Essays on Financial Markets and

Central Bank Policy

by

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Submitted for the Degree of Doctor of Philosophy

Surrey Business School

Faculty of Arts and Social Sciences

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Summary

This Thesis consists of three chapters examining the interaction and comovement between different financial assets in terms of their price, liquidity and volatility, and analysing the impact of the central bank's monetary policy stance on this interaction.

*The interaction of the Stock, Bond and CDS markets: An empirical analysis* examines the price co-movements between the stock, bond, and CDS markets finding differences in the timing with which information is reflected in these asset-markets. It further identifies the factors that generate order flow in these markets focusing on the instruments controlled closely by the central bank. The examination of those instruments includes a comparison between standard and non-standard monetary policy measures and the identification of the monetary transmission channel.

*Sovereign Bond and CDS Market Liquidity. Arbitrage Activities and Central Bank Interventions* analyses the joint dynamics of sovereign bond and CDS market liquidity taking into account the no-arbitrage relationship between them, i.e., the CDS-bond basis, and provides evidence of asymmetric liquidity interaction between the two asset-markets. The examination of central bank interventions and regulatory changes reveals that the ECB's open market purchases and the EU's naked CDS ban managed to limit the mispricing in the sovereign bond and CDS markets and improved the bond-CDS liquidity interaction.

*Volatility and Integration in the European Sovereign Bond and CDS Markets* studies the strength and direction of volatility linkages between European sovereign bond yields and CDS spreads and assesses whether volatility linkages lead to stronger cross-asset integration. The analysis points to the existence of two blocs within the EMU according to the level of bond-CDS integration, a level which in the EMU South is inversely related to the CDS-bond basis. It additionally lends support to the implementation of non-standard monetary policy measures, since an easing in the ECB's policy stance improves the level of cross-asset integration.
Declaration

This thesis and the work to which it refers are the results of my own efforts. Any ideas, data, images or text resulting from the work of others (whether published or unpublished) are fully identified as such within the work and attributed to their originator in the text, bibliography or in footnotes. This thesis has not been submitted in whole or in part for any other academic degree or professional qualification. I agree that the University has the right to submit my work to the plagiarism detection service TurnitinUK for originality checks. Whether or not drafts have been so-assessed, the University reserves the right to require an electronic version of the final document (as submitted) for assessment as above.

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Acknowledgements

I would like to thank Professor Manthos Delis. No words are enough to describe his mind, character, intuition, and knowledge. He is the epitome of a supervisor and educator. He continuously proves why he is considered among the top European academics.

A great deal not only of this work but of other accomplishments as well throughout this period is attributed to Professor Dimitrios Gounopoulos, whose help and guidance has been remarkable. His reputation as an academic and as a person precedes him. He is a role model for every young person in terms of personality, quality of character, integrity, and attitude towards life and work.

I am indebted to Dr. Liang Han and Dr. Andrew Mason since without them I would not have been here from the beginning. We had an outstanding communication and collaboration all those years and it is a privilege to have worked with them. They are both remarkable characters and researchers.

Special thanks to Professor Fotios Passiouras for his inestimable advice and assistance when required the most and of course to Dr. Rafal Wojakowski.

A significant part of this work is attributed to Dr. Chris Mavis. He is an outstanding person and academic and his help has been decisive for raising this Thesis to the highest standards. By providing valuable advice and suggestions he played a pivotal role during the writing process. He additionally performed his institutional role in an exemplar way.

I am also very grateful to Professor Taufiq Choudhry for his excellent insight and invaluable comments. He contributed significantly to the completion of this Thesis during the most important stage. His noble help and support were memorable and played a crucial role when needed the most.

I would further like to thank my colleague Dr. Panagiotis Panagiotou for being a friend and collaborator during this period and I also thank him in advance for doing so in future periods. His has been a source of confidence, inspiration and innovation. He is a remarkable person and researcher.

I am further grateful to Dr. Georgios Palaiodimos for his valuable help, advice and encouragement during an important stage of my academic and professional life. His character and attitude are exemplary. His professional expertise and intuition have been fundamental determinants of my work.
On the same front, Dr. Georgios Bampinas has been an outstanding colleague and co-author. His creative thinking, methodological excellence and remarkable professionalism have been and will continue to be very welcome and appreciated. He has a bright future ahead of him.

Dr. Francesco Sanna has been a great friend, colleague and fellow traveller. His mind and way of thinking are outstanding. He is an incredibly talented person and a shining personality. His help and friendship have been catalytic during my living in Frankfurt. It is a great luck that I have met him.

I would also like to thank Dr. Ioannis Papantonis who has always been on the forefront of academic research. His ideas for cutting-edge work are always well received and welcome.

Dr. Karampatsas has further been a source of encouragement, inspiration and friendship throughout my doctoral studies and therefore I thank him very much and wish him the best for his career.

I am very grateful to all my friends and relatives for their support, confidence and encouragement all those years and I intend to requite their help. In this respect I feel blessed that I have received the help and wishes of all those people from my circle of friends and relatives alike. I am very indebted to every single one of them. Among them Thodoris and Nikolaos helped me immensely during my time in London. Thodoris has been very helpful, supportive and hospitable. He is more than a relative to me and I owe him a lot. Nikolaos has been and still is a great friend not just to me but to a great number of people. His help, attitude and unconditional contribution are remarkable and will never be forgotten. I wish him the very best and I will always stand ready to help him. Giota has further helped me with her advice, encouragement, and well-constructive criticism during my time abroad. She has been a crucial factor for my achievements to date and I wish her every success.

I am also very grateful to a number of academics, researchers, and industry professionals that helped me during this period. I will personally thank them in due time and reciprocate for their help.

Last but most deserved, I thank my parents for their invaluable help and most importantly for cultivating ethos and for providing me with a distinctive framework of values and ideals. I struggle to find a single word or phrase that can describe even to the slightest extent their contribution, encouragement and support during my studies and most importantly, during my life thus far. I owe them everything and my goal is to offer my fellow people all those things that my parents offered me.
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1. Introduction

In the present Thesis I examine the interaction between financial markets and I assess the effectiveness of central banks in affecting this interaction. My research evolves across two parallel but closely connected fronts, that of financial asset-market comovement on the one hand, and that of monetary policy on the other. On the first front, I analyze the comovement and interaction between different financial asset-markets by considering three forms of interaction, namely price, liquidity, and volatility. The analysis of these forms is empirically analyzed within the context of three different chapters, however as these chapters (Sections 3-5) and Literature Review (Section 2) reveal, all three types are strongly interrelated. On the second front, I consider the role of monetary policy in affecting this interaction by attributing particular attention to the recent non-standard policies adopted by central banks following the 2007-2008 financial crisis and the European sovereign debt crisis. The role of monetary policy is considered in each of the three empirical chapters of the Thesis.

The objective of Section 1 is to introduce the reader to the subject of the present Thesis and the reasons for its examination. To this end, in the remainder of the Introduction I briefly discuss the importance of the issue of financial asset-market interaction as well as that of monetary policy (Sections 1.1 and 1.2) and I present an outline of the objective and results of the analysis conducted in each of the empirical chapters of this Thesis (Section 1.3). Since this Thesis is concerned with the policy response to the recent financial and European sovereign debt crises I further incorporate a discussion (Section 1.3) of the differences between the two crises.

1.1 Financial Asset-Market Comovement

The intertemporal comovement and interaction between financial asset-markets constitute important features of the financial market framework and therefore have captured the interest and attention of a number of different market participants: government agencies for regulatory purposes, private and institutional investors for trading and hedging against credit risk, banks and financial institutions for setting capital requirements. The identification of the nature of the joint dynamics between financial assets is of paramount importance to policy makers and financial regulators who monitor the
interaction and correlation between different markets in order to allocate efficiently risk in the financial system and minimize the likelihood of a systemic crisis occurring. This is due to the potential repercussions of financial asset comovement on financial stability. In the case of a negative shock occurring within or transmitting to the financial system, investors proceed to the sale of the same assets simultaneously, thereby resulting in heightened volatility.

In this respect, stronger (positive) correlations between financial assets can be attributed to a form of herding behaviour. This behaviour causes diversification to be less profitable and thus investors might be induced to assume positions of a higher risk, which above a certain point might become excessive. The end result is a surge in financial market risk, which can further contribute to the outbreak of financial crises. Along the same lines, private and institutional investors manage portfolios and/or leverage diversified positions that depend on price data from a number of distinctive assets and are thus, affected by the degree and the nature of correlations and linkages between those assets. In addition, financial institutions incorporate information on the transfer of risk between different assets when pricing structured products that are subject to the interaction of different markets. Thus, the exact identification and constant monitoring of correlations across a broad spectrum of financial assets, is essential for containing systemic risk and enabling the efficient allocation - and diversification - of funds across financial markets.

From a central banking perspective, although the focus of central banks is mainly attributed to price stability, the global financial crisis combined with the Eurozone crisis, has shifted this focus towards the (extreme) financial market developments during the crises periods. This amendment in the objectives of central banks assigns macroprudential policy a crucial role in ensuring systemic resilience and deterring financial market crashes. The revision in central bank thinking and practice is further discussed in Section 1.2 below.

1.2 Monetary Policy

In addition to the examination of the interaction between financial asset-markets, central in my analysis in the present Thesis is the role of monetary policy, and in specific that of non-standard
monetary policy. The consideration of the role of monetary policy is due to the fact that although monetary policy is conducted in terms of variables/objectives that the central bank monitors closely, such as the level of output, employment and inflation,

“the influence of monetary policy instruments on these variables is at best indirect. The most direct and immediate effects of monetary policy actions, such as changes in the Federal funds rate, are on the financial markets; by affecting asset prices and returns, policymakers try to modify economic behaviour in ways that will help to achieve their ultimate objectives”

(Bernanke and Kuttner, 2005)

This importance of monetary policy, and especially of non-standard monetary policy is further enhanced by the recent financial and European sovereign debt crises. The evolution and the intensity of these crises have created new challenges for monetary policy makers in both Europe and the US, which extend beyond the realm of standard theory of monetary policy. Monetary policy is normally conducted in terms of an operating target for the short-term nominal interest rate, i.e., the Federal funds rate in the case of the Federal Reserve, or via the discount rate, i.e., the rate on main refinancing operations (MRO) in the case of the European Central Bank. However, as an initial response to these crises, central banks in major economies drastically reduced their base interest rates to near or zero level (zero lower bound). This reduction was further extended to levels below zero thereafter. Since, the support of the economy through traditional measures was no longer feasible, central banks resorted to measures of non-standard monetary policy.

To this end, the main challenge as well as alternative approach for the current and future conduct of monetary policy pertains to the optimum size of the central bank's balance sheet. As evidenced in Figure 1.1 the Fed's balance sheet expanded from $900 billion in the summer of 2008 to over $2.2 trillion in the fall of 2008. This increase in the size of the central banks' balances sheet was driven by an increase in the reserves that depository institutions hold with the central bank (also

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1 See Mishkin (2001), Curdia and Woodford (2011). The equivalent of the Federal funds rate in Europe is the EONIA (Euro Overnight Index Average), although officially the ECB does not target the interest rate.

2 A description of the measures of non-standard monetary policy is provided in Section 2.6.1.
termed bank reserves), which increased from $10 billion in March 2008 to over $900 billion in April 2009. This surge has consequently led some commentators to suggest that the main interest of US monetary policy has changed, from a policy of targeting interest rates to one termed as “quantitative easing” (Curdia and Woodford, 2011). From a similar perspective the ECB’s balance sheet grew from €2.0 trillion in the beginning of 2010 to almost €3.0 trillion in late 2011, with excess reserves (the current account holdings of banks with the ECB in excess of required reserves) surging from less than €100 billion in the summer of 2011 to over €800 billion in the spring of 2012.

Figure 1.1
Total Assets of Federal Reserve and European Central Bank

Source: Federal Reserve Bank of St. Louis

Source: Statistical Data Warehouse
This shift in central bank thinking and policy raises the issue of whether the supply of bank reserves (or perhaps the monetary base) should be considered as an alternative or even superior operating target for monetary policy (Curdia and Woodford, 2011). It further raises the issue of whether in periods where interest rates are at the zero lower bound - as is the case in the US since December 2008 or in Europe since November 2013 - the amount of bank reserves should constitute the only important monetary policy decision (Mishkin, 2009; Curdia and Woodford, 2011). For all those reasons, in the present Thesis I pay particular focus on the recent policies of quantitative easing implemented by the Fed and the ECB. Within this framework, I examine measures of bank reserves vis-à-vis measures of interest rates in terms of their effectiveness to exert an impact on financial asset-markets.

1.3 The 2007-2008 financial crisis and the European sovereign debt crisis
Pivotal in the empirical analysis of the present Thesis is the examination of the policies adopted by the central banks as a response to the two major financial crises of the 21st century, namely the 2007-2008 financial crisis and the European sovereign debt crisis, alternatively Eurozone crisis. For that reason, the terms ‘‘global financial crisis’’ and ‘‘European sovereign debt crisis’’ are often mentioned throughout the Thesis. Although the two crises share certain similarities - since the financial crisis created the financial and economic conditions for the evolution of the Eurozone crisis - every crisis is distinct with regards to the causes that led to its development. The 2007-2008 financial crisis refers to the US subprime mortgage crisis which subsequently led to the bankruptcy of Lehman Brothers in September 2008 and the development of a banking crisis at the global level. This crisis was triggered by the US housing bubble and the way with which US banks evaded regulatory capital requirements. The repackaging of mortgages into mortgage-backed securities, enabled banks to reduce the amount of capital required against their loans, thereby increasing their ability to make loans many-fold; the end result was the concentration of mortgage default risk in those banks, which render them insolvent at the time of the housing bubble burst (Acharya et al., 2009).
The US-originated crisis and the resulting global financial shocks led to the evolution of the European sovereign debt crisis. Due to these shocks, cross-border financial flows dried up from the end of 2008 onwards, as investors repatriated funds to home markets and reassessed their exposure to the euro area countries (Milesi-Ferretti and Tille, 2011). This process disproportionately affected countries with the greatest reliance on external funding and short-term debt, especially those with weak fiscal and macroeconomic fundamentals, such as Greece, Ireland, Portugal, and Spain (Lane, 2012). These problems were magnified by the bailouts of those countries' banking sectors and the inadequate fiscal measures as a response to the slowing economic activity in the post-2007 period. The event that triggered the Eurozone crisis however was Greece's upward deficit revision in late October 2009, which led to a financing package of 110€ billion and supporting economic policies as part of the respective country's agreement on an economic adjustment programme in May 2010 with the European Commission, the European Central Bank and the International Monetary Fund. The concerns about the solvency of not only Greece, but of all the debt-laden euro area countries intensified, thus leading to the adoption of fiscal consolidation programmes in many euro area countries and the resort to non-standard monetary policies on the part of the ECB. The Greek debt-restructuring in March 2012, the largest one in the history of sovereign defaults further marked the 2010-2012 period which constituted the worst phase of the European sovereign debt crisis.

1.4 Outline of the Empirical Chapters

In the first empirical chapter of the Thesis (Chapter I) which is titled The interaction of the Stock, Bond and CDS markets: An empirical analysis, I examine the interaction between the stock, bond and CDS markets by employing a number of market indices in Europe and the US. The examination is important in light of the immense growth of index trading associated with index mutual funds and exchange-traded funds and the consequent popularity of value-weighted and/or index portfolios (Bhattacharya and Galpin, 2011). In addition, this growth has resulted in an increase in systematic liquidity and systematic risk (Kamara et al., 2008) and in the efficiency of price information (Chordia et al., 2011). Therefore, I assess whether the surge in index trading and passive investment strategies
is associated with enhanced information transmission between the stock, bond, and CDS markets, or information is instead reflected in one market and then transmitted to the rest, thereby giving rise to lead-lag relationships.

However, the recent financial and European sovereign debt crises have redefined the role of central banks; in addition to their inflation mandate, they assumed the role of preserving financial stability. This is because asset price crashes can be severe in the event where central banks either remain passive (unresponsive) or when actively reinforce deflationary pressures. For this reason, I examine the success of central banks in affecting financial markets by attributing particular focus on non-standard measures of monetary policy and the associated expansion of the central banks' balance sheets. Since the Fed is the first central bank to adopt quantitative easing following a major crisis (i.e., the 2007-2008 US credit crunch) I compare the impact of its policy on the domestic financial markets relative to the ECB which resorted to non-standard policies to a lesser extent and only after the escalation of the Eurozone crisis.

I contribute to the literature by examining this interaction at the market level. This enables me to: a) put to the test the “friction-based” and “sentiment-based” theories of comovement according to which market indices are disassociated from underlying fundamentals thereby giving rise to differences in the information transmission and b) address the fact that movements in single-name securities are subject to both idiosyncratic and systematic risk. By shifting the examination from the firm- to the market-level I segregate the systematic risk from the idiosyncratic and focus only on the former. That way I prevent certain idiosyncrasies, such as asymmetric information and insider trading problems, from distorting the timing and magnitude of the cross-asset flow of information.

I additionally contribute on the issue of monetary policy and in particular of the ability of non-standard monetary policy tools in affecting financial markets under certain conditions. These conditions refer to periods of financial market disruption where in addition, the interest rate is at the zero lower bound and thus the central bank is deprived of its main monetary policy tool. In this respect, I shed light on the debate about the role of central banks for ensuring financial stability during extraordinary economic periods. On the one hand, traditional Keynesian approaches suggest the
ineffectiveness of non-standard monetary policy measures during financial crises, however more recent studies (e.g., Mishkin, 2009; Curdia and Woodford, 2011) advocate a greater role for the expansion of the central bank's balance sheet through asset purchases.

By constructing measures that reflect exogenous variations of the central bank's policy stance I ease concerns about the endogeneity between central bank measures and financial market conditions. I alleviate the remaining concerns by considering a vector autoregression (VAR) that a priori assumes the simultaneous interaction of the monetary policy and financial market variables. Furthermore, the identification of the VAR with sign restrictions enables me to determine the asset that acts as the main channel for the transmission of the non-standard measures to financial markets.

Through my analysis I confirm the “friction-based” and “sentiment-based” theories of co-movement, since I find differences in the timing of the information transmission across the stock, bond and CDS markets. These differences are more evident in Europe before the financial crisis, and in the US after the crisis, where information about fundamentals is reflected first in the stock index and then transmitted to the bond and CDS indices. My results further lend support to the Fed's non-standard monetary policy measures. In particular, I show that measures of the Fed's policy stance induce greater movements in the US indices after the crisis compared to the impact exerted by measures of the ECB's stance on the European indices. Among those measures I distinguish measures of bank reserves held with the central bank, thereby providing a rationale for the expansion of the Fed's balance sheet as an instrument of US monetary policy.

The examination of the price comovement and interaction in the first empirical chapter is succeeded by the examination of the other major type of cross-asset interaction, that of liquidity, which is the focus of the analysis conducted in the second empirical chapter (Chapter II), titled *Sovereign Bond and CDS Market Liquidity. Arbitrage Activities and Central Bank Interventions*. To examine the issue of cross-asset liquidity interaction I consider the sovereign bond and CDS markets since the respective asset-markets have been in the core of the liquidity dry-up in the European sovereign financial markets during the Eurozone crisis. In addition, under the Basel III regulatory
framework government bonds and derivative contracts are eligible as “high-quality liquid assets” to be held by banks in order to protect from liquidity shocks and systemic liquidity crises.

Being a cash asset and a derivative contract respectively, the bonds and the CDS are linked via a no-arbitrage relationship, namely the CDS-bond basis, which is the difference between the CDS spread and the credit spread on the bond and is theoretically expected to guarantee the comovement between the two asset-markets. Acknowledging the role played by the CDS-bond basis for the pricing and dynamics of sovereign bonds and CDSs, I further assess how the CDS-bond basis affects the bond-CDS liquidity interaction and whether it drives the two asset-markets towards or away from their equilibrium price.

Sovereign bonds and CDSs have further constituted the target of an unprecedented series of central bank interventions within the European context, while government bonds have been the target of the second round of the Fed's quantitative easing programme. Therefore, I examine the ability of the central banks in Europe and the US to affect the liquidity of the sovereign bond and CDS markets and whether non-standard monetary policy measures are able to restore the equilibrium relationship between the two assets, as reflected in the level of the CDS-bond basis.

The examination is additionally necessitated by the speculative attacks via the CDS market that aimed at elevating the yields on the government bonds of the debt-laden countries of the EMU South. These attacks brought about the EU's regulatory response which was materialized in the form of a ban on the trading of naked CDS contracts, which was however challenged by the International Monetary Fund on the grounds that the ban is detrimental to the liquidity of the sovereign bond market. Given this change in regulation as well as the arguments against it, I analyze the impact of sovereign CDS market liquidity on the liquidity of the sovereign bond market following the ban.

My contribution is three-fold: First, by examining the liquidity interaction between assets linked by arbitrage I show that deviations from their equilibrium price are important drivers of liquidity dynamics and vice versa. The consideration of the CDS-bond basis further enables me to identify which of the two assets acts as a limit to arbitrage. Second, I analyze the effect of central bank interventions and most importantly that of non-standard monetary policy measures that targeted
specifically the two asset-markets, such as the asset purchase programmes implemented through the ECB's Securities Markets Programme and the Fed's second round of quantitative easing. Third, the EU's decision to ban the naked CDS trading acts as a natural experiment that allows me to empirically evaluate whether falling sovereign CDS liquidity exerts a negative impact on the liquidity of the sovereign bond market during the post-ban period.

My results suggest that sovereign bond liquidity drives sovereign CDS liquidity, especially in the countries of the EMU North. I further find that bond illiquidity is the major driver of the deviations from the bond-CDS equilibrium price, thereby supporting the arguments about the most illiquid asset acting as a limit to arbitrage (see Roll et al., 2007; Gârleanu and Pedersen, 2011; Nashikkar et al., 2011). I also provide evidence that the ECB and Fed interventions affected the bond-CDS liquidity dynamics and relieved the pressure on the CDS-bond basis exerted by bond illiquidity, a result consistent with the theoretical predictions of the preferred habitat theory. Contrary to Beber and Pagano's (2013) predictions I support the EU's decision to adopt the naked CDS ban, since in the period following the ban a deterioration in the CDS liquidity improves liquidity in the bond market.

Following the examination of price and liquidity interaction in the first two empirical chapters, in the third empirical chapter (Chapter III) I focus on the issue of financial asset-market volatility and integration. The chapter is titled *Volatility and Integration in the European Sovereign Bond and CDS Markets* and I calculate the dynamic bilateral volatility spillovers between the European sovereign bond and CDS markets during the 2007-2014 period. I conduct the examination within the European context since the severe tensions and negative spillovers observed between and across the respective asset-markets during the Eurozone crisis are crucial from the perspective of macroprudential policy implementation and the minimization of systemic risk. Due to the importance of financial market integration for the transmission of monetary policy - particularly within the confines of a monetary union - I further analyze the extent to which the stance of the ECB's monetary policy and the process towards monetary integration affects the degree of sovereign bond-CDS integration.
My contribution concerns the nature of the examination itself: considering the theoretical arguments that asset volatility constitutes the primary driver of asset integration, I empirically investigate whether an increase in the volatility spillover between the bond and CDS markets in each Eurozone country is associated with an increase in the level of integration between the two asset markets, as reflected in the level of their conditional correlation. In addition, bond and CDS contracts are linked by an equilibrium relationship which is conditional on the level of the bond-CDS conditional correlation. Therefore, I conduct the first empirical examination of the link between asset integration and asset equilibrium relationship, and assess whether a rise in bond-CDS correlation drives the two assets close or away from their equilibrium relationship, thereby eliminating or giving rise to arbitrage opportunities.

I further contribute at the methodological front. In particular I consider a generalized vector autoregression model augmented with common factors that allows me to a) identify the impact of domestic and foreign shocks to sovereign bond and CDS markets while acknowledging their endogenous nature and b) take into account the asymmetric size of these shocks. By recursively estimating the model I calculate the dynamic cross- and intra-market volatility linkages' throughout the total of the examination period and I identify breaks in those linkages' evolution. I additionally differentiate in the field of asset integration by modelling the conditional correlation between the bond and CDS markets - which is a measure of the level of bond-CDS integration - through an asymmetric generalized DCC GARCH. Compared to traditional GARCH approaches, I capture the dynamic and time-varying nature of the bond-CDS relationship. I further address the phenomenon of “asymmetric volatility” where financial asset volatility increases more following a negative rather than a positive shock of the same magnitude. These features are in turn particularly relevant when considering the negative financial and fiscal shocks that have occurred during the European sovereign debt crisis.

My results indicate a unidirectional volatility spillover from the sovereign bond to the CDS market in all EMU countries. Along these lines, Germany qualifies as the main transmitter of bond volatility to the CDS markets of the Eurozone core, while Ireland and Italy emerge as significant bond and CDS volatility contributors to the rest of the European CDS markets. When I proceed to the
asymmetric generalized DCC GARCH analysis I find that an increase in the level of bond-CDS integration in each of the countries of the EMU South coincides with an increase in the bond-CDS volatility spillover in the same countries. Therefore, I support the theoretical arguments about volatility being a major driver of cross-asset correlation (see Aït-Sahalia and Xiu, 2016). I further identify two blocs across the Eurozone, in terms of their level of bond-CDS integration: the EMU South where integration has strengthened after the Lehman Brothers collapse (late 2008), and the rest of the EMU where it has followed the reverse track. By including the CDS-bond basis in my analysis I document an inverse relationship between bond-CDS integration and the CDS-bond basis in the EMU South and Belgium. Lastly, I point to the ability of the ECB to affect integration between the European sovereign bond and CDS markets since I provide evidence that expansionary monetary policy exerts a strong and positive impact on the level of bond-CDS integration.

