | 2.373 | 0.123 |
| | 3y2 | 4.137 | 0.042 | | 3y2 | 3.515 | 0.061 | | 3y2 | 0.005 | 0.946 |
| | 5y1 | 0.465 | 0.495 | | 5y1 | 2.045 | 0.153 | | 5y1 | 0.973 | 0.324 |
| | 5y2 | 0.891 | 0.345 | | 5y2 | 9.630 | 0.002 | | 5y2 | 3.747 | 0.053 |
| FR | 3y1 | 2.320 | 0.128 | NE | 3y1 | 0.603 | 0.437 | | | | |
| | 3y2 | 0.378 | 0.539 | | 3y2 | 0.756 | 0.385 | | | | |
| | 5y1 | 1.970 | 0.161 | | 5y1 | 1.002 | 0.317 | | | | |
| | 5y2 | 5.382 | 0.020 | | 5y2 | 0.088 | 0.766 | | | | |

Note: The test was performed separately for each country, maturity and subperiod (5y1 in the second column point to a 5-year maturity and 1st sub-period).

**Source: Author's calculations**

Fourth, a 3SLS estimate was performed. The method was introduced by Zellner and Theil (1962) and it combines SUR and two-stage least squares estimate (2SLS). Whereas a 2SLS estimate is asymptotically efficient for every single equation, it is not asymptotically efficient for both equations in model (2.11). First and second stage of 3SLS estimates 2SLS, receives residuals and estimates covariances in the third equation of model (2.11). In the last stage Aitken estimate is used to estimate final 3SLS. Results of the model are displayed in the following table.

**Table 4.5: 3SLS results (Chapter 2)**

| | | Belgium | | France | | Ireland | | Italy | | Portugal | | Spain | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Coeff | P-value | Coeff | P-value | Coeff | P-value | Coeff | P-value | Coeff | P-value | Coeff | P-value |
| 1st sub-period | ΔmodelCDS_5Y | 0.318 | 0.001 | 0.972 | 0.321 | 0.547 | 0.000 | 0.558 | 0.000 | 0.716 | 0.000 | 0.445 | 0.000 |
| | Δcpty_5Y | 0.223 | 0.001 | 0.004 | 0.987 | 0.770 | 0.000 | 0.585 | 0.000 | 1.115 | 0.000 | 0.717 | 0.000 |
| | Δliq_5y | -0.565 | 0.096 | 2.309 | 0.488 | -0.019 | 0.889 | -0.114 | 0.579 | -0.337 | 0.005 | 0.475 | 0.030 |
| | ΔmodelCDS_10Y | 0.527 | 0.000 | 1.120 | 0.001 | 0.842 | 0.000 | 0.842 | 0.000 | 1.417 | 0.000 | 0.954 | 0.000 |
| | Δcpty_10Y | 0.103 | 0.065 | -0.062 | 0.494 | 0.138 | 0.668 | 0.373 | 0.000 | -0.112 | 0.743 | 0.281 | 0.013 |
| | Δliq_10y | -0.737 | 0.088 | -2.297 | 0.447 | -0.485 | 0.223 | 0.525 | 0.266 | -0.611 | 0.089 | -0.190 | 0.747 |
| | Adjusted R-squared 5y | 0.316 | | -0.763 | | 0.587 | | 0.643 | | 0.552 | | 0.526 | |
| | Adjusted R-squared 10y | 0.317 | | -0.141 | | 0.213 | | 0.564 | | -0.038 | | 0.385 | |
| 2nd sub-period | ΔmodelCDS_5Y | 0.604 | 0.000 | 0.567 | 0.000 | 0.614 | 0.001 | 0.069 | 0.210 | 0.417 | 0.000 | 0.308 | 0.001 |
| | Δcpty_5Y | 0.472 | 0.000 | 0.337 | 0.000 | 0.732 | 0.000 | 1.509 | 0.000 | 0.871 | 0.000 | 0.801 | 0.000 |
| | Δliq_5y | -0.232 | 0.146 | -0.302 | 0.223 | -0.096 | 0.266 | 0.417 | 0.284 | -0.141 | 0.090 | 0.027 | 0.881 |
| | ΔmodelCDS_10Y | 0.829 | 0.000 | 0.419 | 0.000 | 0.787 | 0.001 | 0.117 | 0.000 | 0.553 | 0.000 | 0.330 | 0.000 |
| | Δcpty_10Y | 0.285 | 0.000 | 0.341 | 0.000 | 0.222 | 0.271 | 1.047 | 0.000 | 0.424 | 0.070 | 0.493 | 0.000 |
| | Δliq_10y | -0.001 | 0.997 | 0.723 | 0.077 | -0.119 | 0.209 | -0.439 | 0.310 | -0.156 | 0.304 | -0.917 | 0.056 |
| | Adjusted R-squared 5y | 0.599 | | 0.526 | | 0.245 | | 0.540 | | 0.423 | | 0.644 | |
| | Adjusted R-squared 10y | 0.392 | | 0.460 | | -0.151 | | 0.433 | | 0.298 | | 0.447 | |