The Thesis is organized as follows: Section 2 reviews the most pertinent studies and presents the theoretical framework governing the empirical examination. The empirical analysis is comprised of Chapters I, II and III and is presented in Sections 3-5. Finally, Section 6 concludes.
2. Literature Review

Section 2 provides the most relevant studies with regards to the issue of asset comovement and the role of monetary policy. The aim of this Section is not to provide an exhaustive literature review but rather present the most important and influential studies that are required for the effective understanding of the subsequent empirical chapters in Sections 3-5. The literature review begins by presenting the fundamental theories that underlie the issue of market comovement, namely the Efficient Market Hypothesis (EMH) and the “friction-based” and “sentiment-based” theories of comovement. According to these contrasting theories, comovement in financial assets either reflects comovement in the underlying fundamentals (Efficient Market Hypothesis), or is delinked from shifts in their underlying fundamentals (“friction-based” and “sentiment-based” theories of comovement).

After the presentation of the theories that analyze the nature and extent of the assets' dependence on underlying fundamentals, follows a discussion of the channels of the information transmission between assets. Particular focus is attributed to the channels of liquidity and volatility, which according to studies at both the theoretical and empirical front, emerge as the main factors for asset comovement and interaction. Since prominent in the present Thesis is the examination of the interaction between bonds and CDS contracts, an additional factor as well as channel that affects those assets' interaction is their equilibrium relationship, i.e., the CDS-bond basis. To this end the discussion is extended in order to present all relevant studies on this theoretical equivalence between the CDS contract and the underlying bond, and also on the overall issue of bond-CDS interaction.

The final part of this Section presents the theoretical foundations of the link between asset prices and monetary policy. It further analyzes the rationale for central banks to incorporate asset prices in their formulation and implementation of monetary policy. Since the focus of the present Thesis is on the impact of non-standard monetary policy measures, the discussion involves a brief description of those measures and provides an overview of the main studies examining the impact of those measures on financial asset-markets.
2.1 The Efficient Market Hypothesis and the “Friction-based” and “Sentiment-based” Theories of Comovement

The proposition that constitutes the cornerstone of modern financial theory is the Efficient Market Hypothesis, further known as the Random Walk Theory. This proposition has been applied extensively to theoretical and empirical studies of financial asset prices as well as fundamental insights into the price discovery process and asset comovement. Owing its existence to the work of Samuelson (1965) and Fama (1965a; 1965b), the Efficient Market Hypothesis maintains that asset prices reflect all publicly available information. To this end, within the context of an information-efficient market any changes in the prices of financial assets must not be predictable if they fully incorporate the information and expectations of all market participants (Samuelson, 1965). The best way to understand this proposition is perhaps through an old joke frequently told among economists, according to which an economist is walking down the road along with companion; when seeing a $100 bill on the ground and the companion reaches down to pick it up, the economist says “Don't bother - if it were a genuine $100 bill someone would have already pick it up” (Lo, 2004). This example although accurately describing the logic underlying the EMH, i.e., the incorporation of all pertinent information in an asset's price (e.g., the $100 bill left laying on the ground), at the same time reveals its primary weakness: the counterfactual assumption with regards to human behaviour, namely rationality (ibid). Since Roberts (1967), it has been customary to distinguish between three types of market efficiency, each corresponding to three different types of information sets:

1) The weak form of Efficient Market Hypothesis which maintains that asset prices fully reflect the information contained in the historical sequence of prices.

2) The semi-strong form of EMH which maintains that in addition to historical price information, asset prices reflect all publicly available information pertinent to the respective asset.

3) The strong form of EMH which maintains that all information, whether publicly available or private, is known to any market participant and fully reflected in asset prices.

Hence, the more efficient the market is, the more random and therefore unforecastable the sequence of asset price changes generated within the respective market. This is due to the presence of
active market participants, who in their search for profits exploit all relevant information at their disposal, thus incorporating this information into market prices and instantly eliminating potential profit opportunities that were existent upon the initiation of the market participants' trades. The instantaneous occurrence of this trading pattern in a world of frictionless markets, rational investors and no trading costs, guarantees in turn that asset prices always reflect all available information (Malkiel, 2003). A direct corollary of the EMH is the traditional theory of price comovement, according to which comovement in prices reflects comovement in fundamental values (Barberis et al., 2005). Since, under the EMH, prices should always be equal to their fundamental value (i.e., the sum of an asset's rationally forecasted cash flows discounted at a rate appropriate for their risk), in a frictionless economy with rational investors any comovement in prices must be due to comovement in fundamentals (Barberis and Shleifer, 2003; Barberis et al., 2005). An asset's fundamental value can change either because of news about that asset's cash flows or because of news about discount rates that are used in order to calculate the asset's future cash flows. Thus, under the traditional theory of price comovement, correlation in asset prices is attributed to correlation in news about either cash flows or discount rates.

However, a number of studies provide evidence that this traditional approach of comovement is incomplete and that prices of similar assets react differently to their common underlying fundamentals. In particular, Hardouvelis et al. (1994) and Bodurtha et al. (1995) examine closed-end funds, the assets of which trade in different countries from the funds themselves. According to the traditional theory of price comovement the returns on these funds must comove with the returns on their underlying assets. In reality however, their returns are found to be disassociated since the closed-end funds appear to comove with the national stock market where they are traded, rather with the stock market in the country where their underlying assets are traded. This is further the case for domestic closed-end funds which appear disassociated from their asset holdings when the latter include large-cap stocks (see Lee at al., 1991). The disassociation between asset returns is also evident when identical (twin) stocks are considered, such as the Royal Dutch shares and the Shell shares respectively. Although these type of stocks should react to the same underlying fundamentals, because
theoretically they are claims to the same cash-flow stream, in practice their returns are delinked from each other (see Froot and Debora, 1999). From a similar perspective, Fama and French (1995) find that the movements between small and value stocks are unrelated to the stocks' reaction on news about underlying fundamentals, while Pindyck and Rotemberg (1988) find that aggregate demand - contrary to traditional approach of comovement - cannot be considered as a plausible source of correlation in the prices of seven different commodities.

The common conclusion of those studies is that asset prices react differently to the same underlying fundamentals. They thus give rise to a new class of “friction-based” and “sentiment-based” theories of comovement, according to which in the presence of economies with frictions or with irrational investors and in which there are limits to arbitrage, comovement in asset prices is delinked from comovement in underlying fundamentals (Shleifer and Vishny, 1997; Barberis et al., 2005). These theories in turn describe three specific views of comovement, namely the category view, the habitat view and the information diffusion view. The first relates to the category view, where the deviation of asset prices from their fundamental values is due to the categorization of assets into categories (e.g., large-cap stocks, oil industry stocks, investment-grade bonds), with the coordinated demand for this categories inducing common factors in those assets' returns (see Barberis and Shleifer, 2003).

Demand-driven is also the habitat view, whereby investors for a number of reasons choose to trade only a subset of all available assets (Barberis et al., 2005). Factors such as liquidity, risk aversion and sentiment cause investors to change their exposure in this subset of assets and consequently create common factors in their returns; this in turn disassociates those assets' returns from their underlying fundamentals (Claessens and Yafeh, 2012). Due to the both the category and habitat views having similar empirical applications they can be merged into a single view, that is the demand-based view (see Greenwood, 2008; Claessens and Yafeh, 2012).

The third view is the information diffusion view, where the presence of market frictions results in information being incorporated more quickly into the prices of some assets than others. Investors having faster access to breaking news and arriving information, as well as the means to
exploit it engage in trading, thereby inducing common factors in asset returns (Barberis et al., 2005). Again, greater asset liquidity (a factor also cited as an explanation under the demand-based view) and lower trading costs, cause the release of good (bad) news to be reflected within the same day only in some assets: these assets consequently move upwards (downwards), whereas the rest of the assets follow the former in their movements after some delay, therefore giving rise to lead-lag dynamics between them (Claessens and Yafeh, 2012).

This difference between the traditional and the “friction-based” and “sentiment-based” theories of comovement, is clearly illustrated in the study of Vijh (1994), who examines the market betas of stocks added to the S&P 500 index and provides the first evidence of “friction-based” and “sentiment-based” comovement. Since Standard and Poor's emphasizes that the choice of stocks for the inclusion in the S&P 500 is based on the effort to make the index representative of the overall US economy, under the traditional view of comovement those index-included stocks' fundamental values should be correlated with other stocks and assets' fundamental values. However, under the demand-based view, the index constitutes a preferred habitat (natural category) for a number of investors. The consequent fund flows in and out of that habitat (category) increases the correlation of index-included stocks within that habitat and disassociates them with their underlying fundamentals (Vijh, 1994). In addition, according to the information-diffusion view, the stocks included in the index reflect faster the incorporation of news about cash flows, owing to the greater liquidity of those assets, their lower trading costs or to the fact that are held by investors with better access to information (Vijh, 1994; Barberis et al., 2005; Claessens and Yafeh, 2012).

To this end, Vijh (1994) offers support to the demand-based and information diffusion views by showing that stocks entering the index start to incorporate market-wide news at the same time with the rest index-included stocks, thereby increasing the stock-correlation within the index and decreasing the stocks' dependence on their underlying fundamentals. This is further verified by Barberis et al. (2005) who building on Vijh's study provide evidence of an even stronger disassociation of S&P 500-included stocks from underlying fundamentals, and therefore support of friction- and sentiment-based comovement which extends to more recent data. Thus, under both
demand-based and information-diffusion views, some stocks' fundamental values become less correlated with other stocks' fundamental values and also with similar assets that are claims to the same cash-flow streams, such as the company's bond issue or a derivative on that stock (Vijh, 1994; Barberis et al., 2005). The difference in the timing of information incorporation affects in turn not only the degree of asset-correlation and dependence on underlying fundamentals but also the lead-lag dynamics within the same or across different asset-markets.

The ‘‘friction-based’’ and ‘‘sentiment-based’’ views on comovement as well as the majority of the empirical studies conducted, primarily concern index-included assets and therefore constitute the primary theories governing index-based investment (Claessens and Yafeh, 2012). Thus, they offer an additional motivation as well as justification for the employment of asset-market indices in the first empirical chapter in Section 3. An additional conclusion derived from the demand-based and information-diffusion views concerns the importance of asset liquidity for the comovement and interactions between asset returns. This role of liquidity as a driver of cross-asset interaction is considered in the formulation of hypotheses in the first empirical chapter of Section 3, where the most liquid asset is expected to lead the less liquid one(s). It further acts as a motivation to examine the liquidity interaction between assets that theoretically should move together in Section 4.

2.2 The Interaction Between Stocks, Bonds and CDSs

The first empirical chapter of the Thesis in Section 3 examines the issue of the comovement and interaction between the stock, bond and CDS markets. For this reason, Section 2.2 presents the theoretical underpinnings of the relationship between the three asset-markets as formulated in the Merton-originated structural models of credit risk. This will provide a theoretical justification for the selection and concurrent examination of stocks, bonds and CDS contracts and further facilitate the understanding of the hypotheses with regards to the sign and nature of those asset-markets' interaction in Section 3.2. After the analysis of the theoretical relationship between the stock, bond and CDS

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3 The role of liquidity in the lead-lag relationships and the general interaction between assets are analyzed in more detail in Section 2.4.
markets, follows an analysis of the empirical studies examining the relationship between the respective asset-markets.

The structural models of credit risk (see Merton, 1974; Black and Cox, 1976) derive the theoretical link between equities, bonds and CDSs. According to these models, under the assumption of efficient markets, a change in a firm's default probability is already reflected in the firm's share price. This is due to the fact that any change in a firm's credit risk does not only affect the prices of credit derivatives written on the firm's assets, such as a futures contract or a CDS, but it further affects the firm's share and bond prices.

When a firm faces unfavourable financial conditions, the resulting increase in the firm-credit risk leads to a consequent increase in the probability of default on the firm's bonds and other obligations. Hence, the price on the firm's bond and the firm's share price will decrease. Additionally, when a firm is in distressed condition, the purchase of insurance against its default becomes more expensive, thereby raising the spread on the CDS contracts written on the firm's bonds. The deterioration in the firm's credit risk will further raise the demand for protection against the potential event of the firm-default, which further causes downward pressure on the firm's share and bond prices. This in turn owes to the sellers of CDS contracts, which hedge their exposure to the firm by shorting either the firm's share or the firm's bond. In efficient markets, this simultaneous interaction between the firm's stocks, bond and CDS contracts constitutes the fundamental basis of arbitrage between equity and debt.

Merton (1974) first modelled the firm's equity as a call option written on the firm's assets with a strike price equal to the firm's face value of debt. Alternatively, a firm's bond is modelled as a put option on the firm's assets with the same strike price. In its simplest form, the structural form of Merton's (1974) model assumes that the firm issues two types of assets, equity and a zero coupon bond. Default occurs at maturity whenever the value of the firm's assets falls below the face value of the zero-coupon bond. Later approaches however relax Merton model's assumptions by allowing default to occur at any time, modelling the default threshold, and considering various dynamics of the
firm's assets and different types of capital structure. Among them, Black and Cox (1976) incorporate safe covenants that allow the creditors to assume control of the borrowing firm when its value drops below a certain threshold, an addition that makes default time uncertain ex ante.

The main finding derived from the structural credit risk models is that an increase in a firm's credit risk and thus in its probability of default results not only in an increase on the spread of the firm's CDS contract, but also in a fall in its share and bond prices. The fact that this relationship is theoretically valid in the presence of efficient markets suggests that under the ‘‘friction-based’’ and ‘‘sentiment-based’’ approaches of asset comovement the dynamics between stocks, bonds and CDSs might evolve differently than the predictions of the Merton-originated models. This restrictive assumption about market efficiency, in combination with that friction- and sentiment-based approaches of comovement primarily refer to index-included assets, serves as a justification for the examination of the interaction between the stock, bond and CDS markets through the employment of market indices in Chapter I (Section 3). It additionally forms the expectation that under index-investing information is not simultaneously reflected across stocks, bonds and CDSs, but - according to the information-diffusion view (see Section 2.1) - is incorporated faster in one asset before being transmitted to the rest. The main reasons for the emergence of these lead-lag relationships are in turn differences in the liquidity and volatility between asset-markets, that affect the assets' capacity with regards to the reception and transmission of information. An analysis of the liquidity and volatility channels is presented in Sections 2.4 and 2.5 respectively.

The hypothesis that stocks, bond and CDS markets do not adjust simultaneously to new information which additionally forms the basis for the examination of the stock-bond-CDS interaction conducted in Chapter I, is further motivated by studies at the empirical front. These studies although focusing on single-name securities reveal differences in the transmission of information between the three asset-markets, that consequently give rise to lead-lag relationships between them. However, these approaches include the studies by Black and Cox (1976), Geske (1977), Leland (1994) and Longstaff and Schwartz (1995).

For an analysis of the ‘‘friction-based’’ and ‘‘sentiment-based’’ theories of asset comovement see Section 2.1.
even though the stock market appears to be leading the information-transmission process, its leading role is not always unambiguous since the CDS market is also found to be transmitting information to the other two asset-markets. The main scepticism about these studies concerns the use of single-name securities and the examination period, which refers to the early and mid 2000’s. The first is important in light of the demand-based and information diffusion views of comovement which have been derived from the examination of index-included securities. In addition, single-name securities have been documented to incorporate both idiosyncratic and systemic risk, while they are also subject to insider trading. The significance of the second lies in that the period up to the 2007-2008 US financial crisis coincided with the unprecedented growth in the size and volume of the CDS market which might have biased the role of CDS contracts as transmitters of information.

In particular, the first examination of the joint dynamics of the stock, bond, and CDS markets was conducted by Longstaff et al. (2003). Their analysis included 68 US firms during the 2001-2002 period and their VAR specification provided evidence that the CDS and stock markets lead the bond market. The same VAR representation is employed by Norden and Weber (2009) in their analysis of an international sample of 58 firms during the 2000-2002 period, with their results suggesting that the equity market induces movements in the CDS and bond markets. Furthermore, according to their vector error correction model (VECM), which is further employed by Blanco et al. (2005) and Zhu (2004; 2006), the CDS market appears to contribute more to price discovery thus causing the bond market to adjust to price movements in the CDS market (a finding consistent with Blanco et al. (2005)). This is however confirmed only for the US and not for the European market.

A general VECM representation is also employed by Forte and Pena (2009) to analyze the price discovery process between stock market's implied credit spreads (i.e., a homogeneous measure of credit risk derived from a modified version of Leland and Toft’s (1996) structural credit risk model) and bond and CDS spreads. Their results suggest that stocks lead CDSs and bonds more frequently than the opposite, while also lend support to the leading role of the CDS market with

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6 The difference between single-name securities and index-included securities and the advantages of employing market indices are analyzed in Section 3.1 of Chapter I.
respect to the bond market. The CDS market is also found to Granger cause bond spread changes (Norden and Weber, 2009; Forte and Pena, 2009), a result in tandem with Coudert and Gex (2010) who tested the above relationships during the 2005 GM and Ford crisis. The only examination at the sovereign level is conducted by Chan-Lau and Kim (2004), with results being considerably different than those at the corporate level: in a sample consisting only of emerging market sovereign issuers no equilibrium relationships are found between the three asset-markets, while no asset-market appears to lead the price discovery process.

2.3 The CDS-bond Basis

Section 2.2 presented the main empirical studies pertaining to the issue of the comovement and interaction between the stock, bond and CDS markets, which is analyzed in the first empirical chapter of the present Thesis (Section 3). The subsequent empirical chapters, i.e., Chapters II and III in Sections 4 and 5 respectively, examine the interaction between the bond and the CDS markets. For that reason, the focus of Section 2.3 is attributed to the equilibrium relationship between bonds and CDS contracts, i.e., the CDS-bond basis, which further constitutes one of the primary channels for the comovement of the two asset-markets (the other major channels being liquidity and volatility, which are analyzed in Sections 2.4 and 2.5 respectively). After the analysis of their equilibrium relationship, Section 2.3 presents the empirical studies conducted on the subject of price discovery and comovement between the bond and CDS markets.

According to the no-arbitrage theory of pricing CDS, the premium of a CDS contract on a reference name, e.g., a bond, should equal the asset-swap spread for the same reference name (in the case of a bond this is the difference between the yield on the bond and the LIBOR curve (Choudhry, 2006)). This theoretical parity, or else the CDS-bond basis, has been proved by previous studies (see Duffie, 1999; Hull and White, 2000), however in practice a number of reasons, such as accrued interest, the cheapest-to-deliver option and counterparty risk cause the basis never to be equal to zero, with market liquidity also playing a key role to this inequality (Hull et al., 2004; Blanco et al., 2005; Zhu, 2006; Chen et al., 2010). In particular, during the pre-2008 financial crisis period, the basis for
the majority of corporate bonds was found to be positive, thereby giving rise to considerable arbitrage opportunities (Blanco et al., 2005; Zhu, 2006; Baba and Inada, 2009).

Despite the studies focusing on the corporate level, the literature on the examination of the CDS-bond basis is also comprised of studies focusing at the sovereign level. In general, while the basis is found to be negative at the corporate level (see Section 2.3.1), when sovereign CDSs and their underlying bonds are considered, the results - although ambiguous - point towards the existence of a positive basis, or at least a non-negative one (see Section 2.3.2). At the theoretical level, Duffie (1999) was the first to derive the theoretical parity between CDS premia and the asset-swap spread, noting however that the ideal corporate bond spread should be the spread over LIBOR or a floating rate note with the same maturity as the CDS referenced on the same firm, otherwise there can be no perfect arbitrage. Furthermore, according to Duffie (1999), this theoretical link holds, only if CDS premia and yield spreads are viewed as a pure measure of credit risk; in the case in which both of them are affected by additional risk sources, e.g. liquidity, these risk sources may exert an impact on this link and cause the basis to deviate from zero. In a similar spirit, Hull and White (2000) tested whether approximate no-arbitrage arguments give accurate valuations of CDSs and thus, whether they impact on the CDS-bond basis. They also provided an application of their methodology with the use of real data.

2.3.1. Corporate Level Examination

The first empirical examination of the theoretical parity between the CDS premium and the asset-swap spread was conducted by Longstaff et al. (2003), with their results suggesting that credit protection is not priced consistently in the corporate bond and the credit derivatives market. The significantly higher - according to Longstaff et al. (2003) - implied cost of credit protection in the corporate bond market, comprises the first evidence of the existence of a negative CDS-bond basis, with the significant tax-related and liquidity components built into the spreads of these corporate bonds being cited as the best plausible explanation for that deviation from parity. In stark contrast to the corporate bonds, CDS premia were found to only depend on the actual default risk of the
underlying bond that were written on. In a later study (see Longstaff et al., 2005), the illiquidity of corporate bonds was also found to add to the equilibrium cost of corporate debt, and therefore being responsible for the deviation (negative in this case also) of the basis from its theoretical parity.

An empirical investigation of the validity of the theoretical relationship between CDS premia and bond credit spreads is also conducted by Blanco et al. (2005) who, in line with Longstaff et al. (2003; 2005), find no evidence that parity holds in their investment grade bonds sample. Their results suggest that the approximate equivalence holds only in the case where the risk-free rate is proxied by the swap rate; they further indicate that the CDS premium and the credit spread form an upper and lower boundary for the true price of credit risk, respectively (Blanco et al., 2005). The exact opposite conclusion, i.e., the CDS premium forming a lower bound and the credit spread forming an upper bound for the price of credit risk, is reached by Fontana (2010). In particular, for the period during the 2007-2008 crisis, the basis is found to be persistently negative, suggesting that it would be cheaper to bear credit risk in the cash market. It appears that cash bonds, due to being funded instruments, have their spreads adversely affected by the cost of funding with a consequent effect on their yields which are driven higher; on the other hand, CDS spreads - which are unfunded instruments - are only affected by counter-party risk being sold at discount (Alexopoulou et al., 2009; Fontana, 2010). Along the same lines, Alexopoulou et al. (2009) and Fontana (2010) find CDS spreads to be more sensitive to changes in systematic risk compared with the corporate bond spreads, a view only denied by De Wit (2006), who in contrast to the bulk of literature, provides evidence about a positive basis, although focusing on a short (1-year) pre-crisis period only (ibid).

2.3.2. Sovereign Level Examination

In contrast to the corporate level, where the CDS-bond basis is found to be negative, the examination at the sovereign level yields considerably different conclusions. The different nature and status of the sovereign borrowers compared to their corporate counterparts is cited as a possible explanation for this divergence. The option of default is less preferred by countries and in the event that a default occurs this is generally accompanied by debt restructuring and/or debt exchange, with the Greek debt
Restructuring being the latest example (Lane, 2012; Blundell-Wignall, 2012). In addition, the problem of asymmetric information is less prevalent at the sovereign level, where information about the financial health of the sovereigns is generally more available and accurate.

Furthermore, CDSs have been used extensively for regulatory arbitrage to minimise the capital banks and government agencies are required to hold; while this tactic can create bank instability, it also adds to market liquidity, with both factors being significant drivers of changes in the level of CDS premia and bond yields (Vayanos and Wang, 2012; Oehmke and Zawadowski, 2013; Praz, 2014). Taking into consideration that the above aspects impact on sovereign CDS and bond prices, and therefore on the theoretical value of the CDS-bond basis, it comes as no surprise that the implied cost of credit protection between the CDS and bond market is significantly different when the focus of examination is shifted from the corporate to the sovereign level.

While the common factor of all pertinent studies is that the analysis includes only emerging countries, different conclusions are reached depending on the credit rating of the securities considered or the time-horizon employed. For instance, in Küçük (2010) speculative grade bonds are found to be more expensive than what is implied by their CDS premia, while when investment grade securities are considered, bond prices and CDS premia are either more balanced or CDS premia are considerably cheaper compared to their underlying bonds, with this divergence being explained by limits to arbitrage due to difficulty of short selling the bond, and also by speculation in the CDS market. In a different study (see Adler and Song, 2010) the CDS and bond markets are found to price credit risk for the emerging market sovereigns equally (with the exception of Argentina and Brazil), with any deviations from parity observed leading towards a positive basis. Last, Ammer and Cai (2011) provide evidence that these two measures of credit risk deviate considerably from their theoretical equivalence in the short run, due to factors such as liquidity and contract specifications, however they estimated a stable long-term equilibrium relationship for the majority of sovereigns examined.

Not only has the CDS-bond basis been the focus of a great number of studies, but the causes of this deviation from parity has also been addressed by the literature, with Blanco et al. (2005) and Küçük (2010) noting that this deviation may be due to investors being unable to short the bond and
therefore, not succeeding in taking advantage of the arbitrage opportunities available. Blanco et al. (2005) also suggest that the cheapest-to-deliver option drives down corporate bond prices with a consequent effect on the basis' theoretical value, a view also shared by Ammer and Cai (2011) and Lin et al. (2011). Particular importance is also given to the liquidity premium, however it is no clear whether it causes the basis to deviate from zero by acting through the CDS or the bond market (Chen et al., 2010; Nashikkar et al., 2011; Vayanos and Wang, 2012; Fontana and Scheicher, 2016).