Note: The table shows the results of model (2.11). Instruments: ΔmodelCDS_5Y(-1), ΔmodelCDS_10Y(-1), Δcpty_5Y, Δliq_5Y, Δcpty_10Y, Δliq_10Y. 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. 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: Author's calculations**

Results of 3SLS are very similar to those of the SUR model in table Table 2.3 and the main finding are confirmed:

1. The dependence of market CDS spread on model CDS spread is country specific and it weakened during the observed period in the case of riskier countries – Italy, Portugal and Spain.
2. The role of counterparty risk mostly increased; it increased in all 10-year cases.
3. The role of liquidity risk is not clear.

Finally, it is worth noting that even if it makes sense that a past value of a variable cannot depend on a future value of another variable and using lagged instruments has become a common practice among econometricians, it effectively does not enable one to escape from simultaneity bias. This finding is demonstrated in an article by Reed (2015) where he also shows that the problem is exacerbated by the presence of serial correlation in the endogenous variable.

The findings above in Chapter 2 are supported by the fact that Johansen cointegration test shows that only in the case of Italy and Spain market and model CDS spreads are cointegrated in the first sub-period and not cointegrated in the second sub-period for both tenors. In the case of other countries, the test showed the same result before and after the change point. To support results of the model in Chapter 3 Johansen test points to no cointegration between CDS spread and government bond spread in the first sub-period in the case of Italy, Portugal and Spain, all 5-year tenors. After the new ISDA rules the cointegration appeared. In the case of other countries, the test showed the same result before and after the change point.

In addition, a simple analysis independent of endogeneity was performed. Suppose a 5-year tenor and Chapter 2:

1. Differences were created:
$$diff_{5Y,t} = modelCDS_{5Y,t} - marketCDS_{5Y,t}$$

2. The differences were cleaned from the effect of counterparty and liquidity risk:
$$diff_{5y,t} = \alpha + \beta_1 cpty_{5Y,t} + \beta_2 liq_{5Y,t} + \varepsilon_t$$
$$diff_{5Y,t}clean = \left(modelCDS_{5Y,t} - marketCDS_{5Y,t}\right) - \widehat{\beta_1} cpty_{5Y,t} - \widehat{\beta_2} liq_{5Y,t}$$

3. The distribution of the time series of these cleaned differences was observed: equality of mean and variance was tested before and after the change point using Welch test (Welch, 1951) resp. Bartlett test (adjusted by Sokal and Rohlf, 1995, and Judge et al., 1985).
4. Steps 1.-3. were repeated for 10-year tenor and the same analysis was performed on model CDS and government bond spread in the model in Chapter 3.

Results of the distribution comparison are shown in the following two tables.

**Table 4.6: Results of analysis of time series differences (Chapter 2 model)**

| | | Sub-period 1 | | Sub-period 2 | | Test of equality | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Tenor | Mean | St dev | Mean | St dev | Mean | Prob | St dev | Prob |
| AT | 5Y | 0.232 | 0.180 | 0.228 | 0.162 | 0.076 | 0.783 | 4.255 | 0.039 |
| | 10Y | 0.026 | 0.097 | 0.104 | 0.177 | 64.962 | 0.000 | 128.430 | 0.000 |
| BE | 5Y | 0.109 | 0.227 | 0.070 | 0.247 | 5.315 | 0.021 | 2.556 | 0.110 |
| | 10Y | 0.049 | 0.284 | 0.030 | 0.188 | 0.991 | 0.320 | 68.111 | 0.000 |
| FI | 5Y | -0.100 | 0.175 | -0.184 | 0.141 | 50.691 | 0.000 | 18.508 | 0.000 |
| | 10Y | 0.228 | 0.075 | 0.147 | 0.113 | 155.089 | 0.000 | 58.544 | 0.000 |
| FR | 5Y | 0.052 | 0.201 | -0.039 | 0.167 | 46.388 | 0.000 | 14.469 | 0.000 |
| | 10Y | 0.131 | 0.153 | 0.039 | 0.176 | 63.445 | 0.000 | 7.327 | 0.007 |
| IR | 5Y | 1.496 | 0.880 | 1.453 | 0.956 | 0.451 | 0.500 | 2.837 | 0.092 |
| | 10Y | 0.726 | 0.484 | 0.792 | 0.549 | 3.412 | 0.065 | 6.539 | 0.012 |
| IT | 5Y | -1.136 | 0.338 | -0.942 | 0.947 | 12.746 | 0.000 | 418.773 | 0.000 |
| | 10Y | -1.224 | 0.704 | -1.074 | 0.980 | 6.688 | 0.010 | 57.677 | 0.000 |
| NE | 5Y | -0.135 | 0.141 | -0.089 | 0.131 | 23.624 | 0.000 | 2.145 | 0.143 |
| | 10Y | -0.152 | 0.105 | -0.407 | 0.119 | 1059.647 | 0.000 | 6.812 | 0.009 |
| PT | 5Y | 0.351 | 0.592 | 0.486 | 0.792 | 7.798 | 0.005 | 33.959 | 0.000 |
| | 10Y | -1.447 | 0.594 | -0.631 | 1.081 | 162.905 | 0.000 | 144.200 | 0.000 |
| SP | 5Y | -0.108 | 0.354 | 0.170 | 0.889 | 30.494 | 0.000 | 328.716 | 0.000 |
| | 10Y | -0.685 | 0.312 | -0.373 | 0.792 | 48.847 | 0.000 | 335.226 | 0.000 |

Note: First four columns of values display mean and standard deviation of the differences in both sub-periods. Next four columns display results of a test of equality of mean (Welch test) and standard deviation Bartlett test) between first and second sub-period. Grey cells highlight significant increase in mean and standard deviation between the first and second sub-period at a 5% significance level.

**Source: Author's calculations**

It is apparent that in the case of riskier countries – Italy, Portugal and Spain – both the mean and standard deviation of the time series increased significantly. Increase in the mean points to the fact that the CDS became cheaper and increase in the standard deviation points to higher volatility and lower trust in CDSs. Results of other countries are not that clear, which is again in line with the results of our original analysis.

**Table 4.7: Results of analysis of time series differences (Chapter 3 model)**

| | | Sub-period 1 | | Sub-period 2 | | Test of equality | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Tenor | Mean | St dev | Mean | St dev | Mean | Prob | St dev | Prob |
| AT | 3Y | -0.388 | 0.073 | -0.321 | 0.049 | 148.458 | 0.000 | 41.065 | 0.000 |
| | 5Y | -0.431 | 0.084 | -0.425 | 0.040 | 0.863 | 0.355 | 133.889 | 0.000 |
| BE | 3Y | -0.584 | -0.634 | -0.487 | -0.603 | 96.509 | 0.000 | 32.078 | 0.000 |
| | 5Y | -0.487 | 0.074 | -0.603 | 0.052 | 423.167 | 0.000 | 31.572 | 0.000 |
| FR | 3Y | -0.479 | 0.047 | -0.467 | 0.058 | 6.505 | 0.011 | 11.308 | 0.000 |
| | 5Y | -0.225 | 0.049 | -0.243 | 0.073 | 11.487 | 0.001 | 39.887 | 0.000 |
| GE | 3Y | -0.329 | 0.023 | -0.274 | 0.042 | 373.126 | 0.000 | 81.589 | 0.000 |
| | 5Y | -0.528 | 0.033 | -0.504 | 0.038 | 59.778 | 0.000 | 5.128 | 0.024 |
| IT | 3Y | -0.185 | 0.147 | -0.441 | 0.149 | 388.048 | 0.000 | 0.035 | 0.852 |
| | 5Y | -0.003 | 0.154 | -0.313 | 0.147 | 545.333 | 0.000 | 0.575 | 0.448 |
| NE | 3Y | -0.296 | 0.077 | -0.244 | 0.029 | 108.294 | 0.000 | 200.242 | 0.000 |
| | 5Y | -0.521 | 0.065 | -0.515 | 0.056 | 1.610 | 0.205 | 8.570 | 0.003 |
| PT | 3Y | -1.488 | 0.313 | -2.008 | 0.295 | 375.662 | 0.000 | 0.939 | 0.333 |
| | 5Y | -1.195 | 0.279 | -1.643 | 0.556 | 222.210 | 0.000 | 133.421 | 0.000 |
| SP | 3Y | -0.431 | 0.135 | -0.765 | 0.148 | 687.009 | 0.000 | 2.204 | 0.138 |
| | 5Y | -0.156 | 0.117 | -0.476 | 0.098 | 1122.618 | 0.000 | 7.894 | 0.005 |

Note: First four columns of values display mean and standard deviation of the differences in both sub-periods. Next four columns display results of a test of equality of mean (Welch test) and standard deviation (Bartlet test) between first and second sub-period. Grey cells highlight significant decrease in mean and standard deviation between the first and second sub-period at a 5% significance level.