2.3.3. The Interaction between Bonds and CDSs

Notwithstanding the focus given on the theoretical equivalence between the CDS premium and the bond credit spread, an additionally important issue addressed by the literature is the comovement between the two asset-markets in order to identify which market leads the other in terms of price discovery. Due to the flexibility and the institutional features of the CDS market where - in contrast to the bond market - short positions are more easily to establish, price discovery is expected to take place mainly in the CDS market (Blanco et al., 2005; Norden and Weber, 2009). The lead of the CDS market is also attributed to the expectation that volatility is mainly transferred from the CDS to the bond market (when default probabilities for bonds increase bond holders resort to the CDS market in order to obtain protection against default risk, thereby increasing the demand for CDSs (Zhu, 2006; Norden and Weber, 2009)). In the empirical part, the majority of studies validates the above expectations, by providing evidence that the CDS market leads the bond market both at the corporate (Blanco et al., 2005; Zhu, 2006; Forte and Pena, 2009; Baba and Inada, 2009) and the sovereign level (Fontana and Scheicher, 2010; Arce et al., 2011; Delis and Mylonidis, 2011). The results of these studies are consequently employed in the formulation of hypotheses in the first empirical chapter in Section 3, according to which the CDS market index is expected to lead the bond market index.

At the corporate level, price discovery is found to occur in the CDS market, mainly due the CDS market being the easiest place in which to trade credit risk, enabling that way informed traders to engage in more frequent and efficient transactions (Blanco et al., 2005; Zhu, 2006). The lead of the CDS over the bond market is verified in the case of a US-only sample (see Blanco et al., 2005), an
international sample (see Zhu, 2006), and in a sample of Japanese financials (see Baba and Inada, 2009), with all studies employing a variety of methods, ranging from Granger causality tests to vector autoregressives and error correction models. It appears that liquidity factors significantly matter not only for the CDS market's lead, but also for the adjustment dynamics between those asset classes, especially in the short-run, an argument also verified by Forte and Pena (2009); the only limitation being the short (2-year) period of examination, which also constitutes a common factor among all studies focusing on the particular issue.

The analysis of the price discovery process between the CDS and bond market yields somewhat different results when the focus is shifted from the corporate to the sovereign level. Even though the CDS market appears to have a leading role over the bond market, this is not a unanimous conclusion, as there is a number of studies arguing in favour of the bond market causing movements in the CDS market and not vice versa. In particular, there is evidence from a 5-year sample of 30 emerging market sovereigns that the bond market leads the price discovery (see Aktug et al., 2012), an argument also finding support from Ammer and Cai (2011); even though in the latter study the bond market does not have a predominant lead, it is nevertheless found to lead the CDS market more frequently than the previous literature suggests, with both studies citing the cheapest-to-deliver option as the most plausible explanation for this differentiation.

Ambiguous results are also presented in Fontana and Scheicher (2010; 2016), where the CDS market leads the bond market in half of the 10 euro area sample countries, while in the other half price discovery is observed in the bond market (in a time-horizon sufficient enough to capture the effect of the 2008 financial crisis). Nonetheless, the financial crisis appears to impact differently on the CDS - bond interaction across the euro area according to Delis and Mylonidis (2011), the Granger causality tests of which revealed that Southern European countries' CDS spreads Granger cause credit spreads following the onset of the crisis. Granger causality tests are also employed by Palladini and Portes (2011) to verify their VECM results about the European CDS market moving ahead of the bond market in terms of price discovery, results that are in tandem with the corporate finance literature. The predominant role of the CDS market in the euro area is also verified in an extended analysis by Calice
et al. (2011). Despite the apparent focus on credit interactions, bid-ask spreads were employed - along with last prices - in order to examine the liquidity spread interactions over the 2009-2010 period, with results suggesting a positive and significant lagged transmission from the liquidity spread of the CDS market to the credit spread in the bond market (Calice et al., 2011).

2.4 Liquidity Interaction

After the analysis of the theoretical propositions governing the bond-CDS interaction and the discussion of the main empirical studies on this issue, Section 2.4 describes one of the main reasons as well as mechanisms of cross-asset interaction, that is, the liquidity channel. The analysis of this channel is essential for the understanding of the hypotheses in Chapter I (Section 3), where the lead-lag relationships between stocks, bond and CDSs are formulated on the basis of their liquidity. It additionally forms the basis for the examination in Chapter II (Section 4), since it provides the theoretical arguments about the liquidity interaction between the sovereign bond and CDS markets. The analysis starts with a brief discussion of the concept of liquidity and then proceeds to the mechanism through which shocks to liquidity in one asset propagate to other assets, thereby affecting their prices.

Liquidity is a rather abstract and complex term: liquidity typically refers to the ease of trading a security. This complexity in the concept of liquidity is due to the various sources that liquidity can arise from. Perhaps the most known source is the exogenous transactions costs. These costs are incurred by the seller and the buyer of the security during the transaction (trading) of the security, and include brokerage fees, order-processing costs, or transaction taxes. An additional source is the demand pressure and inventory risk. This source is related to the presence and availability of buyers in the market the exact moment(s) where sellers need to sell their securities. In particular, when the market is short of buyers, the seller might be forced to sell to a market-maker, who only buys the security in anticipation of a future sale. However, during the holding of the security, the market-maker

7 For an excellent and more detailed survey of the concept of liquidity and the theoretical and empirical studies see Amihud et al. (2005) and Foucault et al. (2013).
is exposed to price changes. These price changes constitute in turn a risk that the market-maker imposes on the seller of the security during their transaction.

Private information regarding fundamentals and/or order flow is a further source of liquidity. Trading with an informed counterparty always entails a loss, since the buyer (seller) of a security might worry that the potential seller (buyer) has private information about the entity issuing the security (Amihud et al., 2005). In contrast to private information about fundamentals, a recent common practice for hedge funds is to close their positions at the end of the trading day. In the event where a trading desk is informed about the timing of a hedge fund's closing out of positions (the order flow), due to the consequent downward pressure on prices, the sale of the same securities by an agent and the purchase at a future time can result in a significant profit for the agent. Lastly, liquidity can also arise due to search friction, i.e., the search for a counterparty to trade a particular security or a large quantity of a given security. This is particularly relevant in the over-the-counter (OTC) markets, where the absence of a central marketplace results in financing or opportunity costs due to the delay in the trading and the consequent price concessions needed in order to facilitate the trading; in the event where this search is avoided and the security is traded without delay, then the agent foregoes the search-related costs but is subject to illiquidity costs (Amihud et al., 2005).

After a discussion of the concept of liquidity and the various sources of liquidity, the focus now is shifted to the reasons and mechanisms that result in liquidity comovements between assets. One possibility for the existence of these comovements is that are generated by common shocks that affect the liquidity of several assets synchronously. The origins of these shocks and the consequent liquidity comovements are either supply-side related to the funding constraints of financial intermediaries, or demand-side and driven by correlated trading activity, the level of institutional ownership and investor sentiment (Karolyi et al., 2012).

In specific, the supply-side is derived from theoretical approaches that examine the role of funding constraints for the provision of liquidity (see Coughenour and Saad, 2004; Brunnermeier and Pedersen, 2009; Hameed et al., 2010). Common in these approaches is the prediction that large market declines or high volatility exert an adverse impact on the funding liquidity of financial intermediaries.
that perform the role of liquidity suppliers to financial markets. The end result is a reduction in those intermediaries' liquidity provision across many securities, which further leads to a decrease in market liquidity and an increase in liquidity comovements (Karolyi et al., 2012). According to the demand-side view, commonality in liquidity is mainly attributed to the trading behaviour of institutional investors (see Kamara et al., 2008; Koch et al., 2009) and the correlated across securities demand for liquidity due to the investors' weak incentives to trade in individual securities (see Chordia et al., 2000; Hasbrouck and Seppi, 2001). In the latter case, these incentives can be driven by the level of transparency and investor protection in a given country (see Morck et al., 2000). Lastly, an additional demand-side explanation relates to investor sentiment, which can result in correlated trading behaviour and thus, to common movements in liquidity within or across asset-markets (see Huberman and Halka, 2001).

However, in addition to common shocks affecting the liquidity of different assets simultaneously, liquidity comovements can further result due to shocks specific to liquidity supply in one asset class propagating to other asset classes. According to this mechanism, liquidity providers in one asset class, e.g., exchange-traded funds (ETFs), often receive information from other asset prices, e.g., from the underlying assets of ETFs; this information-transmission and cross-asset learning eventually results in interconnectedness in the liquidity of those asset classes (Cespa and Foucault, 2014). In specific, dealers in the ETF use the price of the underlying asset as a source of information, since the underlying asset's price reflects information about fundamentals known to that asset's dealers. However, the price of the underlying asset is further subject to transient demand pressures, particularly when the provision of liquidity for dealers in the underlying asset increases (Cespa and Foucault, 2014). Thus, the price of the underlying asset constitutes a noisy signal for dealers in the ETF, with the information transmitted by this signal being analogous to the sensitivity of the underlying asset to transient demand shocks: the less liquid is the underlying asset, the less informative its price is for dealers in the ETF (Korajczyk and Sadka, 2008; Cespa and Foucault, 2014).

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8 This mechanism is analyzed in detail in Cespa and Foucault (2014).
Along the same lines, in the event where a shock to dealers in the underlying asset (such as a fall in the dealers' risk aversion) increases the cost of liquidity provision in that asset, this in turn increases uncertainty for dealers in the ETF and consequently their cost of liquidity provision. The end result is that a drop in liquidity of the underlying asset propagates to the ETF. This spillover causes the price of the ETF to be less informative for dealers in the underlying asset, thereby creating a chain reaction that amplifies the initial shock (Cespà and Foucault, 2014). Hence, there are two risk factors affecting the ETF's liquidity: one specific to the ETF and one specific to the underlying asset. Dealers in the ETF are only informed about the first, while they receive information about the second from the price of the underlying asset. This cross-asset learning creates a feedback loop and therefore an illiquidity multiplier, with the strength of the multiplier being analogous to the sensitivity of each asset price to illiquidity (see Cespà and Foucault, 2014).

The propagation of liquidity through cross-asset learning is valid when dealers are either market-makers or arbitrageurs. This is important when considering assets tied by a no-arbitrage relationship, such as those examined in the present Thesis. The stocks, bonds and CDS contracts are linked via the fundamental no-arbitrage condition between equity and debt (see Section 2.2), while bonds and CDSs through the CDS-bond basis (see Section 2.3). Thus, both mechanisms of liquidity comovements, i.e., the common shocks and the cross-asset learning, are useful in understanding the hypotheses formulated in the analysis of the interaction between the stock, bond and CDS markets in Chapter I (Section 3) and between the sovereign bond and CDS markets in Chapter II (Section 4).

2.5 Volatility Interaction

After the analysis of the liquidity channel, Section 2.5 presents the channel of volatility which constitutes an additional mechanism for the transmission of information between assets. The theoretical foundations of the relationship between asset prices and asset volatility are provided by the work of Ross (1989), where it is shown that in an arbitrage-free economy the volatility of prices is directly related to the flow of information to the asset-market. Similarly to the case of liquidity linkages in Section 2.4, volatility linkages are further divided into two different channels, i.e., one
relating to common information affecting assets simultaneously and one relating to information spillover due to trading activity. The former channel is rather straightforward and as is the case with the demand-side explanation of liquidity comovements, common information stimulates trading activity in more than one asset-markets concurrently by changing investors' expectations and speculative demands (see Harvey and Huang, 1991; Ederignton and Lee, 1993). Sources of volatility that result in common information transmission across financial assets can arise for example from scheduled macroeconomic releases such as those on the unemployment rate, the inflation rate, or the producer price index. In addition, negative shocks, such as a corporate or sovereign default, further affect risk aversion and underlying fundamentals, thereby resulting in a concurrent increase in information and volatility transmission across financial assets (Fleming et al., 1998; Connolly and Stivers, 2005).

The second mechanism that leads to the creation of volatility linkages between assets is information spillover caused by cross-asset hedging. The intuition behind hedging as a source of cross-asset linkages can be easily understood by resorting to the work of Fleming et al. (1998) and assuming two negative correlated asset-markets, such the stock and bond markets, and a trader that operates in both asset-markets. An information event altering the trader's expectations about stock returns, and therefore affecting his demand for stocks, can further affect that trader's demand for bonds. This can occur because of the trader's consideration of the (negative) correlation between stock and bond returns when rebalancing his portfolio, even in the case where the information event leaves the trader's expectations about interest rates (i.e., the primary driver of bond returns) unchanged (Fleming et al., 1998). This is part of the trader's attempt to employ the bond market as a hedge for his speculative position in the stock market. Hence, this initial information event not only affects the trader's demand for stocks and bonds, but further results in an information spillover between the two asset-markets, therefore generating trading and volatility in both asset-markets.

However, an increase in volatility linkages between assets is further expected to result in an increase in those assets' correlation. Under the assumption that prices are represented by martingales, cross-asset correlation is driven by the comovement of the continuous part of the price processes or by
the comovement of their jumps, or by both together (see Aït-Sahalia et al., 2009; Aït-Sahalia and Xiu, 2016). In any case - and particularly in times of heightened market stress where information-related shocks hit all asset-classes simultaneously - an increase in price commonality and/or in jumps leads to an increase in the correlation among assets (Aït-Sahalia and Xiu, 2016). This is particularly evident in the case of a shock to one country (or group of countries), where increased cross-market linkages cause a consequent (significant) increase in cross-market correlations, which in some cases can eventually give rise to contagion phenomena between different asset-markets (Rigobon, 2002; Andersen et al., 2003). Moreover, during these crisis periods investors increase the risk exposure of their portfolios across all assets, thereby leading to a simultaneous adjustment of prices across-the-board and a rise in covariation between asset returns (Aït-Sahalia and Xiu, 2016).

Overall, the analysis of the channels of cross-asset volatility interaction suggests that the cross-asset hedging channel applies to assets primarily employed for hedging, such as stocks and bonds, or a derivative, such as a CDS contract, and the underlying bond. Thus, the examination of the volatility linkages between the sovereign bond and CDS markets in Chapter III (Section 5) is theoretically relevant since these linkages are expected to occur between the two asset-markets via both channels, i.e., through common information and through cross-asset hedging. In addition, the theoretical arguments about increased volatility leading to increased correlation constitute the basis for the analysis of the conditional correlation (which further reflects the level of integration) between the sovereign bonds and CDS contracts in the second part of Chapter III (see Section 5.5). The negative financial and fiscal shocks during the European sovereign debt crisis justify the selection of the European sovereign bond and CDS markets and provide further impetus to the examination of their volatility interaction and level of integration.

2.6. Monetary Policy and Asset Prices

The last part of this literature review is dedicated to the link between monetary policy and asset prices. Since the present Thesis is primarily focused on the period following the financial and the European sovereign debt crises, during which central banks heavily resorted to the use of non-
standard tools of monetary policy, a solid understanding of the nature and scope of these tools is necessary in order to facilitate the transition to the subsequent empirical chapters in Sections 3-5. To this end, Section 2.6 includes a brief introduction of the measures of non-standard monetary policy before proceeding into the examination of the channels with which monetary policy affects asset prices, as well as the reasons for the incorporation of asset prices into the decisions of monetary policy makers.

2.6.1 Non-standard Monetary Policy
The recent global financial crisis and the subsequent Eurozone crisis have been characterized by a widespread introduction of non-standard monetary policy measures, otherwise termed unconventional monetary policy measures. The main distinction between standard and non-standard monetary policy is that under the latter, the central bank actively uses its balance sheet to exert a direct impact on market prices and borrowing conditions beyond the impact exerted by changes in the overnight interest rate. In addition, when interest rates have reached the zero lower bound (i.e., when interest rate reaches zero or near zero), non-standard policies are the only tools available for central banks in order to formulate their monetary policy stance. Non-standard measures have been tailored to the respective economies and their structures and have been employed to protect the real economy from the escalation of the financial crisis, or as was the case in the Eurozone, to enable the functioning of the interbank market and most importantly to preserve the stability of the monetary union during the European debt crisis. Non-standard measures have taken various forms, such as enhanced credit support, credit easing, quantitative easing, enhanced liquidity provision, and loose collateral policies. They have further exhibited differences depending on whether have been implemented within the US or the Eurozone economy. A brief description of those measures follows.

In specific, the first non-standard monetary policy measures by the Federal Reserve have been adopted during the onset of the 2007-2008 financial crisis. These measures have been characterized as credit easing since their objective was to support the efficient functioning of the credit market. To this end, in November 2008 the Federal Reserve announced the first round of asset purchases, also known
as QE1. Under this programme, the Fed purchased $1425 billion of mortgage-backed securities (MBSs) and $300 billion of long-term Treasury bonds, with these purchases corresponding to 12% of US GDP. These purchases were followed by a second round that was termed QE2 and was conducted from November 2010 until June 2011. During these round the Federal Reserve purchased $600 billion of long-term Treasury bonds in an attempt to reduce the level of long-term bond yields. QE2 was subsequently replaced by QE3 (September 2012 - December 2012) were the Fed conducted monthly purchases of MBSs and long-term Treasury bonds amounting to $40 and $45 billion per month respectively. Overall, these three rounds of quantitative easing have increased the size of the Federal Reserve's balance sheet from $0.9 trillion in 2007 to $4 trillion at the end of 2013.

In Europe, the ECB responded to the US-originated financial crisis in October 2008 by adopting full allotment and fixed rate of interest for its Long-term Refinancing Operations (LTROs), i.e., the ECB's main liquidity providing operations. In May 2009 the ECB announced the purchases of €60 billion of covered bonds under its Covered Bond Purchase Programme (CBPP). This programme was later supplemented by the Securities Market Programme (SMP) in May 2010 which included primarily the purchase of government bonds in order to support the stressed government bond markets, particularly those of Greece, Ireland, Italy, Portugal and Spain. Under the SMP, €220 billion of government bonds were purchased (mainly during the periods from May 2010 to June 2010 and from August 2010 to January 2010) amounting to 2.5% of euro area GDP. In September 2012, a new asset purchase programme was announced, namely the Outright Monetary Transactions (OMTs), according to which the ECB planned to conduct purchases of government securities in the secondary market. The securities to be purchased were with maturity of 1 to 3 years and issued by EMU member states under a fiscal consolidation programme, thus aiming to improve the borrowing conditions of the countries under fiscal strain. However, the OMT programme was not eventually

\[\text{\footnotesize The announcement of the OMT was marked by the strong verbal intervention of the ECB's President Mario Draghi, according to which ‘‘Within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough’’ (Speech by Mario Draghi, at the Global Investment Conference in London, 26 July 2012).}\]
utilized. The purchases were conducted instead from the beginning of March 2015 onwards under the expanded Asset Purchase Programme (APP) and were extended to public and private sector securities, amounting on average to €80billion a month. These purchases were intended to be carried out until a sustainable upwards adjustment is achieved in the path of euro area inflation, consistent with an inflation rate below but close to 2% over the medium term. An additional unconventional measure by the ECB was the massive liquidity injection through its Long-term Refinancing Operations (LTROs) that aimed at enhancing bank lending and liquidity in the euro area money market. The two LTROs auctions with maturity of three years were conducted in December 2011 and February 2012 as fixed rate tender procedures with full allotment, i.e., banks had their bids fully satisfied against adequate collateral and on the condition of financial soundness.10 The total amount lent during the two auctions was approximately €1trillion.11

2.6.2 The Channels of Monetary Policy

Following the presentation of non-standard monetary policy measures, Section 2.6.2 analyzes the channels through which non-standard monetary policy is transmitted to asset prices. The most natural channel through which non-conventional policies affect financial markets is the “portfolio balance” channel. Analyzed in Tobin (1961; 1963; 1969) and Brunner and Meltzer (1973), this mechanism describes how central banks affect the level of yields on different financial assets through altering the

10 LTROs with maturity of six and twelve months respectively have also been part of the response to the Eurozone crisis and conducted before the 36-month LTROs.

11 Under the first operation 523 counterparties borrowed in total €489billion and under the second 800 counterparties borrowed €529.5 billion. LTROs were succeeded by the Targeted LTROs (TLTROs), under which the counterparties were entitled to an initial TLTRO borrowing allowance equal to 7% of the total amount of their loans to euro area non-financial private sector, excluding households for house purchase (more information is provided in the ECB’s press release on June 5 2014). TLTROs were conducted in September 2014 and December 2014 and the total amount borrowed was not permitted to exceed this initial borrowing allowance.
relative supplies of financial claims with different durations and liquidity. Thus, the central bank through altering the relative quantities of money and government bonds held by the private sector can exert an impact on financial asset prices and consequently on real investment decisions. This mechanism is based on the assumption of imperfect asset substitutability and on heterogeneity across agents; the former assumption applies to the degree of substitution between bank deposits and bonds held by the public, while according to the latter some agents must hold different portfolios so that prices need to change in order to reach an equilibrium (Joyce et al., 2012).

Next, the “portfolio balance” channel is analyzed within the context of portfolio balance models and models of credit imperfections. Within that context, two main channels emerge through which asset purchases by the central bank can affect financial asset prices and the economy, namely the “portfolio substitution” channel and the “bank lending” channel (see Miles, 2011, 2012; Joyce et al., 2012). According to the “portfolio substitution” channel the purchase of bonds by the central bank reduce the number of bonds held by the banks, increasing at the same time the amount of bank reserves deposited at the central bank. These central bank-purchases of bonds are immediately reflected in a rise in bank reserves and also bank deposits (in the case where the bonds were purchased from non-banks, such as pension funds). This is in turn exactly where the assumption on imperfect substitutability comes into play, since if bank reserves and bank deposits were treated as perfect substitutes this would leave the yields on the purchased bonds unchanged. However, imperfect substitutability is not an implausible assumption. This is due to the preferred habitat theory and the pricing of duration risk.

Large-scale asset purchase programmes, such as the series of QE by the Federal Reserve, or the SMP and the APP by the ECB, involve the exchange of a long-dated asset, i.e., bonds, for a short-

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12 This channel is analyzed in detail in Joyce et al. (2012).

13 In the case of perfect substitutability the economy would enter a liquidity trap where the additional supply of central bank money (in the form of reserves) would not lead to a rise in bond prices and therefore a fall in bond yields. The end result would just be an exchange of this extra central bank money for bonds as banks would just passively accept more reserves held with the central bank (Joyce et al., 2012).
dated one, i.e., bank reserves and bank deposits. Although some investors are indifferent to this change in the duration of the assets held in their portfolios, the greater fraction of it, such as pension funds and insurance companies have long-dated liabilities that prefer to match them with assets of similar duration (Joyce et al., 2012). This need for preserving the duration of their assets results in a demand for assets of a similar maturity, which in combination with the decrease in the volume of long-dated assets outstanding due to the central bank purchases, bids their prices up and drives down their yields. The reduction in the risk premium required by the potential buyers of those assets is translated into a rise in the prices and a consequent fall in the yields on long-dated assets, such as outstanding or newly-issued government bonds, corporate bonds, or equities. Hence, according to this mechanism, the initial central bank purchases and the consequent reduction in bond yields eventually lead to improved borrowing conditions, thereby enabling the raising of funds by corporations; this will further generate greater capital gains for the ultimate owners of those assets, i.e., the households, which will also increase their wealth (Krishnamurthy and Vissing-Jorgensen, 2011; Joyce et al., 2012; Miles 2012). The investment of this extra funding raised by the companies and the consumption of this increase in household wealth will increase aggregate demand and through that output, thereby concluding the “portfolio balance” channel of central bank-conducted asset purchases (Krishnamurthy and Vissing-Jorgensen, 2011; Joyce et al., 2012).

The mechanisms behind this channel are consistent with the preferred habitat theory, where investor clienteles with preferences for a particular segment of the yield curve play a crucial role for the determination of bond yields (see Modigliani and Sutch, 1966; Vayanos and Vila 2009; Greenwood and Vayanos, 2010; Acharya et al., 2012; Gromb and Vayanos, 2012). The main theoretical implication derived from this theory is that a central bank through altering the supply of long-term debt can exert an impact on the level of bond yields. This ability of the central bank to influence the evolution of bond yields is also verified in the presence of risk-averse arbitrageurs (Vayanos and Vila, 2009). Arbitrageurs integrate maturity markets, by exploiting discrepancies between identical bonds and ensuring that the term structure is arbitrage-free; however their risk

14 A description of the asset purchases programmes of the Fed and the ECB is provided in Section 2.6.1.
aversion enables the demand shocks of the clienteles to affect the term structure and therefore constituting an additional determinant of bond prices (Vayanos and Vila, 2009; Gromb and Vayanos, 2012). An extension of preferred habitat approach is the “duration channel”, where the central bank purchases of long-duration assets (medium-to-long-term government bonds) and the supply of zero-duration assets (bank reserves) results in a decrease in the average duration of the stock of bonds held by the private sector (see Vayanos and Vila, 2009; Gagnon et al., 2011). This consequently reduces the premium required to hold duration risk, thereby increasing the price paid by investors in order to hold duration risk when the supply is reduced.