**Source: Author's calculations**

The results of Chapter 3 analysis show that the changes in 5-year tenor are more in line with the main hypothesis that with increased trust mean and standard deviation decreased in the second sub-period. The mean decreased in the case of Italy, Portugal and Spain, the change in standard deviation change is mostly not significant. In the case of Austria and the Netherlands the standard deviation decreased significantly and the change in mean is less significant. The hypothesis was not confirmed in the case of Germany. These findings are not the same but similar to those received in Chapter 3.

To sum up, the main findings in Chapter 2 and 3 are supported by several additional analyses in this chapter and the author believes that the results are not significantly distorted by endogeneity. The analysis is based on solid grounds and the validity of hypotheses is evidenced by market practitioners as well (as discussed in respective chapters).

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# A. Response to Opponents' Reports on Dissertation Thesis

Dear Opponents,

I would like to thank you for your recommendations and valuable advices. They have improved my dissertation considerably. I have responded to all your remarks and included majority of your suggestions into the final version of my dissertation.

**Report of Advisor doc. PhDr. Petr Teplý, Ph.D.**

*Comment 1: Recommendation to update references.*

Answer 1: The references in already published articles could not have been changed. However, in the Introduction and Appendix with the latest calculations up-to-date sources with the most recent findings are used.

**Report of Opponent Prof. Ing. Oldřich Dědek, CSc.**

*Comment 1: Missing explanation of a term „base correlation".*

Answer 1: There are two approaches to correlation determination: implied correlation and base correlation. In both approaches the correlation is determined endogenously. Implied correlation is defined as a correlation for which the net present value of a tranche equals zero. The base correlation approach is slightly more complex as it combines the most junior tranches together and looks for a correlation that sets their total net present value to zero. Hence this approach is more stable. The term is explained at the end of Section 1.4.

**Report of Opponent Prof. David Tripe, BCA (Hons), MBS, PhD, Dip Bank**

*Comment 1: Omission of introductory chapter.*

Answer 1: In our institution a dissertation thesis for the purposes of a pre-defense does not have to be final and it does not have to include all chapters. The introductory chapter was added in this final version. The numbering of the main chapters remains the same (Introduction does not have a chapter number). This is also usual in our institution.

*Comment 2: Reference to an article published by Reuters.*

Answer 2: The reference was corrected. The article was issued in October and it includes the latest available data, i.e. end-September.

*Comment 3: Discussion of political forces impact on the difficulties for CDS holders to exercise their rights during the Greek debt crisis. Inclusion of a comment in Section 2.2.*

Answer 3: It is correct that political forces had an impact on the decisions about CDS trigger. Section 2.2. was enhanced by this comment and a short discussion based on an article in The Guardian (2011) was added. The article points to a simplified approach of European authorities to this topic by saying that the interests of all key institutions are preserved by avoiding a fully-fledged, recognized default and ignoring a trade off between write-offs and lending.

*Comment 4: Comment about German dates in the first paragraph of the page that contains Table 3.2.*

Answer 4: The cause of the sooner break point in the case of Germany was examined but the author cannot think of any major reason for this occurrence. The main hypothesis of the chapter was not confirmed in the case of Germany, i.e. new ISDA conditions did not have a significant positive impact on the link between bond and CDS prices. Therefore, I can at least conclude that the break-date is expected to be caused by different market movers that the new ISDA conditions. A footnote with this explanation was added in Section 3.5.2.

*Comment 5: Inclusion of a brief summary chapter at the end of the dissertation.*

Answer 5: It is not a usual practice in our institution. However, the introductory chapter links the individual chapters together and draws the main conclusions.

*Comment 6: Inclusion of a single list of references rather that listing at the end of each chapter of the references used in the chapter.*

Answer 6: A single list of references was added.

*Comment 7: Missing explanation of bold numbers in Table 1.1.*

Answer 7: The table shows results of CDX valuation for each correlation (rows) and tranche (columns). The bold values show the result of the valuation which is the closest to the actual market price (market price is in the second row of the table). Implied correlation is the value of correlation correspondent to the market price. It is then copied to the last row of the table. This explanation was included in the Note below Table 1.1.

*Comment 8: The opponent proposed several grammatical changes, changes in wording and formatting, English check and one incorrect reference.*

Answer 8: All proposed changes were incorporated in the final version of the Dissertation.