The other channel of non-standard monetary policy transmission is the “bank lending” channel, which refers to the availability of bank credit. This channel is expected to mainly operate under conditions of stress with regards to the availability of funds to the banking sector and constitutes the channel through which monetary policy exerts an impact on the banks’ cost of funds, thereby leading to an additional response in bank lending (see Kashyap and Stein, 1994, 2000). The respective channel which rests on the failure of the Modigliani-Miller (M-M) proposition of banks, is built around the premise that the central bank through its conduct of open market operations can shift banks’ loan supply schedules (Kashyap and Stein, 1994, 1995). 15 Along these lines, a contraction in reserves results in banks reducing the supply of loans with a consequent effect on the (higher) cost of capital for bank-dependent borrowers. The impact of this channel should in turn be greater for banks with less liquid assets since less liquid banks are unable to protect their loan portfolio in the event of a monetary tightening simply by drawing down cash and securities (Stein 1998; Kashyap and Stein, 2000; Kashyap et al., 2002). Thus, to the extent that the central bank supply of bank reserves exceeds the banks’ demand for liquidity, the latter will expand lending, therefore leading to a consequent reduction in the cost of borrowing and the level of bond yields (Joyce et al., 2012). Due to the importance attributed to the transmission of liquidity to the banking sector and through that to the real

15 The lending channel further requires a) some borrowers who cannot find perfect substitutes for bank loans and b) imperfect price adjustment. More details can be found in Bernanke and Blinder (1998).
economy, the “bank lending” channel emerges the primary channel describing the effect of the ECB's massive liquidity injection into the European banking system under the LTRO programme.

In general, the “portfolio balance” and the “bank lending” channels constitute the main channels for the transmission of non-standard monetary policy to financial asset-market prices. These channels provide the theoretical framework for the analysis of the effect of the non-standard policy measures implemented by the ECB and the Fed on the European and US financial asset-markets respectively in the subsequent empirical chapters. They further constitute the basis for the formulation of the hypotheses in the respective chapters, where the large-scale asset purchases and the massive liquidity injection by the central banks during the financial and the Eurozone crises are expected to have positively affected financial asset-markets. Following the Literature Review in Section 2, this Thesis proceeds to the empirical analysis which is presented in Chapters I, II and III of Sections 3-5.
Chapter I

The interaction of the Stock, Bond and CDS markets: An empirical analysis
3.1. Introduction

Economic theory maintains that in a frictionless economy with rational investors, asset prices fully reflect their fundamental values. Given this "rationality assumption", comovement in financial asset prices should reflect only comovement in the underlying fundamentals. In practice however, the comovement of asset prices is often delinked from shifts in their underlying fundamentals, due to the information about these fundamentals being reflected differently on asset prices (see Barberis et al., 2005).

This chapter explores the issue of financial asset price comovement by investigating the price comovement and interaction between the stock, bond and CDS markets. Acknowledging the growing popularity of index trading, especially that associated with index mutual funds and exchange-traded funds, and the consequent surge in the demand for value-weighted or index portfolios (see Bhattacharya and Galpin, 2011), it considers data from US and European market indices that enable the examination to focus on the information flow between these assets at the market-wide level. Particular attention is paid to differences in this interaction when moving from the pre- to the post-financial crisis periods, as well as from the US to the European market. The examination further identifies primitive factors that generate order flow in these assets and, possibly, induce correlated movements in their prices. Among these factors it distinguishes the recent trend in central banking of quantitative easing and the resulting growth in bank reserves held with the central bank. This is motivated by the fact that monetary policy makers might at times respond to large movements in asset prices, as has been the case with the rise and the reduction in the Federal funds rate - partly - due to the concern over "irrational exuberance" in the mid to late 1990s and over the dot-com bubble in the early 2000s respectively (Gilchrist and Leahy, 2002).

See the Efficient Market Hypothesis (EMH) by Samuelson (1965) and Fama (1965; 1970). An analysis of the Efficient Market Hypothesis is provided in Section 2.1.

This is best described by the "friction-based" and "sentiment-based" theories of comovement. These theories are presented in Section 2.1.
The issue of the empirical interaction between financial assets was brought on the top of the agenda due to the financial crisis of 2008 and the subsequent European sovereign debt crisis, when the concerns about the predominant - but disproportional to its size - role played until that time by the CDS market for the global financial system heightened. At the same time, the debate about the influence of the CDS market has been fuelled by the fall in the CDS market's size from $2.00 trillion in early 2007 (and $1694 billion in June 2010) to $670 billion in June 2014. These developments in the CDS and bond markets, were accompanied by movements in the equity market, with the monthly price (in real terms) of the S&P 500 experiencing a plunge of roughly 60% from the October 2007 peak (1764.23) to the March 2009 trough (733.15), before returning to the 2007 level in September 2013.

Still, there is significant unawareness regarding the nature and the specifications of the empirical relationship between these three markets. The rise and fall of the CDS market and its consequences for the underlying bonds' market enhance this unawareness, as they may have induce changes to the morphology of this relationship. Changes that may have been further driven by the drop in the stock prices during the 2007-2009 period, the largest since World War II. These developments serve in turn as a motivation for the examination of the joint interaction between these markets and the way with which this interaction has evolved during the recent decade.

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18 It has been argued that - notwithstanding that the net outstanding amount of CDS contracts on European sovereign reference entities amounted to $500 billion in early 2012, and thereby constituted a relatively small component of the underlying sovereign bonds market - the $4.6 trillion of European bonds backed by CDS contracts combined with the remarkable increase in the CDS market's liquidity since 2008, allowed investors to leverage their opinion on sovereign credit risk and thus, cause developments in the underlying cash market (European Systemic Risk Board, 2013).

19 However, the market risk transaction activity, which refers to the volume of trading, shows an increase in the CDS transaction volumes as measured by notionals from 2011 to 2013; this increase being driven by a surge in CDS index trading.
The investigation of price comovements is particularly relevant considering the progressively stronger linkages across markets, due to faster access to information and trade execution. Most importantly, these markets were subject to several information shocks, mainly due to heightened market uncertainty during the financial and Eurozone crises, as well as to the unprecedented central bank interventions. This in turn provides sufficient variation in price transmission over time, especially when the market was under extreme stress; it further highlights the role of central bank policy for the interaction of financial markets in this changing economic environment.

So far the empirical evidence on market comovements and asset-market linkages is mostly restricted to the examination of a pair of assets, with the first examination of the joint dynamics between the stock, bond and CDS markets being conducted by Longstaff et al. (2003), as part of a general examination of the pricing of credit risk in the CDS market. Their vector autoregressive (VAR) analysis of a sample of 68 US firms during the 2001-2002 period suggested that the CDS and stock markets lead the bond market, while the same VAR representation in the analysis of an international sample of 58 firms during 2000-2002 by Norden and Weber (2009) concluded that the stock market leads both the CDS and bond markets. A vector error-correction model (VECM) representation is also employed by Forte and Pena (2009) to analyze the price discovery process between stock market's implied credit spreads and bond and CDS spreads, with results suggesting that stocks lead CDSs and bonds more frequently than the opposite, while also lending support to the leading role of the CDS market with respect to the bond market.

Studies include those by Fama and French (1993), Kwan (1996), Hotchkiss and Ronen (2000), Baele et al. (2010) for stocks and corporate bonds (however there is no consensus on which of the two markets has the lead over the other), those by Longstaff et al. (2003), Byström (2005), Acharya and Johnson (2007), Fung et al. (2008), Norden and Weber (2009), Forte and Pena (2009), for stocks and CDSs (providing dubious results), and those by Longstaff et al. (2003), Hull et al. (2004), Blanco et al. (2005), Norden and Weber (2009), Forte and Pena (2009), Das et al. (2014), for corporate CDSs and bonds (where information is generally transmitted from CDSs to bonds). A detailed review of the literature on the interaction between stock, bond, and CDSs and an analysis of the channels of this interaction is provided in Sections 2.2 to 2.3.3.
The common characteristic of these studies is the employment of firm-specific data, without a consideration of the drivers that induce movements across these asset-markets. This chapter contributes to the above studies by addressing both issues. First, it shifts the focus of the examination to the market-level by employing market indices, which (in contrast to single-name contracts) are able to capture the information flow at the market-level, while providing returns representative of the broader market. Second, it considers the primitive factors that induce financial asset price movements and affect cross-asset interaction. Among those factors, it examines the role of monetary policy and in particular the shift towards non-standard policy measures.

The focus attributed to the market level is necessitated by existing evidence that changes in single-name securities’ prices are driven by systematic and/or firm-specific risk, hence the transmission mechanism between asset returns at the firm level may have been influenced by the individual securities’ response to changes in market-wide systematic risks and/or to non-systematic shocks (Hull et al., 2004; Acharya and Johnson, 2007). Thus, the employment of market indices limits the noises in information flow due to firm-specific risks and enables the segregation of the impact of market-wide factors from that of the idiosyncratic ones, allowing that way the analysis to concentrate on market risk solely. Idiosyncratic risks, such as asymmetric information and insider trading problems, have been documented to have a strong presence in the CDS market (Acharya and Johnson, 2007; Fung et al., 2008). The vast exposure of the CDS market to idiosyncratic risks is due to the nature of the credit derivatives market itself, since by definition almost all major players are insiders (Acharya et al., 2007). These risks have also important implications for the efficiency of credit risk pricing as well as for credit risk transfer, e.g., to the underlying securities such as corporate bonds, thereby adding noise to the information flow between them (Acharya et al., 2007).

The idiosyncrasies further impact on the credit risk - and thus on the information - flowing from the CDS markets to the stock markets, with this flow being concentrated on days with negative credit news and for entities that experience adverse credit events. However, additional noise on the stock-CDS information flow arises from the fact that idiosyncrasies, such as insider trading, are also heavily present in the stock market, with a number of studies documenting that insider trading lowers
liquidity and increases trading costs (see Easley et al., 1996; Chun and Charoenwong, 1998; Bettis et al., 2000; Brockman and Chung, 2003; Fishe and Robe, 2004). This is dictated by the basic tenet of market microstructure theory according to which, liquidity partially reflects the information asymmetry created by informed traders; thus market makers may alter the quoted depth as well as the bid-ask spreads (i.e., the primary measure of asset liquidity) in response to perceived increases in insider trading (Kavajecz, 1998; Dupont, 2000). Since liquidity is one of the main channels for the propagation of information between assets, insider trading is elevated into a primary determinant of stock-CDS interaction.\textsuperscript{21} Despite its effect on stock liquidity, insider trading furthers raises the cost of equity capital (Bhattacharya and Daouk, 2002) and results in greater volatility (Du and Wei, 2004).\textsuperscript{22}

Given these adverse effects on the information flow between stocks, bonds and credit derivatives any study on the interaction between single-name contracts must take into account the idiosyncrasies present. Due to the employment of market indices these idiosyncrasies are diversified away and are prohibited from adding bias to the directional relationship of the information flow between different assets. The removal of these idiosyncrasies is especially important for investors in CDS and equity market indices as well as investors in general, since market indices serve as benchmarks for the evaluation of single-name investments.

The segregation of these idiosyncrasies is further important in order to consider the effectiveness of monetary policy, which constitutes the second contribution of this chapter. In this respect, the examination of the information flow at the market level is crucial since monetary policy aims at affecting broader economic and financial market aggregates. The consideration of the role of monetary policy is an essential component of this chapter's analysis and enables the extension of previous studies on an issue that remains unexplored: the identification of the factors that generate order flow in financial asset-markets and result in correlated price movements between them. Among those factors, monetary policy emerges as the principal candidate for causing movements in financial

\textsuperscript{21} A description of the liquidity channel and the ways with which affects the comovement and interaction between assets is provided in Section 2.4.

\textsuperscript{22} The importance of volatility for cross-asset interaction is analyzed in Section 2.5.
asset-markets, especially when considering that through their impact on asset prices and returns, central banks try to modify economic behaviour in ways that will help to achieve their ultimate objectives (Bernanke and Kuttner, 2005). However, the 2007-2008 financial crisis has casted doubts on the ability of central banks to achieve their objectives; due to the shocks to credit markets from the financial crisis, the argument is that monetary policy is unable to lower the cost of credit and hence, renders central banks ineffective, or to express it differently:

“We are already, however, well into the realm of what I call depression economics. By that I mean a state of affairs like that of the 1930s in which the usual tools of monetary policy - above all the Federal Reserve’s ability to pump up the economy by cutting interest rates - have lost all traction”

(Krugman, 2008)

Thus, this chapter contributes to the debate about the (in)effectiveness of monetary policy in times of crisis. Although the Keynesian tradition argues against the effectiveness of conventional and non-conventional measures during extreme market stress, some recent approaches (see Mishkin, 2009; Curdia and Woodford, 2011) suggest a greater role for those measures. Along these lines this chapter’s contribution further concerns the consideration of the recent shift in central bank thinking and practice: in this new environment of zero and even negative interest rates, monetary policy is conducted by means of central bank balance sheet expansion through the purchase of assets. The novelty of the examination is not limited to the evaluation of the impact of monetary policy on asset prices and their interaction, it is further extended to the determination of the channel of monetary transmission. The adoption of a vector auto-regression (VAR) model with sign restrictions enables for the identification of the channel through which non-standard measures are transmitted to asset prices. Most importantly, it allows for a consideration of a counterfactual: how monetary transmission changes in the event where this channel does not operate?

The results of this chapter's empirical analysis indicate differences in the timing with which information is reflected in the stock, bond and CDS markets. These differences are more evident in Europe pre-crisis, and in the US post-crisis where, consistent with “friction-based” and “sentiment-based” theories of comovement (see Barberis et al., 1998; 2005; Boyer, 2011), index comovement
appears to be delinked from the underlying fundamentals.\textsuperscript{23} During these periods, information about fundamentals is found to be reflected first in stocks and then transmitted to corporate bonds and CDSs. Results also point to a rather low degree of integration in the European financial markets before the financial crisis and a moderate improvement thereafter. Thus, the stock index emerges as the asset that assumes the central role in the information transmission to the credit and derivatives market indices.

The results further reveal that measures of the Federal Reserve's monetary policy stance induce greater movements in the US market indices after the financial crisis, with these post-crisis movements generally being greater than the movements induced by similar measures of the ECB's policy stance in the European market indices. This in turn lends support to the Federal Reserve's implementation of non-standard policies. In addition, measures of banks reserves held with the central bank exert a considerable influence on US market indices, providing a rationale for the supply of bank reserves as an instrument of US monetary policy. The effect of monetary policy on asset prices is primarily transmitted through the stock market. In this respect, the counterfactual analysis reveals that when this channel is not operative, the ECB's monetary policy is transmitted distortedly on the European corporate bond market.

The remainder of this chapter is organized as follows: Section 3.2 sets the hypotheses, Section 3.3 describes the dataset, Section 3.4 analyzes the joint dynamics between the market indices and Section 3.5 analyzes the role of macroeconomic variables. Section 3.6 concludes.

3.2. Hypotheses
The Efficient Market Hypothesis and the Merton-originated structural models of default risk maintain that in efficient markets the firms' default probability should have already been incorporated in the stock market. Thus, in the event of a firm facing unfavourable financial conditions, the probability of

\textsuperscript{23} For a discussion of the “friction-based” and “sentiment-based” theories of comovement see Section 2.1.
default on the respective firm's bonds and other obligations goes up, lowering that way the firm's financial soundness; this comprises the fundamental basis of arbitrage between equity and debt.\textsuperscript{24}

Therefore, the choice of the respective assets is based on their potential inter-linkage. Furthermore, especially pre-crisis, the increasing use of derivatives in the pursuit of higher yields across traditional asset classes has tighten the relationships between various assets, thereby prompting the expectation of transmission of volatility and information. Moreover, the credit derivatives market has possibly overreacted during the crisis, paving the way for contagion phenomena between different markets. According to the IMF (2007), a potential volatility shock or contagion episodes in the financial system could trigger a series of drastic portfolio adjustments and disorderly unwinding of positions. These developments pre- and during the crisis provide further impetus to the chapter's research question.

Despite this theoretically-expected negative correlation of stocks relative to bonds and CDSs, information is expected to be transmitted from the stock and CDS markets to the bond market, i.e., from the most liquid market to the less liquid one.\textsuperscript{25} This is commanded by the flexibility and the institutional features of the stock and CDS markets relative to those of the bond market, as well as their increased liquidity relative to that of the bond market (Fung et al., 2008; Norden and Weber, 2009; Corzo et al., 2012). We expect this relationship to be evident in Europe pre-crisis, where we anticipate that the stock market leads the less liquid and of a smaller size corporate bond and CDS markets.

\textit{Hypothesis 1: In Europe pre-crisis, the stock and CDS market indices lead the bond market index. The stock index leads the CDS market index.}

\textsuperscript{24} The Merton-originated structural models of default risk and the theoretical framework governing the interaction between stocks, bonds, and CDSs are analyzed in Section 2.2.

\textsuperscript{25} An analysis of the previous studies according to which the stock market is expected to lead the information transmission process is provided in Sections 2.2 to 2.3.3. Furthermore, the importance of liquidity for the information transmission and interaction between the stock, bond, and CDS markets is analyzed in Section 2.4.
However there are reasons to expect that these relationships do not automatically hold and that they exhibit differences when we move from the pre- to the post-crisis period, or from the US to the European market. Therefore, three additional hypotheses are formulated which correspond to the pre- and post-crisis periods in the US and the post-crisis period in Europe respectively.

The greater degree of market integration in the US relative to Europe, combined with the greater size and liquidity of the US corporate CDS market predisposes us to expect the existence of two-way linkages between all three US indices. This proposition is further supported by the sweeping reforms made by the National Association of Securities Dealers (NASD) in July 2002 which resulted in an improvement in the transparency and liquidity of the corporate bond market (Edwards et al., 2004; Bessembinder et al., 2006; Goldstein et al. 2007; Downing et al., 2007). That leads to a different hypothesis about the joint dynamics between the three US markets:

**Hypothesis 2**: In the US pre-crisis, there is bidirectional transmission of information between the market indices.

We also anticipate that post-crisis the joint dynamics of the US and European indices are different compared to the period before. This is mainly attributed to regulatory changes after the financial crisis that impacted negatively on liquidity and diminished the risk appetite by market intermediaries. Prominent among these changes are regulatory reforms such as Basel III or the Dodd-Frank Wall Street Financial Reform and Consumer Protection Act of 2010. These reforms have resulted in greater capital and liquidity requirements for banks and financial intermediaries, thereby diminishing their ability to maintain large inventories of corporate bonds; they further reduced the

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26 In July 2002 the NASD engaged in sweeping reforms of the reporting requirements for over-the-counter corporate bond transactions in order to enhance the transparency of the corporate bond market, with these reforms resulting in the public transmission of information on most corporate bond transactions through the Trade Reporting and Compliance Engine, or TRACE (see Downing, 2007).
return on capital of market-making activity.\textsuperscript{27} The end result was a decline in dealer inventories, as well as in the ability for dealers to act as effective market-makers.

\textit{Hypothesis 3: In the US post-crisis, the stock index leads the bond and CDS indices. The bond index leads the CDS index.}

The lead of the stock index in Hypothesis 3 is based on the previous arguments about the implementation and the impact of regulatory reforms. In addition, the decreased liquidity of the corporate bond and CDS markets relative to that of the stock market post-crisis, weakens the linkages between stocks on the one hand and bonds and CDSs on the other, by decreasing the impediments to arbitrage, which are considered by theory as a fundamental factor of the equity-credit market integration (Kapadia and Pu, 2012). It is reasonable to expect a greater role of the corporate bond market relative to that of the CDS market post-crisis. This argument is only partly based on the vertical drop in the size and liquidity of the corporate CDS market post-crisis. It is further supported by the reversal of the migration of institutional investors to the CDS market, that rendered the bond market less liquid and inactive. In addition, despite its negative impact on the corporate bond market, the Dodd-Frank Act is associated with increasing bond returns and decreased stock returns, thereby strengthening the channel flowing from the stock to the bond market, raising the latter market's importance for investors (Gao et al., 2011). In any case, we expect a disassociation between the bond and CDS indices, since the correlation between similar assets decreases with liquidity (Beber et al., 2009).

In Europe the situation is different. On the one hand we would expect the market indices to be more integrated post-crisis, mainly due to the ongoing process of financial integration in the EMU. This argument is further reinforced by the fact that the comovement between asset prices tends to be excessively high during volatile periods.\textsuperscript{28} However, this expectation is challenged by the arguments

\textsuperscript{27} Furthermore, the Volcker Rule proprietary trading prohibition has exerted a significant impact on Over-The-Counter trading desks, given intermingled activity.

\textsuperscript{28} See French and Roll (1986), Hamao et al., (1990), Andersen, (1996). An analysis of the role of volatility for the transmission of information between different assets is provided in Section 2.5.
about the role of liquidity as a positive contributor to the correlation and integration between similar assets. The sovereign debt crisis has adversely affected liquidity in both the European bond and CDS markets. This drop in liquidity is further bolstered by the November 2012 ban on short selling, and the lack of post-trade transparency, especially in the bond and CDS markets. Thus, the above arguments about the deteriorating liquidity in the bond and CDS markets lead to the following hypothesis:

**Hypothesis 4: In Europe post-crisis, the stock index leads the bond and CDS indices.**

Since the comovement of different markets might be attributed to a lead-lag relationship between the prices of these markets, in the event where macroeconomic or monetary shocks become reflected in one market before the other, then price movements in one market could influence price movements in the other; this in turn may indicate an indirect channel for the transmission of monetary policy to the price of one market via the price of another market (Goyenko and Ukhov, 2009). On the empirical front, there is a number of studies examining the relation of macroeconomic fundamentals and macroeconomic news to asset pricing dynamics, differentiating on several grounds, such as the choice of news, the market under examination (bonds, stocks, or currencies) and the statistical approach.²⁹

However, the nature of the relationship between asset price comovement and monetary policy during a period of changing economic and monetary conditions, has not been examined thus far. This relationship is nevertheless expected to be considerably strong, since for example, accommodative monetary policy may favourably affect asset prices through its effect on liquidity (Garcia, 1989), as well as on volatility (Harvey and Huang, 2002) and interest rates (Kuttner, 2001).³⁰ Still, monetary policy may have a different effect on financial assets due to fundamental differences between those

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³⁰ Of course falling asset prices might also induce the central bank to ease its monetary stance, thereby highlighting the possibility of reverse causality (see Goyenko and Ukhov, 2009).
assets.\textsuperscript{31} Macroeconomic factors such as unexpected productivity declines and inflationary shocks are further expected to affect asset prices directly and indirectly through their effect on liquidity and volatility (Strongin, 1995; Goyenko and Ukhov, 2009).\textsuperscript{32} Whether the response to monetary policy shocks and macroeconomic information is different across the three markets is an empirical question that this chapter explores.

**Hypothesis 5:** The impact of monetary shocks is greater post-crisis. Post-crisis, the impact is greater in the US than in Europe.

It is reasonable to expect a greater role for monetary policy during recessions. This is also suggested by models of market segmentation according to which, asset purchases are particularly more effective in lowering asset prices when markets are not functioning normally (see among others Vayanos and Vila, 2009; Greenwood and Vayanos, 2010).\textsuperscript{33} However, differences are further expected regarding the impact of monetary policy between the US and Europe, especially when considering the non-traditional character of the policies implemented by the Fed and the ECB in response to the financial and Eurozone crises.\textsuperscript{34} In specific, there is evidence that the Fed's Large-Scale Asset Purchases (LSAPs) have a significant impact in lowering corporate credit risk, as well as in reducing the cost of insuring against default-risk (Gilchrist and Zakrajsek, 2013).

On the other hand, the ECB's bond purchases and Long-Term Refinancing Operations (LTROs) announcements had an effect mostly on sovereign yields, especially on those of the periphery countries (Rogers et al., 2014). The hypothesis is further supported by the argument that the

\[\text{\textsuperscript{31} Stock prices are affected through the discount rate and potentially expected dividends, bond prices through expectations of future short rates and potentially the term premium, and CDS spreads through the discount rate and potentially through the probability of default.}\]

\[\text{\textsuperscript{32} While an increase in productivity is expected to increase return on risky investments and therefore, cause an outflow from the bond and CDS markets into the stock market, the effect of inflation shocks is still uncertain.}\]

\[\text{\textsuperscript{33} The channels for the transmission of monetary policy are presented in Section 2.6.2.}\]

\[\text{\textsuperscript{34} A description of measures of non-standard monetary policy is provided in Section 2.6.1.}\]
propagation of monetary policy depends on arbitrageur risk. Due to the increased risk aversion in Europe (as evidenced by the flight-to-quality and flight-to-liquidity flows to the German government bonds) we expect the propagation of monetary policy to be limited relative to the US. Additional support comes from the fact that one of the channels of monetary policy transmission is through bond yields into the other asset prices, and the evidence that this pass-through is greater for the US (Rogers at al., 2014). An additional factor is that the ECB's willingness to implement unconventional policies was slowed due to considerations about the “unusual” character of the measures, contrary to the US where the Fed's accommodative policy was initiated at an earlier stage.

3.3. Data

The data employed in the analysis is comprised of daily and weekly mid-prices, i.e., the mid-points between bid quotes and ask quotes, for the major stock, bond, and CDS indices in the US and Europe over the 2004-2014 period. Since the study is examining the empirical relationship between the three markets as this is evolved during the last decade and considering the 2007-2008 global financial crisis the whole sample is divided into two different sub-periods, the period before and after the financial crisis respectively. The cut-off date for the partition of the sample is the 31/08/2008, which corresponds to the bankruptcy of the Lehman Brothers and is associated with the escalation of the crisis. This cut-off date is further employed in the literature (see Bai and Collin-Dufresne, 2011) and is additionally confirmed by the Bai and Perron test for structural breaks. In addition the months following the Lehman Brothers' collapse were associated with a repricing in sovereign credit risk and a surge in risk aversion within the European context, therefore indicating the spread of the US-originated crisis to the international financial markets and the materialization of the global financial

35 See model of preferred habitat by Vayanos and Vila, (2009). A discussion of this model can also be found in Section 2.6.2.