**Report of Opponent Prof. RNDr. Jiří Witzany, Ph.D.**

*Comment 1: Structured finance CDOs presented more than 50% of issuance volume in 2004-2007. The discussion in the dissertation should not neglect this aspect of CDOs. The valuation of 125 underlying credit entities is much simpler than in case of structured finance CDOs.*

Answer 1: Section 1.1. states that CDOs rank among the more advanced structured products and the model used for their valuation are very complex. At the end we admit that we use a simple model the main purpose of which is to suitably illustrate sensitivities and key features of CDO valuation. The aspect, that majority of the market is structured finance CDOs is a useful argument supporting our arguments about the complexity of financial products. I included this argument in the first introductory chapter of the dissertation.

*Comment 2: Missing link between the mortgage market, MBS market, the CDO market, and finally the CDX tranche market impacted by defaults of the large financial institutions.*

Answer 2: The discussion was included in the introductory chapter. There is nearly a page discussing the main interconnections.

*Comment 3: Selection of German government bond yields as a proxy of risk-free rates in the second chapter. The proxy has become problematic as even German government went up. Selection of IRS as a proxy of risk-free rate in the third chapter. Recommendation to use OIS rates.*

Answer 3: Selection of a risk-free rate is a problematic issue because there is no absolutely risk-free rate on the market. It is a common practice by researches and market practitioners to use either a government bond or treasury bill yield of a high-rated country (e.g. US or Germany), interest rate swaps or overnight index swap. All these approaches are common. In the second chapter Germany was chosen as a benchmark because of the lowest bond yields among the analyzed countries. This selection ensures non-negative spread over the benchmark. 5-year EUR OIS traded during the observed period on average 7.5 basis points above the 5-year German government bond yield (Source: Bloomberg). The fact that OIS is higher than the German bond yield, i.e. there is a negative spread, would lead to problematic CDS valuation. Shorter tenor of the OIS would not be optimal because it would not reflect the correct maturity of the instrument. Another convenient argument for the use of the bond yield is that both instruments are cash instruments and as a result both yields include a premium for liquidity. By subtracting these yields the liquidity component is excluded and the result is better comparable with unfunded CDS spread. Discussion after Table 2.3 admits that the low significance of parameters in the first sub-period in the case of less riskier countries might be caused by the low spreads, however I believe that OIS would not change the significance. In the third paper the argumentation is similar. Considering the fact that I did not perform the CDS valuation, IRS rates could be used although implying a negative spread (the regression is performed on differenced data and the negative level does not play a role).

*Comment 4: Investigation of a correlation between the counterparty risk proxy (consisting of CDS spread of the largest banks) and other explanatory variables in the second chapter.*

Answer 4: At the end of Section 2.6.1. we include a post-estimation analysis. It includes a comment that the correlation coefficient between the regressors was calculated and ranges between 0.3 to 0.5 which does not point to collinearity. It supports an argument that bond market in the Eurozone and mostly banks CDS market in the United States are not that close to each other.

*Comment 5: What is meant by the adjustment of CDS premiums quoted in USD for Eurozone governments by the EUR/USD cross-currency swap values. There might be certain small impact of the currency mismatch, but probably negligible and not easy to quantify.*

Answer 5: CDSs on Eurozone countries are USD denominated instruments and Eurozone bonds (from which model CDS quotes are derived) are EUR denominated instruments. Eurozone bond yield expressed in USD would be different because of different level of EUR and USD interest rates and exchange rate expectations. To reach a USD equivalent yield of a EUR denominated bond a USD investor would need to first borrow EUR for USD in a cross-currency swap with the same maturity as the maturity of the bond and then buy the EUR denominated bond. The overall yield of these two transactions is the USD equivalent yield. There is a footnote below Table 2.1 which comments on the issue.

*Comment 6: Exogeneity of the explanatory variables – its testing and alternative approaches.*

Answer 6: To adequately address this comment I added Chapter 4 in a dissertation with a short note on endogeneity. It provides additional analyses enhancing the findings of the previous chapters. It should fully cover the topic of exogeneity of the time series analyzed in Chapter 2 and Chapter 3.

*Comment 7: The regression and the time series model in Chapter 3 is based on daily changes. Would the author expect the fundamental relationship between the bond spread and CDS premiums to change if weekly or monthly data were used?*

Answer 7: The findings in Chapter 3 are not supporting the hypothesis that after the change of ISDA conditions the link between bond and CDS spread increased for all countries. To verify that this finding is not caused too much noise in daily data the model was recalculated using weekly data. Monthly data would lead to only 12 observations per sub-period. The results of the weekly data changes were very similar to the original findings. A note commenting the weekly data re-estimation was added at the end of Section 3.5.3.