36 The Bai and Perron test for structural breaks is presented in Table 3.2. As a robustness check the cut-off date is set on 10 May 2010, which corresponds to the ECB's announcement of its securities markets programme (SMP) and coincides with the escalation of the European sovereign debt crisis.
crisis. Therefore, the first sub-period refers to the period before the main phase of the global financial crisis (27/09/2004 (in the US) and 22/06/2004 (in Europe) until 31/08/2008).\(^{37}\) The second is the period after the Lehman Brothers collapse and covers the worst effects of the financial crisis on the markets (from 01/09/2008 until 31/05/2014). Section 3.3.1 introduces the indices selected from the stock, bond, and CDS markets. Detailed information about the source, and the calculation of the market indices is provided in Table 3.1.

3.3.1. The stock market

The sample contains last prices of the S&P 500 Index, a capitalization-weighted index designed to measure the performance of the broad US economy through changes in the aggregate market value of 500 stocks representing all major industries. For Europe, the FTSE Eurotop 100 Index is selected, an index composed of 100 of the most highly capitalized blue chip companies in Europe (based in Belgium, France, Germany, Italy, The Netherlands, Spain, Sweden, Switzerland, United Kingdom). The index measures the collective performance of the most actively traded stocks on the major European stock exchanges, representing the European stock market as a whole.\(^{38}\)

3.3.2. The bond market

The dataset consists of last prices of the BofA Merrill Lynch U.S. Corporate Master Index, an index comprised of publicly-issued, fixed-rate, nonconvertible investment grade dollar-denominated, SEC-registered corporate debt having at least one year to maturity and an outstanding par value of at least $250 million. For the European market the iBoxx Euro Corporate Bond Index, is employed, which is comprised of investment grade fixed-coupon bonds, step-ups, rating-driven bonds, and other bonds

\(^{37}\) The starting date for the US is one year after the first CDS index for the US market was launched and constitutes the first business day for which data is available for. In Europe, the starting date corresponds to the introduction of the first CDS index for the European market.

\(^{38}\) The information on the S&P 500 Index is provided by S&P Dow Jones Indices and by Bloomberg. The information on the FTSE Eurotop 100 Index is provided by FTSE Russell and by Nasdaq.
with known cash flows, all with minimum maturity of 1 year, and minimum issue of €500 million. The indices are weighted by the market value of their outstanding bonds in order to be representative of the market, since no other weighting scheme would permit a uniform portfolio held jointly by all investors. In addition, this scheme is perfectly aligned with passive investing strategy; since the constituent bonds are at market-value proportions, the weights will evolve over time, automatically adjusting, thereby relieving investors of the need to update the portfolios weights.39

3.3.3. The CDS market

The dataset includes last prices of the Markit CDX North American Investment Grade Index, which is composed of 100 liquid North American entities with high yield credit ratings that trade in the CDS market. For the European market, the Markit iTraxx Europe Index is employed, the benchmark index for Europe, consisting of 125 liquid European entities with investment grade credit ratings that trade in the CDS market. The entities comprising the index are primarily from Great Britain, France, and Germany (weights of 22%, 21%, and 14% respectively), and secondarily from the Netherlands, Switzerland, Italy (weights of 9%, 8%, and 6% respectively). For both indices 5-year maturities are considered, since the 5-year tenor consists the most liquid and frequently quoted part of the credit curve and therefore, the most traded maturity for CDS contracts.40

3.3.4. Descriptive Statistics

Tables 3.3 and 3.4 contain descriptive statistics for the price level and the percentage changes (in basis points (bps)) in the stock and bond indices, and the spread and the change in the spread of the

39 The countries covered by the European bond index are primarily France, Germany, Italy, and secondarily Austria, Belgium, Finland, Greece, Ireland, Luxembourg, Netherlands, Portugal, Slovakia, Spain. The information on the BofA Merrill Lynch U.S. Corporate Master Index is provided by the ETF Database. The information on the iBoxx Euro Corporate Bond Index is provided by Markit.

40 The information on the Markit CDX North American Investment Grade Index and the Markit iTraxx Europe Index is provided by Markit.
CDS indices.\footnote{In contrast to the stock and bond indices which are comprised of the prices of the constituent stocks and bonds respectively, the CDS indices are quoted at a theoretical traded spread in basis points; hence, the change in the CDS index is also quoted in basis points. To ensure the comparability of the market indices, as in Fung et al. (2008), Norden and Weber (2009), Corzo et al. (2012), the percentage change in each of the stock and bond market indices is calculated and converted to basis points, i.e., the following equation is employed: $\frac{(\text{Index Price at time } T' - \text{Index Price at time } T - 1)}{\text{Index Price at time } T - 1} \times 10000$.} Even though the mean change in the bond index is of the same magnitude in both the US and Europe (around 2 basis points), the mean change in the US stock and CDS indices is 2 and 10 times that of their European counterparts (3 bps versus 1.7 bps, and 0.10 bps compared to 0.01 bps for the stock and CDS indices respectively).

In the US, all indices exhibit positive mean changes during the pre- and post-crisis periods; interestingly, the post-crisis value of the CDS index is 6 times lower than pre-crisis and close to zero (0.035 bps). Similarly, all European indices exhibit positive mean returns (and CDS spread changes) during the pre-crisis period. The same pattern is observed post-crisis, with the exception of the CDS index where the mean change is slightly negative (-0.019 bps). However, financial markets appear more volatile post-2008, with market indices generally exhibiting higher standard deviation compared to their pre-crisis values, probably due to the unfolding Eurozone crisis.

Figure 3.1 presents the evolution in the level of the US and European market indices. In the US, the onset of the 2007 financial crisis is marked by a significant and steady increase in the spread of the CDS index, reaching its peak in mid-2008 during the Lehman Brothers collapse. This rise in CDS spreads was accompanied by a steep fall in the price of the stock and bond indices until about the spring of 2009, when they started rising back to their previous levels. The turbulence in the European financial markets is mainly observed in two stages; the first is during the US-originated crisis and on the onset of the Eurozone crisis in 2009, while the second begins after the second half of 2011. The months leading to the Greece debt restructuring in early 2012 managed to temporarily calm
the markets, however a new CDS spread hike occurred until about ECB's verbal intervention in September 2012.

3.4. Vector Autoregression Analysis

3.4.1. Methodology

This section includes the analysis of the intertemporal comovement of the stock, corporate bond, and corporate CDS market indices within the context of the US and European markets. Since this chapter's hypotheses are based on the fundamental assumption that information is first reflected in an asset and then transmitted to the other with a lag, the econometric specification must account for the dynamic structure of the variables selected. For that reason, a three-dimensional vector autoregressive model is employed in order to examine the joint interaction of the market indices, due to the particular model's ability to capture lead-lag relationships within and between stationary variables in a simultaneous multivariate framework. VAR models have also been used extensively in the literature on comovements (see Gwilym and Mike, 2001; Engsted and Tanggaard, 2004; Longstaff et al., 2005; Blanco et al., 2005; Norden and Weber, 2009; Longstaff, 2010). To further check whether the market indices are cointegrated and therefore an error correction term should be included in the VAR equation the Johansen test for cointegration is employed. The results of the test in Table 3.5 provide evidence of zero cointegrating equations, thereby suggesting a VAR model without an error correction term.43

[Insert Tables 3.5 about here]

Hence, the following VAR model of order p, where \( Y_t \) is a \((3 \times 1)\) vector, is selected to model the lead-lag relationship between the stock, bond, and CDS indices

\[
Y_t = c + \sum_{i=1}^{p} \Pi_i Y_{t-i} + \varepsilon_t ,
\]  

(3.1)

---

42 For a review of the literature on asset comovement see Sections 2.2. to 2.3.3.

43 The results of the Johansen test are presented in Table 3.5.
where \( Y_t = (Y_{1t}, Y_{2t}, Y_{3t})' \), \( c \) is a \((3 \times 1)\) vector of intercept terms, \( \Pi_t \) is a \((3 \times 3)\) coefficient matrix, \( \varepsilon_t \) is a \((3 \times 1)\) vector of innovations following a multivariate normal distribution with variance \( \Sigma \), and \( t = 1, \ldots, T \). The empirical form of the VAR model is:

\[
\begin{align*}
STOCK_t &= c_1 + \sum_{i=1}^{p} \alpha_{1i} STOCK_{t-i} + \sum_{i=1}^{q} \beta_{1i} \Delta CDS_{t-i} + \sum_{i=1}^{r} \gamma_{1i} BOND_{t-i} + \varepsilon_{1t} \tag{3.2} \\
\Delta CDS_t &= c_2 + \sum_{i=1}^{p} \alpha_{2i} STOCK_{t-i} + \sum_{i=1}^{q} \beta_{2i} \Delta CDS_{t-i} + \sum_{i=1}^{r} \gamma_{2i} BOND_{t-i} + \varepsilon_{2t} \tag{3.3} \\
BOND_t &= c_3 + \sum_{i=1}^{p} \alpha_{3i} STOCK_{t-i} + \sum_{i=1}^{q} \beta_{3i} \Delta CDS_{t-i} + \sum_{i=1}^{r} \gamma_{3i} BOND_{t-i} + \varepsilon_{3t} \tag{3.4}
\end{align*}
\]

Where \( STOCK_t \) is the daily return on the stock market index, \( \Delta CDS_t \) is the daily change in the spread of the corporate CDS market index, \( BOND_t \) is the daily return on the corporate bond market index.\(^{44}\) The lag structure and the maximum lag order \( p, q, r \) have been determined using the Akaike-Information (AIC) and the Schwarz-Information (SIC) criteria.\(^{45}\) The motivation for placing the CDS index before the bond index comes from the fact that the CDS market is more liquid and hence might induce movements in the bond market of a larger magnitude and at a more frequent rate than vice versa (Collin-Dufresne et al., 2001; Blanco et al., 2005).

\(^{44}\) As reported in Section 3.3.4, the returns in the stock and bond indices are multiplied by 100, i.e., they are percentage changes. The term "return" is used for expositional convenience.

\(^{45}\) The lag length depends on the nature of the series (daily or weekly), the market (US and Europe) and the period examined (pre- and post-crisis), and it varies from eight to twelve and from four to seven for the daily and weekly frequency respectively. When the AIC and SIC criteria provide different results for the optimum lag size, the model is estimated according to both criteria, although a preference is given to the AIC especially when the frequency of the data decreases. This is because the AIC tends to produce more accurate impulse responses for all realistic sample sizes, particularly in low-frequency data; AIC also results in the highest average reduction in mean-squared error compared to other criteria (Ivanov and Kilian, 2005). A Lagrange-Multiplier is implemented to test autocorrelation in the residuals at the lag order selected.
3.4.2. The Interaction of Stocks, Bond, and CDS Market Indices

Table 3.6 presents the results from the VAR analysis of the daily series, where there is evidence of two-way linkages across market indices. The only case in which we observe a clear lead of one index over the other indices is in Europe pre-crisis, where lagged corporate CDS spread changes and lagged corporate bond returns have no significant impact on stock returns, thereby confirming the stock market's lead over both the corporate CDS and bond markets stipulated in Hypothesis 1. However, contrary to Hypothesis 4, post-crisis this one-way relationship is no longer observable, since both the corporate CDS and bond indices begin to induce movements in the stock index.46

[Insert Table 3.6 about here]

In the US, there is evidence that stock returns lead corporate bond returns pre-crisis; however there is a bidirectional relationship between stock returns and corporate CDS spread changes, since the latter do exert some impact (albeit small) on the former, suggesting that Hypothesis 2 is not verified. Similarly to Europe, we observe a two-way relationship between all three US indices post-crisis, although the corporate CDS market's impact is considerably small and occurs at later lags, suggesting a significant influence (if not lead) on the part of the stock market. This in turn verifies the argument in Hypothesis 3 about the stock-CDS relationship, but not that about the stock-bond relationship. Hypothesis 2 is only partially confirmed with regards to the CDS-bond relationship, since in the pre-crisis US, corporate CDSs lead corporate bonds; nevertheless, this relationship is reversed post-crisis, with the corporate bond index obtaining the lead over the corporate CDS index, thereby lending support to Hypothesis 3.

In Europe however, there is a two-way interaction between the corporate CDS and bond markets during both sub-periods. Interestingly, there is a fundamental difference between Europe and the US regarding the nature of the impact of bond returns on CDS spread changes. While this impact

46 In particular the corporate CDS index coefficients have both signs, while those of the bond index are positive and larger with a size equal to 0.74 at the first lag.
is negative in the US, during the pre-crisis period in Europe the corporate bond index impacts positively on the corporate CDS index at the first lag (the coefficient is 1.7).  

To verify the findings from the VAR analysis a Granger causality test is performed for the same set of market indices in Europe and the US. The Granger test uses the information from the VAR to examine the ability of each of the market indices to induce movements (Granger cause) in each of the other market indices. By regressing the dependent variable $y$ on its own lagged values and on the lagged values of the independent variable $\chi$ the Granger causality test examines whether the lagged coefficients of $\chi$ are jointly zero. The test's null hypothesis is that the variable $\chi$ does not Granger cause variable $y$. In table 3.7 the cell associated with the $i_{th}$ row variable and the $j_{th}$ column variable shows the $\chi^2$ statistics and corresponding $p$-values in parentheses. Looking at the US in Panel A, the value in the cell (1,3) is 27.936 and significant at the 1% level thereby suggesting that during the pre-crisis period the stock market index Granger causes the bond market index. On the contrary, the value in the cell (3,1) is 6.569 and statistically insignificant, which indicates that during the same period, movements in the US bond market index are not informative for the US stock market index. The remaining coefficients from the Granger causality tests in Panels A and B of Table 3.7 are interpreted similarly.

The results from the Granger causality test provide evidence of two-way causation between market indices, thereby standing in contrast to a strand of the literature that argues in favour of the stock market's lead in terms of information transmission (see among others Norden and Weber, 2009; Forte and Pena, 2009). However, there are also cases where causality runs solely from one index (mainly the stock) to the other; this is evident in Europe pre-crisis and in the US post-crisis, where causality runs strictly from the stock to the corporate CDS and bond markets. Stock returns appear informative in predicting corporate bond returns since the stock index Granger causes the corporate

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47 This suggests that corporate bond investors in Europe resort instantly to the corporate CDS market for protection, thereby bidding CDS spreads up; nevertheless, this relationship is no longer evident post-crisis.

48 A detailed presentation of the previous studies' findings is provided in Sections 2.2, 2.3.1, and 2.3.2.
bond index in Europe pre-crisis, and in US during both sub-periods. Stock returns further contain information for corporate CDS spread changes since the stock index appears to Granger cause the corporate CDS index in Europe pre-crisis, while there is no causal effect stemming from the corporate CDS index. The declining CDS market's importance for the US post-crisis is also verified by the one-way Granger causality from the stock and bond indices to the CDS index. This is contrary to the corporate CDS market's role pre-crisis, where it appears to Granger cause returns in both the US and European corporate bond markets, without evidence of reverse causality. In Europe however, corporate CDSs Granger cause corporate bonds (and not vice versa), indicating that the corporate CDS market still contains information for movements in corporate bond returns after the crisis.

The implications of these results concern the direction and timing of information transmission across the stock, bond, and CDS markets. When these asset-markets are disassociated from underlying fundamentals, information primarily stems from the stock market index and directs to the corporate bond and CDS market indices, verifying the ability of the stock index in accurately reflecting information at the market level. From the investor perspective, this lead of the stock index identifies the respective asset as the driver of movements in the bond and CDS market indices and constitutes it as the asset to watch in order to forecast/anticipate movements in the bond and CDS indices. They additionally reveal that the importance of the corporate CDS market is only confined within the European context and not in the US, suggesting that US stock and bond market indices are more accurate reflectors of corporate default risk. The overall implications of the VAR analysis are discussed in Section 3.4.4.

3.4.3. Robustness Analysis

The chapter's findings so far suggest that the dynamics between the selected market indices exhibit differences when moving from the pre- to the post-crisis period and/or when moving from the US to the European market. The present section checks the robustness of these findings. The first robustness check allows for the decreased liquidity in the CDS market post-crisis, and places the corporate bond market index before the corporate CDS market index in the VAR specification of equations (3.2)-
The results are virtually the same under the alternative ordering. A further test concerns the change of the cut-off date for the European market indices to 10 May 2010, which corresponds to the intensification of the Eurozone crisis. Results show that although pre-crisis the stock index induces movements in the corporate bond and CDS indices of a significant size and at many lags, the latter also exert an impact - albeit small - on the former (results are omitted for brevity). This suggests that the relatively improved integration in the European markets observed post-crisis is a an ongoing process that is enhanced, but not entirely driven, by the sovereign debt crisis.

[Insert Tables 3.8 and 3.9 about here]

The VAR analysis is additionally conducted at the weekly frequency with the inclusion of the exogenous variables to control for possible influences. Following Collin-Dufresne et al. (2001), the following exogenous variables are included in the VAR:

*The 10-Year Government bond yield*:
This includes weekly series of the 10-year benchmark Treasury rates for the US ($\Delta TRATE$), and the 10-year German government bond yield for Europe ($\Delta GDBR$).

*The slope of the term structure*:
The slope of the yield curve is defined as the difference between the 10-year and 2-year benchmark Treasury yields for the US (USSLOPE), and the difference between the 10-year and 2-year German government bond yields for Europe (EURSLOPE). This proxy is considered by Collin-Dufresne et al. (2001) to serve two purposes; an indication of expectations of the future level of short rates, and a measure of overall economic health.

*Implied volatility for the CBOE index*:
a measure of global risk aversion in the financial markets ($\Delta VIX$ for both the US and Europe).

Thus, the alternative ordering becomes: STOCK, $\Delta$CDS, BOND, $\Delta$TRATE, USSLOPE, $\Delta$VIX for the US, and STOCK, $\Delta$CDS, BOND, $\Delta$GDBR, EURSLOPE, $\Delta$VIX for Europe. Results in Tables 3.8 and 3.9 indicate that the lead-lag and the Granger causality relationships still hold for the model with exogenous variables. The most notable difference concerns the coefficients' size, which is slightly greater in the absence of the exogenous variables; this serves as an indication that the latter variables pick up a portion of the impact of the endogenous variables on other endogenous variables.
in the model. In addition, in the pre-crisis US, a bidirectional (instead of a unidirectional) causality is observed between the stock and corporate bond indices.

3.4.4. Discussion

Modern portfolio theory (see Markowitz, 1952) proposes how rational investors should use diversification with imperfectly correlated assets in order to optimize their portfolio with respect to its expected return and its risk or volatility. Thus, the econometric analysis of Sections 3.4.2 and 3.4.3 provided information regarding the correlation and the dynamic interaction of a number of selected assets in order to assist in the construction of portfolios. This is of particular importance, especially when considering passive investment strategies, which are predominantly based on the use of market indices. Investors can diversify their portfolios across assets if this appears to be optimal in an expected risk-return sense; having all available information about asset comovements, like correlations of returns and transmission of shocks between assets, is therefore essential in making such an optimal asset allocation decision (Perold, 2004; Brandt and Diebold, 2006).

It appears that the morphology of the relationship between the market indices examined exhibits a number of differences when moving from the pre- to the post-crisis period, or from the US to the European market; this morphology is to a moderate degree similar to that suggested by previous

49 As a sensitivity check the VAR analysis is conducted by replacing the selected market indices with a number of alternative indices. The additional indices employed for the stock market include the Russell 3000 Index, and the Dow Jones Industrial Average Index for the US, and the FTSEurofirst 300 Index and the EURO STOXX 50 Index for Europe. For the corporate bond market the indices selected are the Barclays Capital US Corporate Investment Grade Index, and the Barclays Capital US Corporate High Yield Index for the US, and the Bank of America Merrill Lynch EMU Corporate Bond Index, and the iBoxx Liquid Euro Corporate Index for Europe. For the corporate CDS market, the Markit North American High Yield Index and the Markit iTraxx Europe HiVol Index are selected for the US, and the European market respectively. The VAR specification with the alternative indices yields essentially the same results with the initial indices, probably due to the significantly high correlation between intra-asset indices.
empirical studies, however considerable deviations from those studies are also manifested.\textsuperscript{50} The econometric results reveal a difference in the timing with which information is reflected in the market indices. The importance of the issue of the timing and the amount of information transmitted from one index (market) to the other lies in its use for asset allocation purposes, since informational spillovers constitute the crux of dynamic cross-market hedging strategies (see Fleming et al., 1998; Kodres and Pritsker, 2002). This difference in the reflection of information is more evident in Europe pre-crisis, and in the US post-crisis where, consistent with ‘‘friction-based’’ and ‘‘sentiment-based’’ theories of comovement (see Barberis et al., 1998; 2005; Boyer, 2011), index comovement appears to be delinked from the underlying fundamentals.\textsuperscript{51}

In particular, the lead of the stock index over the corporate bond and CDS indices in Europe pre-crisis, suggests that during this period the corporate bond and CDS markets are not fully integrated with the stock market. Thus, information about fundamentals appears to be reflected first in stocks and consequently transmitted to corporate bonds and CDSs. This is in line with previous studies, as well as with the overall status of financial integration in the pre-crisis EMU, which was still at a lower degree compared to the US. Post-crisis however - and still within the EMU - corporate bond and CDS indices begin to impact on the stock index, showing signs of increasing financial integration. Part of this is reflected in the post-crisis results, where stock returns affect more frequently (and at more lags) corporate bond returns and CDS spreads. This supports the theoretical propositions about the role of volatility as an important driver of market integration (see French and Roll, 1986; Hamao et al., 1990; Longin and Solnik, 1995; Andersen, 1996).

In the US, the corporate CDS and bond markets appear to be significantly more integrated with the stock market however, daily corporate bond index returns do not affect stock index returns pre-crisis. This pre-crisis lack of integration between stock and corporate bonds is largely attributed to the period during the crisis (July 2007-September 2009), where unreported results show that corporate bond index returns are uninformative for stock index returns, while their correlation is close to zero.

\textsuperscript{50} A detailed presentation of the previous studies' findings is provided in Sections 2.2, 2.3.1, and 2.3.2.

\textsuperscript{51} For a discussion of the ‘‘friction-based’’ and ‘‘sentiment-based’’ theories of comovement see Section 2.1.
This is not surprising, since there is evidence that at daily or even higher frequencies, the stock-bond correlation decreases during periods of high stock market uncertainty, mainly due to the flight-to-quality phenomenon (Connolly et al., 2005; 2007). Hence, in the event of severe market stress the diversification benefits among the stock and bond indices vanish, thus creating the need for alternative assets which, when used in combination with stocks, result in greater diversification (Connolly et al., 2005; Yang et al., 2009).

It might be the case that the regulatory reforms implemented by ISDA since July 2002 have not improved the transparency and liquidity of the corporate bond market (contrary to Edwards et al., 2004; Bessembinder et al., 2006; Goldstein et al. 2007; Downing et al., 2007). The generally small impact exerted by the stock index on that of corporate bonds could be also justified by the fact that the information transmission from the stock to the corporate bond index occurs within the same day, as it is the case with scheduled macroeconomic announcements. As mentioned above, the post-crisis dynamics between the US indices, are in line with those suggested by previous theoretical and empirical studies, and also similar to those in Europe pre-crisis, i.e., the stock index leads the corporate bond and CDS indices. However, there is also evidence about a relatively low degree of integration between the stock index on the hand, and the corporate bond and CDS indices on the other, thus lending support to the theoretical notion that a fall in liquidity reduces the impediments to arbitrage, which is considered as a fundamental factor of the equity-credit market integration (see Kapadia and Pu, 2012).

A significant and common finding for both the US and European markets after the crisis, is the low correlation and decreased interaction between the corporate bond and CDS indices, thereby lending support to the arguments that correlation between similar assets decreases with illiquidity (Beber et al. 2009). However, while in Europe it is the corporate bond index that appears uninformative for movements in the corporate CDS index, in the US the reverse occurs. This in turn

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52 This might be attributed to the lower liquidity (in terms of the mean and standard deviation of their bid-ask spreads and of the transactions volume) of the bond market relative to that of the CDSs within the European market, while in the US while the reverse occurs.
acts as a limit to the ability of investors to obtain a perfect hedge when investing in the credit market, i.e., as a limit to arbitrage (see Schleifer and Vishny, 1997; Duffie, 2010). This occurs through the impact on the CDS-bond basis, thereby altering the arbitrage and/or hedging opportunities when trading the basis and resulting in significant profit variations; this is also verified by Bai and Dufresne (2011), offering as a potential explanation the counterparty risk and the collateral quality (in this case the corporate bonds). 53

3.5. Macroeconomic Factors

Hitherto, the study focused on the intertemporal comovement of the stock, bond and CDS markets at the daily level, providing evidence of varying interaction between their returns, and highlighting the different way with which this interaction has evolved within the context of the US and European economy respectively. The examination's focus is now shifted to a number of standard macro and risk premium factors in order to identify the effect of monetary policy on return movements, particularly over longer time horizons where economic state variables are expected to have greater explanatory power. The nature of the examination and of the variables selected is motivated by the arguments that in a world of uncertainty the feasible outcome achieved by the central bank might be different depending on whether it sets the interest rate or the aggregate bank reserves (see among others Pool, 1970; Goodfriend, 1991; Rudebusch, 1995).

In their search for a reliable indicator of monetary policy, academic economists in the monetarist tradition have long directed their attention to instruments that the central bank controls closely on a daily or weekly basis, such as borrowed and non-borrowed reserves or the interbank

53 The sign of the relationship between market indices appears to be time-invariant and generally along the lines suggested by the EMH and the Merton-originated structural models of default; thus, the positive stock-bond and the negative stock-CDS association is also valid under index investing. However, the expected negative bond-CDS association is not the case for Europe pre-crisis, where corporate bond returns induce a positive movement on corporate CDS spreads one day ahead. This suggests that corporate bond investors resort instantly to the corporate CDS market for protection, thereby bidding CDS spreads up.
lending rate (Bernanke and Mishkin, 1992; Woodford, 1994). Thus, the Federal funds rate (termed FED) and the EONIA (termed EONIA) are selected as the primary indicators of the monetary policy of the Federal Reserve and the ECB respectively.\footnote{Even though, the Federal funds rate is considered to be the most reliable indicator of the Fed's monetary policy stance (see Bernanke and Blinder, 1992), the EONIA is largely influenced by liquidity issues, rather than (solely) by monetary policy considerations; this leads to the inclusion of an additional variable (termed EURORATE), consisting of the EONIA along with an array of interest rates (Perez-Quiros and Sicilia, 2002; Bohl et al., 2007).} Furthermore, taking into account Strongin's (1995) arguments that non-borrowed reserves' innovations can be employed to identify the Fed's monetary policy disturbances a measure of non-borrowed reserves is constructed net of the noise resulting from the Fed's accommodation of the demand for reserves.\footnote{The analysis in this section follows Goyenko and Ukhov (2009). To construct this measure the non-borrowed reserves and total reserves are normalized by a 36-month moving average of total reserves. Then the normalized non-borrowed reserves are regressed on normalized total reserves to distinguish between changes in reserves which are the outcome of the Fed's policy innovations and changes in reserves which are due to the Fed's accommodation of demand innovations. The residuals are then collected to form the NBRX variable, with higher values of the respective variable being associated with accommodative monetary policy. More details can be found in Strongin (1995), Patelis (1997), Christiano et al. (1999), and Goyenko and Ukhov (2009).}

However, in recent years we have witnessed a shift in modern central bank thinking and practice away from the concept of non-borrowed reserves, towards that of required and excess reserves; this shift was marked by the Fed's QE program and the euro area interbank lending market impairment which resulted in the banks' currently holding high levels of excess reserves with the Fed and the ECB respectively (Bindseil, 2004; 2006; Bindseil and Jablecki , 2011).\footnote{A discussion of this shift in monetary policy stance is provided in Section 1.2.} Hence, by employing the method for the construction of the NBRX measure two additional variables are formed, the “orthogonalized” required reserves (termed RRX), and excess reserves (termed ERX). The latter variables are the main variables employed for the euro area since, due to its short history, the ECB never targeted the mix between borrowed and non-borrowed reserves. For that reason, special...
attention is also given to the mix between excess (and required) reserves and total reserves, termed ER/TR (RR/TR).

The list of macroeconomic variables further includes measures of the central banks' success at achieving their ultimate objectives in the previous periods. In this respect, a measure of inflation (termed CPI and HICP in the US and Europe respectively), and a measure of economic activity, such as the industrial production index (termed IP), are included. In contrast to the daily market indices data, macroeconomic and monetary policy variables are available at lower-frequencies. The macroeconomic and monetary policy variables are log-transformed before entering the analysis, and the VAR model specified in equation (3.1) is employed. More specific, IP, CPI, money market interest rates, and measures of orthogonalized reserves are endogenous and placed before the market indices, the ordering of which remains the same as in equations (3.2)-(3.4). The specification depends on the argument that, while financial markets respond to monetary policy, monetary policy is relatively exogenous to the financial market developments (Goyenko and Ukhov, 2009). Examples of earlier studies placing monetary policy variables before financial market variables within a VAR specification are those of Thorbecke (1997), Chordia et al. (2005) and Goyenko and Ukhov (2009).

Table 3.10 contains the results of the Granger causality tests, which indicate that macroeconomic variables have different predictive ability with regards to movements in all market indices. In particular, movements in inflation (CPI - HICP), and in money market rates (FED - EONIA) are informative in predicting index movements in the US and Europe pre-crisis. The primary indicator of US monetary policy (NBRX) shows limited predictive ability, in contrast to the alternative measure (ER/TR) which is more informative for changes in the stock and corporate CDS indices.

In Europe, both monetary policy indicators (ERX and ER/TR), Granger cause stock returns and corporate CDS spread changes. However, no monetary policy indicator appears able to affect US or European corporate bond returns pre-crisis. Post-crisis, US macroeconomic variables show greater

57 Augmented Dickey-Fuller unit-root tests indicate non-stationarity in the data.

58 Similar results are obtained with the alternative variable for European market rates, i.e., EURORATE.
predictive ability than their European counterparts; this is the case with industrial production (IP), as well as with measures of the Fed's policy stance, which include information about future movements in US market indices. This is contrary to the situation in Europe, where - excluding IP - most variables appear unable to induce movements in all market indices.59

[Insert Table 3.10 about here]

The use of impulse response functions (IRFs), presented in Figure 3.2, provides us with a more clear picture.60 According to the IRFs, pre-crisis US and European stock returns respond positively to a shock to FED and EONIA respectively, suggesting that initially the market perceives an interest rate rise as a signal of better-than-expected economic conditions. This response exhibits greater persistence in the US, since it is translated into a permanent upward movement in the stock index. Relative to interest rate shocks, a rise in the US “orthogonalized” non-borrowed reserves (NBRX), or in the ECB's mix of excess and total reserves (ER/TR), exerts a negative impact on the stock indices, signifying that central bank reserves act in tandem with interest rates: a rise in the former reflects a loosening of monetary policy and therefore, is perceived as a sign of worse-than-expected economic conditions resulting in a downward movement in stock prices. Productivity and - especially - inflationary shocks also exert a moderate impact on US and European stock indices, although this impact is relatively weaker than that of monetary shocks.

[Insert Figure 3.2 about here]

59 However, there is some evidence that indicators of the ECB's monetary policy stance, i.e., ERX, ER/TR, and RRX, contain information for movements in the European corporate bond market.

60 The impulse response function traces the impact of a one-time, unit standard deviation, positive shock to one variable on the current and future values of the endogenous VAR variables. This shock is referred to as “shock” or “innovation” for expositional convenience throughout the text. Since the actual variance-covariance matrix of the errors is unlikely to be diagonal, the errors need to be orthogonalized so to isolate shocks to one of the variables in the VAR. The usual practice is to use standard Cholesky decompositions of the VAR residuals keeping the ordering of the endogenous variables unchanged, thus allocating any correlation between the residuals of any two elements to the variable placed first in the ordering.
The response of the credit and derivatives market indices to interest rate shocks generally parallels that of the stock index; the only exception is the response of corporate CDS spreads in the US, the positive response of which to a Federal funds shock indicates that the US corporate CDS market does not perceive the rise in money market rates as a sign of economic recovery. Again, bond and CDS market indices appear considerably responsive to bank reserve shocks; among them, the CDS indices exhibit stronger reaction than their bond counterparts, with the US CDS index falling by almost 2 standard deviations in response to a one standard deviation rise in NBRX, while in Europe the CDS index responds (negatively) on a one-to-one basis to a standard deviation positive shock in the bank reserve measures. In any case, the CDS market's reaction is relatively greater when compared to that of the stock and bond markets' reaction.

A similar dependence of stock returns to interest rate and bank reserve shocks in both Europe and the US is further observed in the post-crisis period, although the response of the US stock index to bank reserves shocks is significantly stronger when compared to that of the European index. This ability of bank reserves to induce movements in stock returns is of particular importance in the US, where the last change in the Federal funds target occurred in late 2008 and thus, the Fed was deprived of its main monetary policy tool. Therefore, a policy based on non-borrowed reserves emerges as a viable alternative to the Fed's interest-rate policy that was primarily the case at the time.

In contrast to the stock market however, US and European CDS markets appear more responsive to monetary policy shocks in the post-2008 period. This pattern is primarily evident with regards to the European CDS market's response where the spreads literally over-react and move (downwards) by almost 10 and 6 standard deviations to shocks to interest rates and bank reserves respectively. This combined with the relatively weaker post-crisis response of the European corporate bond index to monetary policy shocks indicates that the derivatives market has gained in importance relative to the bond market in Europe. This over-reaction of the CDS market relative to the pre-crisis period is further the case with regards to shocks to macroeconomic variables. However, this reaction in significantly greater when the source of shocks is the level of productivity rather than the price level, probably due to the low-inflation in the post-2008 period in Europe.
On the other hand, the reaction of the US corporate CDS spreads - although weaker than the one exhibited by their European counterparts - is nevertheless stronger than pre-crisis, reaching the 40bps level or one standard deviation when non-borrowed reserves shocks are considered. In addition, US corporate bond returns not only exhibit a stronger post-crisis response to monetary policy shocks, they now increase following a rise in the amount of non-borrowed reserves, signifying that the supply of bank reserves by the Fed is perceived favourably by market participants. This in turn verifies the earlier argument about the ability of bank reserves to induce financial asset movements even when a zero interest-rate policy is being implemented.

The examination further allows for the fact that the central bank may respond to developments in the financial markets, by placing the monetary policy variables after market indices; the new VAR ordering becomes: IP, CPI (HICP), STOCK, CDS, BOND, FED (EONIA), measures of “orthogonalized” reserves. Granger causality results and IRFs are generally the same as under the previous ordering, thereby verifying the above relationships.61

3.5.1. Discussion

Overall, the VAR analysis of Section 3.5 suggests that the ability of macroeconomic and monetary policy variables in predicting movements in market indices is greater in the US than in Europe. Impulse response functions reveal that the response of the US and European market indices to macroeconomic and monetary shocks is qualitatively but not always quantitatively similar. Quantitatively however, the respective indices exhibit relatively higher sensitivity in the US than in Europe in the post-crisis period; the higher sensitivity is mainly observed with regards to the US stock and bond markets' reaction to the amount of reserves held with the central bank. This is attributed to the timing, the size, and the nature of the measures adopted by the Federal Reserve which are different to those adopted by the ECB.

61 Results are omitted for brevity.
Contrary to the Fed's asset purchases which included agency debt, mortgage-backed securities and long-term treasury bonds, the ECB's policy interventions targeted entirely the sovereign bond market. However, the ability of declines in sovereign bond yields to be transmitted to other asset prices has been questioned (see Eggertsson and Woodford, 2003; Krishnamurthy and Vissing-Jorgenson, 2013). Furthermore, even to the extent that the ECB-induced sovereign bond yield declines are able to be transmitted to the other asset prices, two facts limit their effectiveness. The first refers to the political considerations and the limitations stemming from the Lisbon Treaty on the ECB's purchase of sovereign debt. Due to these considerations, the ECB's asset purchases were only conducted at a limited degree not with the objective of affecting asset prices but of addressing the inter-bank market dysfunctions and restoring the transmission mechanism of euro area monetary policy. Second, the asset purchases through the SMP adopted in May 2010 were sterilized, therefore limiting their ability to ease monetary and financing conditions, while the large-scale asset purchases through the Outright Monetary Transaction (OMT) program announced in August 2012 were not utilized until the time of the writing.

On the other hand, the fall of the Federal funds rate to the 0-0.25bps points range, resulted in the adoption of non-standard policy measures by the Fed at an earlier stage. In addition, asset purchases such as those conducted through the Fed's LSAP primarily targeted the corporate sector. This strong impact of the Fed's non-standard measures is largely attributed to the LSAP which succeeded in lowering corporate credit risk and reducing the cost of insuring against default-risk that was consequently translated to a decline in corporate CDS spreads; it further induced a significant easing of financial conditions in both the household and business sectors (Gilchrist and Zakrajsek, 2013). These results are further consistent with the findings that the first LSAP lowered significantly the CDS spreads on lower-rated corporate bonds (see Krishnamurthy and Vissing-Jorgensen, 2011), as well as with evidence that the Fed's monetary policy shocks exerted a considerable - albeit short lived - impact on corporate bond yields during the period of zero interest rates (see Wright, 2012).

62 The Article 125 of the Lisbon Treaty prohibits purchases of sovereign debt that function as sovereign bailouts of EMU Member States, while Article 123 prohibits monetary financing.
An additional factor contributing to this weaker impact of the ECB's monetary policy on asset prices concerns the higher degree of risk aversion within the euro area financial markets context. The degree of risk aversion is crucial for the propagation of monetary policy, since preferred habitat models suggest that central bank interventions and decisions about the short rate are transmitted along the term structure of interest rates through the carry trades of arbitrageurs. In the event of high risk aversion (e.g., under-capitalization of arbitrageurs), monetary transmission is limited and forward rates under-react considerably to changes in the level of expected short rates (Vayanos and Vila, 2009). Therefore, the higher risk aversion across the euro area at both the corporate and sovereign level - in the form of higher bond yields and CDS spreads - compared to the US, constitutes an additional impediment for the transmission and effectiveness of the ECB's policy measures.

The above findings are important in the light of US monetary policy, which is ordinarily considered solely in terms of choosing an operating target for a short-term nominal interest rate, i.e., the Federal funds target rate. Yet, due to the extraordinary nature of the financial crisis and because the Federal funds policy rate was promptly dropped to its effective lower bound of near zero percent by late 2008, other dimensions of policy have occupied much of the Federal Reserve's - as well as other central banks' - attention as a means of stabilizing the financial markets; in this respect, the component of the Fed's liabilities constituted by reserves held by depository institutions has increased by approximately 280 times since the summer of 2008, suggesting that the main instrument of US monetary policy has shifted, from an interest-rate policy to one dubbed as quantitative easing (Curdia and Woodford, 2011).

It further builds a case for Europe, since the ECB's key rates have also been brought near zero entering 2014. This is important especially when considering the post-crisis IRFs, where the current amount of reserves held with the ECB has not exerted the intended impact on the bond market, whereas the CDS market - although exhibiting a very significant response to bank reserves shocks - is still heavily dependent on movements on money market rates. Should interest rates cease being the ECB's main monetary policy tool, then a greater - relative to the current situation - supply of bank

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63 An analysis of the preferred habitat models is provided in Section 2.6.2.
reserves might be needed in order to move the European credit and derivatives markets to the intended direction. The findings of this section do not suggest that the supply of bank reserves (or perhaps the monetary base) can be regarded as a superior operating target for monetary policy, however they provide a solid argument that it might be considered as a viable alternative, able to exert an impact on financial markets.

Monetary policy shocks appear to have a greater impact post- rather than pre-crisis in the US, which has been the field of an unprecedented monetary expansion under the QE programs. This lends support to theoretical arguments that the expansion of the central banks' balance sheet through the purchase of assets is more effective in lowering asset prices when markets are not functioning normally (see Vayanos and Vila, 2009; Mishkin, 2009; Greenwood and Vayanos, 2010). The significance of this finding can be seen within the context of the US financial crisis, where the predominant view among some participants in the Federal Open Market Committee (FOMC) meeting in October 2008 (when the crisis was escalating), was that financial dislocations might diminish the effectiveness of the Fed to conduct monetary policy by cuts in the Federal funds target rate; this in turn provides a rationale for a risk-management approach on the part of the central banks with the aim of offsetting the contractionary effects from financial crises (Board of Governors of the Federal Reserve System, 2008; Mishkin, 2009).

Results point to a moderate, albeit significant, sensitivity of market indices to macroeconomic variables, such as measures of inflation and industrial productivity, that becomes moderately stronger post-crisis. This is explained by the fact that interest rate setting is done judgementally by employing a number of macroeconomic signals, but in a way that can be approximated with reference to the Taylor rules, according to which interest rates respond more than one for one to inflation changes and also to output gap fluctuations; since these macroeconomic signals are indicators of changes in the implementation of monetary policy it is logical to be taken into consideration by financial market participants and reflected in financial asset prices (Joyce et al., 2012). This sensitivity also carries implications for portfolio construction, since it implies that a portfolio dominated by a single index or
strategy is more likely to be susceptible to extreme macro-conditions and that combining indices may be an effective way to reduce macro-risk exposures.

Overall, the moderately greater impact of macroeconomic and monetary variables post-crisis, combined with the relatively greater responsiveness of US market indices compared to those in Europe, provides justification for Hypothesis 5. Results in Section 3.4.2 suggest the presence of two-way linkages between the stock, bond, and CDS markets; however, when these linkages cannot be established, the stock index is the primary channel through which information is transmitted to the bond and CDS indices.64 This is also verified by results in section 3.5 with regards to the transmission of information contained in macroeconomic variables. The combination of the results in sections 3.4.2 and 3.5 suggest the existence of an indirect effect of monetary policy on bond and CDS indices. The stock index can therefore act as an indirect channel for the transmission of monetary shocks to the bond and CDS indices.

3.5.2. The Indirect Effect of Monetary Shocks

Since an interest rate is typically the instrument set by monetary policy-makers, asset prices on debt instruments are a predominant channel through which monetary policy affects the economy. Thus, monetary policy should have a direct effect on the bond and CDS indices. However, the analysis in the previous section indicates that monetary policy affects the bond and CDS indices primarily indirectly through the stock index. This raises the question of whether developments in the macroeconomy can be transmitted integral to the credit and derivatives market via the direct channel. Thus, this section examines whether certain type of shocks, such as supply shocks, demand shocks, and contractionary monetary policy shocks, are transmitted to each of the bond and CDS market indices directly, without the indirect assistance of the stock index.

64 The direction and size of the lead-lag relationships between the market indices observed in section 3.4.2 are verified by the VAR analysis in the present section. The sign and size of coefficients is generally along the same lines with those suggested under the initial VAR ordering with only the financial market variables.
To accomplish this, the initial VAR is re-estimated by imposing sign restrictions according to the method of Uhlig (2005), and making two independent mutually-exclusive assumptions: a) shocks affect the stock market, and thus also affect the bond and CDS markets indirectly through the stock market, and b) shocks do not affect the stock market, and thus are only transmitted directly to the bond and CDS markets. The last assumption excludes any direct effect of shocks on the stock index, thereby enabling the identification of the direct transmission of the shocks into the bond and CDS market indices. The method is explained in detail in Appendix 3.B.

Figure 3.3 reports the IRFs for the weekly series during the 2004-2014 period. The IRFs are obtained from the estimation of two VARs; one where the shock is transmitted to all endogenous variables (although the sign of the endogenous variables' response varies), and one where the shock has a zero impact on the stock market (zero-sign). In the US, the response of the bond and CDS markets to all three type of shocks is essentially the same between the two VARs, both in terms of direction and magnitude. In Europe however, the exclusion of the stock index from the transmission of shocks, causes the bond index to respond either in the opposite direction (supply shock), relatively stronger (demand shock), or only instantly (monetary policy shock). This highlights the importance of the stock market for the transmission of macroeconomic and monetary policy shocks within the European context, in contrast to the US, where this transmission occurs without frictions even in the absence of the stock market, probably owing to the greater size of the corporate bond and CDS markets relative to that in Europe.

3.6. Conclusion

This chapter analyzes the joint dynamics of the stock, bond, and CDS markets in Europe and the US over the 2004-2014 period. The analysis differentiates from previous studies by employing a number of market indices. This allows for the separation of the idiosyncratic risks that are present in single-name contracts and that impact on cross-asset information flow from the market-wide risks, thereby enabling the examination to concentrate on market risk solely. An additional differentiation concerns
the consideration of the recent trend in central bank practice of quantitative easing and the expansion of the central bank's balance sheet. In this respect the chapter identifies the role of this new monetary stance for the generation of order flow in these markets, as well as the channel of monetary transmission.

The empirical results indicate differences in the timing with which information is reflected in the stock, bond, and CDS markets, with these differences being more evident in Europe pre-crisis, and in the US post-crisis where, consistent with “friction-based” and “sentiment-based” theories of comovement (see Barberis et al., 1998; 2005; Boyer, 2011), index comovement appears to be delinked from the underlying fundamentals. During these periods, information about fundamentals is found to be reflected first in stocks and then transmitted to corporate bonds and CDSs. The stock market additionally emerges not only as an efficient, but also as a necessary channel for the transmission of the ECB's monetary policy to the European bond market, since in the absence of the former, shocks to demand and supply, as well as monetary shocks are transmitted distorted to the latter market. The analysis further reveals that monetary policy induces greater movements in the US market indices after the financial crisis, with these post-crisis movements generally being greater than the movements of the European indices, thereby lending support to the Federal Reserve's implementation of non-standard policies. In addition, measures of banks reserves held with the central bank exert a considerable influence on US market indices, providing a rationale for the supply of bank reserves as an instrument of US monetary policy.

An important implication arising from this study concerns the optimal asset allocation decisions in the context of passive investment strategies which primarily involve the trading of market indices. In particular, in times of crisis when informational efficiency deteriorates, the stock index retains its ability to reflect first and transmit information to the bond and CDS indices. This points to the need for monitoring the stock index for anticipating movements in the corporate bond and CDS indices. Furthermore, in periods of heightened market stress the lag in the information transmission across the market indices limits the diversification benefits across stocks, bonds and CDS contracts, at least at the market level. This in turn prompts investors to search for alternative assets with a higher
degree of comovement in order to achieve greater diversification when trading market indices. In a similar vein, the post-crisis disassociation between corporate bond and CDS spreads raises attention to the limited ability of investors to obtain a perfect hedge when investing in the corporate debt and credit derivatives market.

This study further carries implications for the risk-management conducted by central banks in times of financial market turmoil and particularly when interest rates are at the zero lower bound. The strong impact exerted by the measures of bank reserves on financial asset-prices indicates that when the effectiveness of cuts in the central policy rate are diminished by financial dislocations, the supply of bank reserves constitutes an efficient means of intervention in the financial markets. By rejecting the early Keynesian arguments about the ineffectiveness of monetary policy during crises, the analysis of this chapter suggests that (aggressive) non-standard monetary policy is able to lower the cost of credit and therefore ease the contractionary effects of a recession. The results of the analysis further concern the timing for the conduct of non-standard policy interventions; they suggest that the expansion of the central banks' balance sheet through the purchase of assets is more effective in easing financial market stress when markets are not functioning normally, thereby confirming the relevant theoretical propositions (see Vayanos and Vila, 2009; Vayanos, 2010 for models of preferred habitat, and Mishkin, 2009).

The differences in the impact of monetary policy on asset prices when moving from the US to the European financial markets are relevant for the conduct of euro area monetary policy. In the event of an interest rate drop to the zero or negative level, a greater - relative to the current - expansion of the ECB's balance sheet emerges as the principal means for intervening in the European debt and credit derivatives markets. This is further reinforced by the chapter's findings about the dependence of the European corporate bond market on the stock market, since without the latter the effect of monetary policy on the former is transmitted distortedly.
<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>FREQUENCY</th>
<th>SOURCE</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>STOCK (US)</td>
<td>Daily/Weekly</td>
<td>Bloomberg</td>
<td><strong>Main Variable:</strong> The percentage change in the S&amp;P 500 index. <strong>Robustness Section:</strong> The percentage change in the Russell 3000 index. The percentage change in the Dow Jones Industrial Average Index.</td>
</tr>
<tr>
<td>STOCK (EUR)</td>
<td>Daily/Weekly</td>
<td>Datastream</td>
<td><strong>Main Variable:</strong> The percentage change in the FTSE Eurotop 100 Index. <strong>Robustness Section:</strong> The percentage change in the FTSEurofirst 300. The percentage change in the EURO STOXX 50 Index. The calculation of the stock indices involves the multiplication of each stock in the index by the number of shares used in the index calculation; the product is then by a factor (divisor) in order to be scaled down to a more easily handled number. In the event of a stock addition or deletion, the divisor is adjusted in order to exclude the possibility of a change in the index’s value or level, thereby offsetting the change in the market value of the index. The divisor is further adjusted in the event of any corporate action that induces changes in the market value of the constituent stocks.</td>
</tr>
<tr>
<td>BOND (US)</td>
<td>Daily/Weekly</td>
<td>Bloomberg</td>
<td><strong>Main Variable:</strong> The percentage change in the BofA Merill Lynch U.S. Corporate Master Index. <strong>Robustness Section:</strong> The percentage change in the Barclays Capital US Corporate Investment Grade Index (formerly called The Lehman Brothers US Corporate &amp; Investment Grade Index). The percentage change in the Barclays Capital US Corporate High Yield Index.</td>
</tr>
<tr>
<td>BOND (EUR)</td>
<td>Daily/Weekly</td>
<td>Datastream</td>
<td><strong>Main Variable:</strong> The percentage change in the Markit iBoxx. <strong>Robustness Section:</strong> The percentage change in the iBoxx Liquid Euro Corporates Index. The calculations of the bond indices are based on quotes from multiple market-makers. These quotes are ordered separately from the highest to the lowest and then their maximum dispersion is checked, i.e. the distance between the highest and the lowest quote, in order to determine their eligibility for consolidation. From the eligible quotes, the highest and lowest quotes are eliminated, and the arithmetic average of the remaining eligible quotes is calculated to determine the consolidated quote. In cases where no observable data is available or where the data's depth/quality is insufficient, either the last index price will be carried forward, or a curve-based pricing model will be calculated from end-of-day prices.</td>
</tr>
<tr>
<td>CDS (US)</td>
<td>Daily/Weekly</td>
<td>Bloomberg</td>
<td><strong>Main Variable:</strong> The change in the Markit CDX North America Investment Grade Index. <strong>Robustness Section:</strong> The change in the Markit North American High Yield Index. <strong>Main Variable:</strong> The change in the Markit iTraxx Europe. <strong>Robustness Section:</strong> The change in the Markit iTraxx Europe HiVol. The Markit CDX is broken into five sub-sect indices, i.e. consumer cyclical, energy, financials, industrial, and telecom, media and technology. The major sectors contributing to the iTraxx are consumer products (14%), banks (13%), manufacturing (11%), retail (10%), and basic industries (10%). The pricing of the CDS indices involves the calculation of the index constituents using linear interpolation of the two closest terms for which composites are available. Once the survival probabilities of each constituent are calculated at each coupon payment date, the Present Value (PV) of each index constituent is calculated using the trade details of the index. This in turn allows for the calculation of the PV of the Index (Weighted Average of the PVs of the constituents) and the Accrued Interest on the Index, which is employed to solve for the curve that gives the theoretical spread of the index.</td>
</tr>
<tr>
<td>CDS (EUR)</td>
<td>Daily/Weekly</td>
<td>Bloomberg</td>
<td><strong>Main Variable:</strong> The change in the Markit CDX North America Investment Grade Index. <strong>Robustness Section:</strong> The change in the Markit North American High Yield Index. <strong>Main Variable:</strong> The change in the Markit iTraxx Europe. <strong>Robustness Section:</strong> The change in the Markit iTraxx Europe HiVol. The Markit CDX is broken into five sub-sect indices, i.e. consumer cyclical, energy, financials, industrial, and telecom, media and technology. The major sectors contributing to the iTraxx are consumer products (14%), banks (13%), manufacturing (11%), retail (10%), and basic industries (10%). The pricing of the CDS indices involves the calculation of the index constituents using linear interpolation of the two closest terms for which composites are available. Once the survival probabilities of each constituent are calculated at each coupon payment date, the Present Value (PV) of each index constituent is calculated using the trade details of the index. This in turn allows for the calculation of the PV of the Index (Weighted Average of the PVs of the constituents) and the Accrued Interest on the Index, which is employed to solve for the curve that gives the theoretical spread of the index.</td>
</tr>
<tr>
<td>Variable</td>
<td>Frequency</td>
<td>Provider</td>
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</tr>
<tr>
<td>----------</td>
<td>-----------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>ΔTRATE</td>
<td>Daily/Weekly</td>
<td>Datastream</td>
<td></td>
</tr>
<tr>
<td>ΔGDBR</td>
<td>Daily/Weekly</td>
<td>Datastream</td>
<td></td>
</tr>
<tr>
<td>SLOPE</td>
<td>Daily/Weekly</td>
<td>Datastream</td>
<td></td>
</tr>
<tr>
<td>US-EUR</td>
<td>Daily/Weekly</td>
<td>Datastream</td>
<td></td>
</tr>
<tr>
<td>ΔVIX</td>
<td>Daily/Weekly</td>
<td>Datastream</td>
<td></td>
</tr>
<tr>
<td>FF</td>
<td>Weekly/Monthly</td>
<td>FRB of NY</td>
<td></td>
</tr>
<tr>
<td>NBRX</td>
<td>Weekly/Monthly</td>
<td>FRB of St. Louis</td>
<td></td>
</tr>
<tr>
<td>RRX (US)</td>
<td>Weekly/Monthly</td>
<td>FRB of St. Louis</td>
<td></td>
</tr>
<tr>
<td>ERX (US)</td>
<td>Weekly/Monthly</td>
<td>FRB of St. Louis</td>
<td></td>
</tr>
<tr>
<td>ER/TR</td>
<td>Weekly/Monthly</td>
<td>FRB of St. Louis</td>
<td></td>
</tr>
<tr>
<td>RR/TR (US)</td>
<td>Weekly/Monthly</td>
<td>FRB of St. Louis</td>
<td></td>
</tr>
<tr>
<td>EONIA</td>
<td>Daily/Weekly</td>
<td>ECB</td>
<td></td>
</tr>
<tr>
<td>EURO-RATE</td>
<td>Daily/Weekly</td>
<td>Datastream</td>
<td></td>
</tr>
<tr>
<td>RRX (EUR)</td>
<td>Weekly/Monthly</td>
<td>ECB</td>
<td></td>
</tr>
<tr>
<td>ERX (EUR)</td>
<td>Weekly/Monthly</td>
<td>ECB</td>
<td></td>
</tr>
</tbody>
</table>

ΔTRATE: The change in the 10-year benchmark U.S. Treasury rate.

ΔGDBR: The change in the 10-year German government bond yield.

SLOPE: The change in the difference between the 10-year U.S. benchmark Treasury yield and the 2-year U.S. benchmark Treasury yield.

US: The change in the difference between the 10-year U.S. benchmark Treasury yield and the 2-year U.S. benchmark Treasury yield.

Europe: The change in the difference between the 10-year German government bond yield and the 2-year German government bond yield.

ΔVIX: The change in the implied volatility for the CBOE index.

FF: The change in the effective Federal funds rate.

NBRX: The change in the orthogonalized non-borrowed reserves of U.S. depository institutions with the Federal Reserve. The variable is constructed as follows: Non-borrowed reserves and total reserves are normalized by a 36-month moving average of total reserves. Then, normalized non-borrowed reserves are regressed on normalized total reserves. The residuals from this regression are collected to form the orthogonalized non-borrowed reserves. Non-borrowed reserves are equal to total reserves minus borrowed reserves.

RRX (US): The change in the orthogonalized required reserves of U.S. depository institutions with the Federal Reserve. The method for the calculation of this variable is the same as in the NBRX variable with required reserves replacing non-borrowed reserves. Required reserves are the amount of funds that a depository institution must hold in reserve against specified deposit liabilities.

ERX (US): The change in the orthogonalized excess reserves of U.S. depository institutions with the Federal Reserve. The method for the calculation of this variable is the same as in the NBRX variable with excess reserves replacing non-borrowed reserves. Excess reserves equal total reserve balances less required reserves.

ER/TR: The change in the ratio of excess reserves to total reserves.

RR/TR: The change in the ratio of required reserves to total reserves.

EONIA: The change in the EONIA. The EONIA is computed as a weighted average of the interest rates on euro-denominated unsecured overnight lending transactions, as reported by a panel of contributing banks.

EURO-RATE: The change in a set of interest rates. The method for the calculation of this variable is analyzed in detail in Appendix 3.A.

RRX (EUR): The change in the orthogonalized required reserves of euro area credit institutions with their national central bank. The method for the calculation of this variable is the same as in the NBRX variable with required reserves replacing non-borrowed reserves.

ERX (EUR): The change in the orthogonalized excess reserves of euro area credit institutions with their national central bank. The method for the calculation of this variable is the same as in the NBRX variable with excess reserves replacing non-borrowed reserves.
<table>
<thead>
<tr>
<th></th>
<th>Weekly/Monthly</th>
<th>Agency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER/TR (EUR)</td>
<td></td>
<td>ECB</td>
<td>ER/TR: The change in the ratio of excess reserves to total reserves.</td>
</tr>
<tr>
<td>RR/TR</td>
<td></td>
<td></td>
<td>RR/TR: The change in the ratio of required reserves to total reserves.</td>
</tr>
<tr>
<td>CPI</td>
<td>Weekly/Monthly</td>
<td>Bureau of Labour</td>
<td>The change in the log of CPI.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Europe: The change in the log of the euro area IP Index.</td>
</tr>
<tr>
<td>HICP</td>
<td>Monthly</td>
<td>Eurostat</td>
<td>The change in the log of HICP.</td>
</tr>
</tbody>
</table>

* All percentage changes in the stock and bond indices are expressed in basis points.
Table 3.2
Bai and Perron Test for Structural Breaks

This table presents the results of the Bai and Perron test for the presence of structural breaks for the time series of each of the STOCK, BOND, and CDS. A regression is run for each of the STOCK, BOND, and CDS where each of this variable is regressed on the other two and on a vector of exogenous variables. Then the Bai and Perron test is run. Null hypothesis is that there is a structural break. The Wald test is then performed for the break date for each of the series of the STOCK, BOND, and CDS. Null hypothesis is that there is no structural break. STOCK is the percentage change on the S&P 500 (US) and on the FTSE Eurotop 100 (EUR). BOND is the percentage change on the BofA ML U.S. Corporate Master Index (US) and on the iboxx (EUR). CDS is the change in the spread on Markit CDX (US) and on Markit itraxx (EUR). Exogenous variables include the 10-year government bond yield, the slope of the term structure, and the implied volatility for the CBOE index. Variables are at the daily frequency for the US and Europe during the 2004-2014 period. Data is from Bloomberg and Thomson Reuters and cover the period from September 2004 (US), and from 22 June 2004 (Europe), to 21 May 2014. Panels A and B include results for the US and Europe respectively for the 2004-2014 period. ***, **, and * marks denote statistical significance at the 1, 5, and 10% level, respectively.

### Panel A. USA

<table>
<thead>
<tr>
<th>Break test</th>
<th>STOCK F-statistic</th>
<th>5% critical value</th>
<th>BOND F-statistic</th>
<th>5% critical value</th>
<th>CDS F-statistic</th>
<th>5% critical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 vs. 1</td>
<td>32.8445</td>
<td>25.652</td>
<td>42.1215</td>
<td>39.877</td>
<td>34.0898</td>
<td>35.232</td>
</tr>
<tr>
<td>1 vs. 2</td>
<td>26.1228**</td>
<td>32.481</td>
<td>33.1989**</td>
<td>35.481</td>
<td>26.9860**</td>
<td>24.051</td>
</tr>
<tr>
<td>3 vs. 4</td>
<td>11.4632</td>
<td>15.745</td>
<td>18.4020</td>
<td>19.098</td>
<td>15.0623</td>
<td>18.049</td>
</tr>
</tbody>
</table>

Break date | Chi2 p-value | Chi2 p-value | Chi2 p-value
-----------|--------------|--------------|--------------|
31082008   | 152.1244***  | 0.0000       | 137.0634***  | 0.0000         | 125.9720**     | 0.0025           |

### Panel B. Europe

<table>
<thead>
<tr>
<th>Break test</th>
<th>STOCK F-statistic</th>
<th>5% critical value</th>
<th>BOND F-statistic</th>
<th>5% critical value</th>
<th>CDS F-statistic</th>
<th>5% critical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 vs. 1</td>
<td>27.3201</td>
<td>24.012</td>
<td>36.4320</td>
<td>32.158</td>
<td>37.1508</td>
<td>36.081</td>
</tr>
<tr>
<td>1 vs. 2</td>
<td>20.4501**</td>
<td>21.105</td>
<td>29.2443**</td>
<td>28.212</td>
<td>31.9465**</td>
<td>33.239</td>
</tr>
<tr>
<td>2 vs. 3</td>
<td>17.3277</td>
<td>17.953</td>
<td>24.5402</td>
<td>25.199</td>
<td>27.0589</td>
<td>29.982</td>
</tr>
</tbody>
</table>

Break date | Chi2 p-value | Chi2 p-value | Chi2 p-value
-----------|--------------|--------------|--------------|
31082008   | 134.6410***  | 0.0000       | 152.6845***  | 0.0000         | 139.2992***     | 0.0000           |
This table shows daily and weekly means, standard deviations, minimums, and maximums of STOCK, ΔSTOCK, BOND, ΔBOND, CDS, and ΔCDS. STOCK is price of the S&P 500 (US) and of the FTSE Eurotop 100 (EUR). ΔSTOCK is the percentage change (i.e. the return multiplied by 100) on STOCK. BOND is the price of the BofA ML U.S. Corporate Master Index (US) and of the iBoxx (EUR). ΔBOND is the percentage change (i.e. the return multiplied by 100) on BOND. CDS is the spread on Markit CDX (US) and on Markit iTraxx (Europe). ΔCDS is the change in CDS. Market indices prices and spreads are from Bloomberg and Thomson Reuters and cover the period from September 2004 for the US, and from 22 June 2004 for Europe, to 21 May 2014. Panel A includes descriptive statistics for daily data, and Panel B includes descriptive statistics for weekly data.

### Panel A. Daily Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs.</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>USA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STOCK</td>
<td>2430</td>
<td>1306.7670</td>
<td>231.6565</td>
<td>676.5302</td>
<td>1897.4500</td>
</tr>
<tr>
<td>ΔSTOCK</td>
<td>2429</td>
<td>3.0533</td>
<td>130.2400</td>
<td>-9.0352</td>
<td>11.5809</td>
</tr>
<tr>
<td>BOND</td>
<td>2489</td>
<td>1901.7450</td>
<td>348.1216</td>
<td>1434.9800</td>
<td>2543.7270</td>
</tr>
<tr>
<td>ΔBOND</td>
<td>2488</td>
<td>2.16173</td>
<td>32.21027</td>
<td>-227.9158</td>
<td>198.5459</td>
</tr>
<tr>
<td>CDS</td>
<td>2196</td>
<td>89.7261</td>
<td>42.4450</td>
<td>29.0303</td>
<td>280.4165</td>
</tr>
<tr>
<td>ΔCDS</td>
<td>2195</td>
<td>0.1015</td>
<td>5.1745</td>
<td>-45.5062</td>
<td>122.5000</td>
</tr>
<tr>
<td><strong>Europe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STOCK</td>
<td>2548</td>
<td>2443.7650</td>
<td>401.9015</td>
<td>1411.6500</td>
<td>3377.2000</td>
</tr>
<tr>
<td>ΔSTOCK</td>
<td>2547</td>
<td>1.6951</td>
<td>122.9243</td>
<td>-786.4486</td>
<td>1032.7030</td>
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<td>BOND</td>
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### Panel B. Weekly Data

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<td>81.0250</td>
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<td>404.0824</td>
<td>1420.2100</td>
<td>3370.8100</td>
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<td>51.3333</td>
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Table 3.4
Descriptive Statistics. Pre- and Post-Crisis Periods. Daily Series

This table shows daily means, standard deviations, minimums, and maximums of \( \Delta \text{STOCK} \), \( \Delta \text{BOND} \), \( \Delta \text{CDS} \), and \( \Delta \text{CDS} \) in the US and Europe for the periods 2004-2008 and 2008-2014. \( \text{STOCK} \) is price of the S&P 500 (US) and of the FTSE Eurotop 100 (EUR). \( \Delta \text{STOCK} \) is the percentage change (i.e. the return multiplied by 100) on \( \text{STOCK} \). \( \text{BOND} \) is the price of the BofA ML U.S. Corporate Master Index (US) and of the iboxx (EUR). \( \Delta \text{BOND} \) is the percentage change (i.e. the return multiplied by 100) on \( \text{BOND} \). \( \text{CDS} \) is the spread on Markit CDX (US) and on Markit itraxx (Europe). \( \Delta \text{CDS} \) is the change in \( \text{CDS} \). Market indices prices and spreads are from Bloomberg and Thomson Reuters and cover the period from September 2004 for the US, and from 22 June 2004 for Europe, to 21 May 2014. Panel A includes descriptive statistics for daily data in the US for the pre-crisis (2004-2008) and the post-crisis (2008-2014) periods. Panel B includes descriptive statistics for daily data in Europe for the pre-crisis (2004-2008) and the post-crisis (2008-2014) periods.

Panel A. USA

<table>
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<tr>
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<th>PRE-CRISIS</th>
<th>POST-CRISIS</th>
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</thead>
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<td>Mean</td>
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<td>(\Delta\text{STOCK})</td>
<td>989</td>
<td>1.9226</td>
</tr>
<tr>
<td>BOND</td>
<td>1015</td>
<td>1591.635</td>
</tr>
<tr>
<td>(\Delta\text{BOND})</td>
<td>1014</td>
<td>1.0825</td>
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<td>61.28564</td>
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<tr>
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### Panel B. Europe

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<th>Post-Crisis</th>
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Table 3.5
Johansen Test for Cointegrating Equations

This table presents the results of the Johansen test for the number of cointegrating equations in the equation for the stock market index, the CDS market index, and the bond market index (all in levels). Null hypothesis is that at each rank there are as many cointegrating equations as the number of the rank. Variables are at the daily frequency for the US and Europe during the 2004-2014 period. The stock market index is the value of the S&P 500 (US) and of the FTSE Eurotop 100 (EUR). The CDS market index is the spread on Markit CDX (US) and on Markit iTraxx (EUR). The bond market index is the value of the BofA ML U.S. Corporate Master Index (US) and the iBoxx (EUR). Data is from Bloomberg and Thomson Reuters and cover the period from September 2004 (US), and from 22 June 2004 (Europe), to 21 May 2014. Panels A and B include results for the US and Europe respectively for the 2004-2014 period. ** mark denotes statistical significance at the 5% level.

Panel A. USA

<table>
<thead>
<tr>
<th>Maximum rank</th>
<th>Log-likelihood</th>
<th>Eigenvalue</th>
<th>Trace statistic</th>
<th>5% critical value</th>
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<td>42.3988</td>
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<td>3</td>
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<td>0.0944</td>
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Panel B. Europe

<table>
<thead>
<tr>
<th>Maximum rank</th>
<th>Log-likelihood</th>
<th>Eigenvalue</th>
<th>Trace statistic</th>
<th>5% critical value</th>
</tr>
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<tbody>
<tr>
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</table>
Table 3.6 presents the coefficients (row 1) and the corresponding p-values (row 2) of the endogenous VAR variables at the daily frequency for the US and Europe during the 2004-2008 and 2008-2014 periods. The ordering of the VAR variables is STOCK, CDS, BOND. STOCK is the percentage change on the S&P 500 (US) and on the FTSE Eurotop 100 (EUR). CDS is the change in the spread on Markit CDX (US) and on Markit itraxx (EUR). BOND is the percentage change on the BofA ML U.S. Corporate Master Index (US) and on the iboxx (EUR). Data is from Bloomberg and Thomson Reuters and cover the period from September 2004 (US), and from 22 June 2004 (Europe), to 21 May 2014. Panels A and B include results for the US for 2004-2008 and 2008-2014 respectively. Panels C and D include results for Europe for 2004-2008 and 2008-2014 respectively. The Table further presents the Jarque-Bera test for normally distributed residuals and the Lagrange-multiplier test for autocorrelation of residuals at different lag order. ***, **, and * marks denote statistical significance at the 1, 5, and 10% level, respectively.

<table>
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<th>CDS</th>
<th>BOND</th>
</tr>
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<td>STOCK (t-1)</td>
<td>0.0671*** (0.0248)</td>
<td>-1.838*** (0.305)</td>
<td>-0.0653** (0.0310)</td>
</tr>
<tr>
<td>STOCK (t-2)</td>
<td>-0.0653** (0.0310)</td>
<td>0.184* (0.0974)</td>
<td>0.0430* (0.0238)</td>
</tr>
<tr>
<td>STOCK (t-3)</td>
<td>0.294*** (0.0973)</td>
<td>0.791** (0.354)</td>
<td>0.0520** (0.0260)</td>
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<tr>
<td>STOCK (t-4)</td>
<td>0.184* (0.0974)</td>
<td>0.261*** (0.0964)</td>
<td>0.0520** (0.0260)</td>
</tr>
<tr>
<td>STOCK (t-5)</td>
<td>0.0656** (0.0271)</td>
<td>-0.0170** (0.00807)</td>
<td>0.130*** (0.0264)</td>
</tr>
<tr>
<td>STOCK (t-6)</td>
<td>-0.0763*** (0.0290)</td>
<td>0.0230*** (0.00886)</td>
<td>-0.166* (0.0933)</td>
</tr>
<tr>
<td>STOCK (t-7)</td>
<td>0.0656** (0.0271)</td>
<td>-0.0235*** (0.00786)</td>
<td>0.0656** (0.0271)</td>
</tr>
<tr>
<td>STOCK (t-8)</td>
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<td>0.0217*** (0.00795)</td>
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</tr>
<tr>
<td>STOCK (t-9)</td>
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<td>-0.177** (0.0740)</td>
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<td>CDS (t-1)</td>
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<td>0.261*** (0.0964)</td>
<td>0.0520** (0.0260)</td>
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<tr>
<td>CDS (t-2)</td>
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<td>0.0230*** (0.00886)</td>
<td>0.0656** (0.0271)</td>
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<tr>
<td>CDS (t-3)</td>
<td>0.261*** (0.0964)</td>
<td>-0.0235*** (0.00786)</td>
<td>0.0656** (0.0271)</td>
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<td>CDS (t-4)</td>
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<td>-0.177** (0.0740)</td>
<td>0.0656** (0.0271)</td>
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<tr>
<td>CDS (t-6)</td>
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<td>-0.0170** (0.00807)</td>
<td>0.130*** (0.0264)</td>
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<tr>
<td>CDS (t-7)</td>
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<td>0.0230*** (0.00886)</td>
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<td>BOND (t-4)</td>
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<td>BOND (t-6)</td>
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Lagrange-multiplier for Autocorrelation of Residuals
(H0: no autocorrelation at lag order)

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<td>(0.746)</td>
<td></td>
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</tr>
<tr>
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CDS (t-8)  
-0.0214*  
(0.0125)  
-0.0585***  
(0.0202)  
BOND (t-1)  
-0.442**  
(0.220)  
BOND (t-2)  
0.316**  
(0.135)  
-0.466**  
(0.219)  
BOND (t-3)  
BOND (t-4)  
BOND (t-5)  
BOND (t-6)  
BOND (t-7)  
BOND (t-8)  
0.0613*  
(0.0371)  
Observations  
1,478  
1,478  
1,478  
RMSE  
0.01321  
0.09128  
0.04562  
R-squared  
0.5404  
0.5387  
0.4944  
Jarque-Bera Normality Test  
4.132  
(0.165)  
2.959  
(0.224)  
2.265  
(0.248)  
Lagrange-multiplier for Autocorrelation of Residuals  
(H0: no autocorrelation at lag order)  
Lag 1 chi-squared: 5.1452  
(0.797)  
Lag 2 chi-squared: 6.1567  
(0.611)  
Lag 3 chi-squared: 6.1240  
(0.619)  
Lag 4 chi-squared: 4.9830  
(0.851)  
Lag 5 chi-squared: 8.5414  
(0.397)  
Lag 6 chi-squared: 7.1415  
(0.595)  
VARIABLES STOCK CDS BOND  
STOCK (t-1) -0.0803**  
(0.0320)  
-0.947***  
(0.0943)  
0.0115***  
(0.00212)  
STOCK (t-2)  
STOCK (t-3)  
STOCK (t-4)  
STOCK (t-5)  
STOCK (t-6)  
STOCK (t-7)  
STOCK (t-8)  
CDS (t-1)  
-0.00333***  
(0.00228)
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<th>(t-7)</th>
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<td>2.989 (0.232)</td>
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<td>BOND (t-9)</td>
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Observations: 1,579
RMSE: 0.09561
R-squared: 0.4180

Jarque-Bera Normality Test
(H0: Normally Distributed Residuals)
4.658 (0.146)
2.967 (0.202)
2.598 (0.290)

Lagrange-multiplier for Autocorrelation of Residuals
(H0: no autocorrelation at lag order)
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<td>8.6562 (0.318)</td>
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Table 3.7
Granger Causality Tests. Daily Series

Table 3.7 presents $x^2$ statistics (row 1) and the corresponding $p$-values (row 2) of pair-wise Granger causality tests between endogenous VAR variables at the daily frequency for the US and European markets pre- and post-crisis. Null hypothesis is that row variable does not Granger cause column variable. The ordering of the panel VAR endogenous variables is STOCK, CDS, BOND. STOCK is the percentage change on the S&P 500 (US) and on the FTSE Eurotop 100 (EUR). CDS is the change in the spread on Markit CDX (US) and on Markit iTraxx (EUR). BOND is the percentage change on the BofA ML U.S. Corporate Master Index (US) and on the Iboxx (EUR). Market indices prices and spreads are from Bloomberg and Thomson Reuters and cover the period from September 2004 for the US, and from 22 June 2004 for Europe, to 21 May 2014. Panel 1 and 2 include results for daily data in the US and Europe respectively. ***, **, and * marks denote statistical significance at the 1, 5, and 10% level, respectively.

Panel A. USA

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<tr>
<td>STOCK</td>
<td>44.689***</td>
<td>107.08***</td>
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<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
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<td>CDS</td>
<td>53.604***</td>
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<td>(0.000)</td>
<td>(0.185)</td>
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<td>BOND</td>
<td>6.569</td>
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<td>(0.765)</td>
<td>(0.261)</td>
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Panel B. Europe

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<tr>
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<tr>
<td>STOCK</td>
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<tr>
<td>STOCK</td>
<td>111.32***</td>
<td>297.58***</td>
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<td>(0.000)</td>
<td>(0.000)</td>
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<tr>
<td>CDS</td>
<td>9.5784</td>
<td>20.616**</td>
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<td>(0.296)</td>
<td>(0.014)</td>
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<tr>
<td>BOND</td>
<td>3.8362</td>
<td>14.673</td>
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<td>(0.872)</td>
<td>(0.100)</td>
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Table 3.8
VAR Results. Robustness Analysis

Table 3.8 presents the coefficients (row 1) and the corresponding \( p \)-values (row 2) of the endogenous and exogenous VAR variables at the weekly frequency for the US and European markets during the 2004-2008 and 2008-2014 periods. The ordering of the panel VAR endogenous variables is STOCK, CDS, BOND. STOCK is the percentage change on the S&P 500 (US) and on the FTSE Eurotop 100 (EUR). CDS is the change in the spread on Markit CDX (US) and on Markit iTraxx (EUR). BOND is the percentage change on the BofA ML U.S. Corporate Master Index (US) and on the iBoxx (EUR). Exogenous variables are placed at the end of the VAR ordering and include the 10-year government bond yield, the slope of the term structure, and the implied volatility for the CBOE index. Market indices prices and spreads are from Bloomberg and Thomson Reuters and cover the period from September 2004 for the US, and from 22 June 2004 for Europe, to 21 May 2014. Panels 1 and 2 include results for weekly data in the US for 2004-2008 and 2008-2014 respectively. Panels 3 and 4 include results for weekly data in Europe for 2004-2008 and 2008-2014 respectively. The Table further presents the Jarque-Bera test for normally distributed residuals and the Lagrange-multiplier test for autocorrelation of residuals at different lag order. ***, **, and * marks denote statistical significance at the 1, 5, and 10% level, respectively.

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<td>-0.340***</td>
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<td><strong>STOCK (t-2)</strong></td>
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<td>0.0352**</td>
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<td><strong>STOCK (t-3)</strong></td>
<td>0.0352**</td>
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<td><strong>STOCK (t-4)</strong></td>
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<td>0.0705***</td>
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<td><strong>CDS (t-1)</strong></td>
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<td>-0.0116**</td>
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<td><strong>CDS (t-4)</strong></td>
<td>-0.00890*</td>
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<td><strong>BOND (t-3)</strong></td>
<td>-0.102**</td>
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<td><strong>BOND (t-4)</strong></td>
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<td>27.98***</td>
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<td>-0.0659***</td>
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Lagrange-multiplier for Autocorrelation of Residuals
(H0: no autocorrelation at lag order)
Panel 2. 2008-2014. US

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<td>-0.840*** (0.184)</td>
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<td>STOCK (t-4)</td>
<td>-0.614*** (0.188)</td>
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<td>STOCK (t-5)</td>
<td>0.142** (0.0581)</td>
<td>0.327* (0.192)</td>
<td>-0.0364** (0.0171)</td>
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<td>STOCK (t-6)</td>
<td>0.157*** (0.0579)</td>
<td>-0.791*** (0.191)</td>
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<td>-0.0129** (0.00507)</td>
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<td>-0.00839* (0.00505)</td>
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<td>-0.00828* (0.00468)</td>
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<td>BOND (t-1)</td>
<td>0.956*** (0.206)</td>
<td>-1.498** (0.681)</td>
<td>-0.240*** (0.0606)</td>
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<tr>
<td>BOND (t-2)</td>
<td>0.315* (0.179)</td>
<td>0.158*** (0.0526)</td>
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<td>BOND (t-3)</td>
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<td>BOND (t-4)</td>
<td>0.0910* (0.0519)</td>
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Jarque-Bera Normality Test
(H0: Normally Distributed Residuals)

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Lagrange-multiplier for Autocorrelation of Residuals
(H0: no autocorrelation at lag order)

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\[ \Delta \text{GDBR} \quad 32.45^{***} \]
\[ \text{EURSLOPE} \quad -12.72^{**} \]
\[ \text{VIX} \quad -0.760^{***} \quad 1.423^{***} \quad 0.0288^{*} \quad (0.0658) \quad (0.225) \quad (0.0173) \]

Constant

Observations 211
RMSE 0.01561 0.07844 0.06974
R-squared 0.04078 0.4988 0.5081

Jarque-Bera Normality Test

\begin{tabular}{lcc}
Constant & Observations & RMSE & R-squared & Jarque-Bera Normality Test (H0: Normally Distributed Residuals) \\
& & & & \\
211 & 0.01561 & 0.07844 & 0.06974 & 0.4078 & 0.5081 & 3.357 \\
\end{tabular}

Lagrange-multiplier for Autocorrelation of Residuals (H0: no autocorrelation at lag order)

\begin{tabular}{lcc}
Lag 1 & Lag 2 & Lag 3 \\
(0.594) & (0.381) & (0.197) \\
Lag 4 & Lag 5 & Lag 6 \\
(0.241) & (0.484) & (0.463) \\
\end{tabular}


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Lagrange-multiplier for Autocorrelation of Residuals
(H0: no autocorrelation at lag order)

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Table 3.9
Granger Causality Tests. Weekly Series

Table 3.9 presents $x^2$ statistics (row 1) and the corresponding $p$-values (row 2) of pair-wise Granger causality tests between endogenous VAR variables at the weekly frequency for the US and European markets pre- and post-crisis. Null hypothesis is that row variable does not Granger cause column variable. The ordering of the panel VAR endogenous variables is STOCK, CDS, BOND. STOCK is the percentage change on the S&P 500 (US) and on the FTSE Eurotop 100 (EUR). CDS is the change in the spread on Markit CDX (US) and on Markit itraxx (EUR). BOND is the percentage change on the BofA ML U.S. Corporate Master Index (US) and on the iboxx (EUR). Exogenous variables are placed at the end of the VAR ordering and include the 10-year government bond yield, the slope of the term structure, and the implied volatility for the CBOE index. Market indices prices and spreads are from Bloomberg and Thomson Reuters and cover the period from September 2004 for the US, and from 22 June 2004 for Europe, to 21 May 2014. Panels A and B include results for weekly data in the US and Europe respectively for the pre-crisis (2004-2008) and the post-crisis (2008-2014) periods. ***, **, and * marks denote statistical significance at the 1, 5, and 10% level, respectively.

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Table 3.10
Granger Causality Tests. Macroeconomic Variables

Table 3.10 presents $x^2$ statistics (row 1) and the corresponding $p$-values (row 2) of pair-wise Granger causality tests between endogenous VAR variables at the weekly frequency for the US and European markets pre- and post-crisis. Null hypothesis is that row variable does not Granger cause column variable. The ordering of the VAR endogenous variables in the examination for Europe is IP, HICP, EONIA (alternatively EURORATE), ER/TR (alternatively ERX), STOCK, CDS, BOND. STOCK is the percentage change in basis points in the S&P 500 (US) and in the FTSE Eurotop 100 (EUR). CDS is the change in the spread on Markit CDX (US) and on Markit iTraxx (EUR). BOND is the percentage change in basis points in the BofA ML U.S. Corporate Master Index (US) and in the iBoxx (EUR). IP is the Industrial Production and Capacity Utilization index (Europe) and Industrial Production index (US). HICP is the Harmonized Index of Consumer Prices. CPI is the CPI inflation. EONIA is the EONIA rate. EURORATE is a basket of weekly interest rate data including the EONIA, the EONIA-swap with maturities of one-week, one, two and three-months, and the closest three-month EURIBOR futures. FED is the Federal funds effective rate. ER/TR is the mix between excess and total reserves. NBRX is the orthogonalized non-borrowed reserves. ERX is the orthogonalized excess reserves. Market indices prices and spreads are from Bloomberg, and Thomson Reuters. Data on industrial production, inflation, money market rates, and aggregate reserves are from the ECB, the Federal Bank of New York, the Federal Bank of St. Louis, and Thomson Reuters. The examination period is from September 2004 for the US, and from 22 June 2004 for Europe, to 21 May 2014. Panels A and B include results for weekly data in the US and Europe respectively for the pre-crisis (2004-2008) and the post-crisis (2008-2014) periods. ***, **, and * marks denote statistical significance at the 1, 5, and 10% level, respectively.

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<td>(0.284)</td>
<td>(0.367)</td>
<td>(0.007)</td>
</tr>
<tr>
<td></td>
<td>(0.014)</td>
<td>(0.000)</td>
<td>(0.267)</td>
<td>(0.139)</td>
<td>(0.181)</td>
<td>(0.066)</td>
</tr>
</tbody>
</table>
Figure 3.1

Daily Time-Series of Market Indices

This Figure presents the daily time-series of the Stock, Bond, and CDS indices in the US and Europe for the 2004-2014 period. Graph A presents the daily time-series of the price level of the S&P 500 and of the BofA ML U.S. Corporate Master Index, and of the spread level of the Markit CDX over the 2004-2014 period (the Markit CDX is scaled up by 10 to enhance comparability between the indices). Graph B presents the daily time-series of the price of the FTSE Eurotop 100 and of the Iboxx, and of the spread level of Markit iTraxx over the 2004-2014 period (the Iboxx, and the Markit iTraxx are scaled up by 10 to enhance comparability between the market indices). Market indices prices and spreads are from Bloomberg and Thomson Reuters and cover the period from September 2004 for the US, and from 22 June 2004 for Europe, to 21 May 2014.

Graph A. USA

CDX is scaled up by 10.

Graph B. Europe

Iboxx, and iTraxx are scaled up by 10.
Figure 3.2  
Response to Endogenous Macroeconomic Variables  
**Graph A. Response of US Market Indices to Macroeconomic Shocks. Pre-Crisis. Weekly Series**  

**Stock Index**
- Response of STOCK to CPI
- Response of STOCK to IP
- Response of STOCK to FED
- Response of STOCK to NBRX

**Bond Index**
- Response of BOND to CPI
- Response of BOND to IP
- Response of BOND to FED
- Response of BOND to NBRX

**CDS Index**
- Response of CDS to CPI
- Response of CDS to IP
- Response of CDS to FED
- Response of CDS to NBRX
Graph B. Response of European market indices to macroeconomic shocks. Pre-Crisis. Weekly Series

**Stock Index**

- Response of STOCK to HICP
- Response of STOCK to IP
- Response of STOCK to EONIA
- Response of STOCK to ER/TR

**Bond Index**

- Response of BOND to HICP
- Response of BOND to IP
- Response of BOND to EONIA
- Response of BOND to ER/TR

**CDS Index**

- Response of CDS to HICP
- Response of CDS to IP
- Response of CDS to EONIA
- Response of CDS to ER/TR

Stock Index

- Response of STOCK to CPI
- Response of STOCK to IP
- Response of STOCK to FED
- Response of STOCK to NBRX

Bond Index

- Response of BOND to CPI
- Response of BOND to IP
- Response of BOND to FED
- Response of BOND to NBRX

CDS Index

- Response of CDS to CPI
- Response of CDS to IP
- Response of CDS to FED
- Response of CDS to NBRX
Graph D. Response of European Market Indices to Macroeconomic Shocks. Post-Crisis. Weekly Series

Stock Index

- Response of STOCK to HICP
- Response of STOCK to IP
- Response of STOCK to EONIA
- Response of STOCK to ER/TR

Bond Index

- Response of BOND to HICP
- Response of BOND to IP
- Response of BOND to EONIA
- Response of BOND to ER/TR

CDS Index

- Response of CDS to HICP
- Response of CDS to IP
- Response of CDS to EONIA
- Response of CDS to ER/TR
Figure 3.3
Response to Endogenous Monetary Variables


Supply Shock

FULL RESTRICTED VAR

Response of BOND to Supply Shock.

Response of CDS to Supply Shock.

NO SHOCK THROUGH THE STOCK MARKET

Response of BOND to Supply Shock.

Response of CDS to Supply Shock.

Demand Shock

FULL RESTRICTED VAR

Response of BOND to Demand Shock.

Response of CDS to Demand Shock.

NO SHOCK THROUGH THE STOCK MARKET

Response of BOND to Demand Shock.

Response of CDS to Demand Shock.
Monetary Policy Shock


Supply Shock
Demand Shock

FULL RESTRICTED VAR

Response of BOND to Demand Shock.

Response of CDS to Demand Shock.

MONETARY POLICY SHOCK

Response of BOND to Demand Shock.

Response of CDS to Demand Shock.

Full Restricted VAR

Response of BOND to Monetary Policy Shock.

Response of CDS to Monetary Policy Shock.

No Shock Through the Stock Market

Response of BOND to Monetary Policy Shock.

Response of CDS to Monetary Policy Shock.
Appendix 3.A

Principal Components Analysis and information on the calculation of the EURORATE interest rate variable

Principal components analysis (PCA) captures the common variation pattern from a set of time series in the form of one or more linear combinations. The aim is to summarize in one variable the information context of a set of interest rates. This is feasible by estimating the eigenvectors and eigenvalues from the variance-covariance matrix of our set of interest rates. The eigenvectors form linear combinations of the set of interest rates and the eigenvalues indicate the proportion of total variance explained by each combination. These combinations, also termed principal components, are then ranked according to their contribution to the total variance of the original set of interest rates. In this chapter we are interested in that combination which is able to better capture the common variation of the EONIA times series and the EURIBOR future; thus, only the first principal component is selected. Before proceeding to the PCA all interest rates are standardized in order to prevent the most volatile rate from dominating the analysis. The following method can be found in Perez-Quiros and Sicilia (2002).

In particular, the selected set of interest rates includes: weekly and monthly changes in the EONIA, the EONIA swap of 1 week, 1 month, 2 months, and 3 months and the EURIBOR future of 3 months. We form a vector \( X = (X_{1t}, X_{2t}, X_{3t}, X_{4t}, X_{5t}, X_{6t}) \), where

\[
X_{1t} = \text{The EONIA rate.}
\]

\[
X_{2t} = \text{The 1-week EONIA swap.}
\]

\[
X_{3t} = \text{The 1-month EONIA swap.}
\]

\[
X_{4t} = \text{The 2-month EONIA swap.}
\]

\[
X_{5t} = \text{The 3-month EONIA swap.}
\]

\[
X_{6t} = \text{The 3-month EURIBOR future.}
\]

The interest rates are grouped into four vectors:

\( \text{PC}_{\text{short}} \), which includes the EONIA, the 1-week EONIA swap, and the 1-month EONIA swap.
$PC_{\text{long}}$, which includes the 2-month EONIA swap, the 3-month EONIA swap, and the 3-month EURIBOR future.

$PC_{\text{all}}$, which includes all 6 interest rates.

$PC_{\text{no--eonia}}$, which is equal to $PC_{\text{all}}$ without the EONIA.

The combination that captures best the common variation in the vector $\mathbf{X}$ of interest rates is the combination $PC_j$, such that $PC_j = XC_j$, where $j = 1, \ldots, 4$ and stands for $PC_{\text{short}}$, $PC_{\text{long}}$, $PC_{\text{all}}$, and $PC_{\text{no--eonia}}$, and $C$ is a (6x1) vector.

For the calculation of the value of the vector $C$ a maximisation problem is solved subject to the fact that the weights must add to one. This results in a vector $C = (C_1, C_2, C_3, C_4, C_5, C_6)$, which is the characteristic vector associated with the highest eigenvalue of $XX'$.

The estimated weights of the series are:

$C_{\text{short}} = (0.2416, 0.6837, 0.6886, 0.0000, 0.0000, 0.0000)$

$C_{\text{long}} = (0.0000, 0.0000, 0.0000, 0.6658, 0.6728, 0.3225)$

$C_{\text{all}} = (0.1079, 0.3955, 0.5173, 0.508, 0.528, 0.1653)$

$C_{\text{no--eonia}} = (0.5192, 0.3978, 0.5112, 0.208, 0.203, 0.183)$
Appendix 3.B

VAR with sign restrictions

Given a VAR specified as:

\[ Y_t = c + \sum_{i=1}^{p} B_i Y_{t-i} + u_t, \tag{B3.1} \]

where \( Y_t \) is a \( m \times 1 \) vector, at time \( t = 1, \ldots, T \), \( B_i \) are coefficient matrices of size \( m \times m \) with \( i = 1, \ldots, p \), and \( u_t \) is the one-step ahead prediction error. The innovation of the specific method, is the decomposition of the prediction error \( u_t \) into economically meaningful or fundamental innovations. If there are \( e \) a total of \( m \) independent and normalized with variance 1, fundamental innovations can be written as a vector \( \nu \) of size \( m \times 1 \) with \( E[\nu\nu'] = I_m \). By adopting the independence assumption, we need to find a matrix \( A \) such that \( u_t = Av_t \). The only restriction imposed on \( A \) is:

\[ \Sigma = E[u_t u_t'] = E[\nu_t \nu_t']A' = AA', \tag{B3.2} \]

where \( \Sigma \) is the variance-covariance matrix of the prediction error, \( u_t \).

In order to find the innovation corresponding to a monetary policy shock, Uhlig (2005) identifies a single column \( \alpha \in \mathbb{R}^m \) of the matrix \( A \) in equation (B3.2). This vector \( \alpha \in \mathbb{R}^m \) is called an impulse vector, if and only if there is a matrix \( A \), such that \( AA' = \Sigma \) and so that \( \alpha \) is a column of \( A \). If \( AA' = \Sigma \) is the Cholesky decomposition of \( \Sigma \), then \( \alpha \) is an impulse vector if and only if there is an \( m \)-dimensional vector \( \alpha \) of unit length so that \( \alpha = Aa \). Then given an impulse vector \( a \), the appropriate impulse response is calculated by letting \( r_i(k) \in \mathbb{R}^m \) be the vector response at horizon \( k \) to the \( i \)th shock in a Cholesky decomposition of \( \Sigma \). Hence, the impulse response \( r_\alpha(k) \) for \( \alpha \) is given by:

\[ r_\alpha(k) = \sum_{i=1}^{m} a_i r_i(k). \tag{B3.3} \]

For a vector \( \tilde{b} \neq 0 \) with \( (\Sigma - \alpha\alpha')\tilde{b} = 0 \) normalized so that \( b'\alpha = 1 \), the real number \( \nu_\alpha^{(a)} = b'u_t \) is the scale of the shock at date \( t \) in the direction of the impulse vector \( \alpha \), and \( \nu_\alpha^{(a)} \) is a part of \( u_t \), which is attributable to that impulse vector. Hence, \( b \) is the appropriate row of \( A^{-1} \). The above proposition along with the proof is included in Uhlig (2005).

\[ ^{65} \text{The VAR specification, the proposition and the associated information are taken from Uhlig (2005).} \]
Below are the sign restrictions imposed on the VAR in the case of: a) a supply shock, b) a demand shock, c) a monetary policy shock. In each matrix, the first column refers to the first period from which the restriction is imposed, the second column refers to the last period to which the restriction is imposed, and the third column defines the sign of the restriction. The first model is the full restricted VAR, i.e., the shock is transmitted to the stock market and then indirectly to the bond and CDS markets (without excluding any direct transmission of the shock to bond and CDS markets). The second model is the restricted VAR without restrictions on the stock market, i.e., the shock is transmitted directly to the bond and CDS markets and not indirectly through the stock market.

### Supply Shock

**VAR with Full Restrictions**

\[
\begin{array}{ccc}
1 & 2 & -1 \\
1 & 2 & -1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
\end{array}
\]

**VAR with no Shock through the Stock Market**

\[
\begin{array}{ccc}
1 & 2 & -1 \\
1 & 2 & -1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
\end{array}
\]

---

### Demand Shock

**VAR with Full Restrictions**

\[
\begin{array}{ccc}
1 & 2 & 1 \\
1 & 2 & 1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
\end{array}
\]

**VAR with no Shock through the Stock Market**

\[
\begin{array}{ccc}
1 & 2 & 1 \\
1 & 2 & 1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
\end{array}
\]

---

### Monetary Policy Shock

**VAR with Full Restrictions**

\[
\begin{array}{ccc}
1 & 2 & -1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
\end{array}
\]

**VAR with no Shock through the Stock Market**

\[
\begin{array}{ccc}
1 & 2 & -1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
1 & 2 & -1 \\
1 & 2 & 1 \\
\end{array}
\]
Chapter II

Sovereign Bond and CDS Market Liquidity. Arbitrage Activities and Central Bank Interventions
4.1. Introduction

“The notion that financial assets can always be sold at prices close to their fundamental values is built into most economic analysis, and before the crisis, the liquidity of major markets was often taken for granted by financial market participants and regulators alike. The crisis showed, however, that risk aversion, imperfect information, and market dynamics can scare away buyers and badly impair price discovery”

(Bernanke, 2010)

Liquidity, defined as the ease of trading a security without affecting its price, is a fundamental concept in finance and thus incorporated into a number of asset pricing models (Amihud et al., 2005). In this respect, fluctuations in market liquidity affect real and financial investment decisions, causing investors to demand higher returns for less liquid assets. However, as the recent financial crisis revealed, in the event of extreme market conditions liquidity can drastically decrease or dry-up. Such liquidity shocks constitute a potential channel through which financial asset prices are linked by liquidity, thereby giving rise to phenomena of liquidity comovements. These liquidity dry-ups and the resulting liquidity comovements act as impediments to trade and consequently investment, thereby hampering the efficient allocation of risk and capital across the economy; they thus ultimately pose a threat to financial market stability. The liquidity-induced interaction between financial assets is also supported by theoretical approaches which support the notion that the liquidities of different assets

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66 Those models include among others, the capital asset pricing model (CAPM), the arbitrage pricing theorem (APT), the consumption CAPM, and the international CAPM. A discussion on the concept of liquidity and the sources of liquidity is provided in Section 2.4.

display comovements. These comovements are of time-variant nature and can be the outcome of supply shocks related to funding constraint of financial intermediaries (Coughenour and Saad, 2004; Hameed et al., 2010), demand shocks related to international and institutional investors' trading behaviour (Chordia et al., 2000; Hasbrouck and Seppi, 2001; Kamara et al., 2008; Koch et al., 2009), to the incentives to trade individual securities (Morck et al., 2000), as well as to changes in the investor sentiment (Huberman and Halka, 2001).

However, liquidity comovements also arise due to shocks specific to the liquidity supply in one asset class propagating to other asset classes. According to the liquidity propagation mechanism (see Cespa and Foucault, 2014), a drop in the liquidity of one asset causes that asset's price to become less informative for liquidity providers in the other asset, thereby causing the other asset's liquidity to drop as well; the end result is that the liquidity of those two assets becomes interconnected. Leaving aside market-wide factors, this propagation of liquidity from one asset to the other mainly occurs through market-making activities and arbitrage activities (Pelizzon et al., 2015). While the former type of activities is pertinent to all types of assets and drives liquidity transmission through changes in the quoted bid-ask spreads or the quoted quantity, arbitrage activities pertain only to those assets linked via arbitrage, such as a derivative and the underlying security: when a deviation from the equilibrium level occurs, arbitrage activity restores the no-arbitrage condition.

This chapter investigates the liquidity comovements between the bond and CDS markets through changes in the bid-ask spreads focusing on the no-arbitrage relationship between those markets, i.e., the CDS-bond basis, the role of which helps identify whether the movements in liquidity

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68 For an excellent survey see Amihud et al. (2005), and Vayanos and Wang (2012).

69 A detailed analysis of the sources of liquidity comovements is provided in Section 2.4. Additional information can be found in Karolyi et al. (2012).

70 See Chordia et al. (2005) and Goyenko and Ukhov (2009) for an empirical examination of liquidity propagation between the US stock and bond markets.

71 This liquidity propagation mechanism is discussed in detail in Section 2.4.
arise from a change in the information available to investors or from the actions of arbitrageurs.\textsuperscript{72} The analysis is in the context of the European and US sovereign markets, taking into account the recent financial and the European sovereign debt crises. This allows for the further examination of the impact of central banks' non-conventional policy actions, as well as of the naked CDS ban - that targeted specifically the government bond and CDS markets in Europe - and thus serve as natural experiments for the examination of the liquidity movements between the two assets. To my knowledge, this is the first study that investigates the liquidity dynamics between sovereign bonds and CDSs and how these dynamics relate to arbitrage activities and also to the actions of central banks and regulatory authorities.

The examination of liquidity is of considerable relevance since it has evolved into a factor sufficient to trigger or aggravate a crisis giving rise to the phenomenon commonly referred to as flight-to-liquidity (Beber et al., 2009). Most importantly, illiquidity is a fundamental feature of the recent financial crisis and the European sovereign debt crisis.\textsuperscript{73} During the US-originated crisis the stoppage in interbank market lending and the collapse in the asset-backed and mortgage-backed securities markets caused liquidity to dry up; as the crisis intensified, most of the decline in bank credit production was attributed to liquidity risk exposure (see Cornett et al. (2011) for evidence). The immediate regulatory reaction to the crisis was the imposition of bans on short-selling, which resulted in an additional disruption in liquidity (Beber and Pagano, 2013).

In Europe, the financial and macroeconomic imbalances of the periphery states, i.e., Greece, Ireland, Italy, Portugal, and Spain, were reflected in rising spreads on those states' sovereign bonds. The strong interdependence between banks and the heavy cross-border exposure to sovereign debt induced the transmission of sovereign default risk to the banking sector and then across the Eurozone.\textsuperscript{74} However, despite that the roots of the Euro debt crisis can be found in the imbalances

\textsuperscript{72} More information on the CDS-bond basis is provided in Section 2.3.

\textsuperscript{73} Earlier events include the Russian bond default, the fall of Long-Term Capital Management.

\textsuperscript{74} Note that the term Eurozone is used by most authors and commentators synonymously with the term EMU, which stands for Economic and Monetary Union. In the present Thesis the two terms are used interchangeably.
inherent in the financial and macroeconomic position of the periphery states, the speculative attacks launched by investors via the CDS market were considered by EU officials as the driving force behind the liquidity dry-up in the European sovereign debt markets. Regulatory authorities in Europe also responded with a ban on short selling, giving rise to a central policy debate over the impact of naked CDSs on the liquidity of the underlying sovereign bond market. 75

Hence, the European sovereign debt crisis provides the ideal setting for the examination of liquidity interaction across assets, with the sovereign bond and CDS markets emerging as the most suitable candidates since not only they are linked via a no-arbitrage condition, but also due to the sovereign bond-CDS interaction being at the crux of the Eurozone crisis. 76 Their candidacy is further reinforced by the fact that they have been continuously exposed to changes in the information set, as well as to fiscal- and macroeconomic-related shocks mainly due to the heightened market uncertainty and the fiscal developments during the Eurozone crisis.

In addition, the bond-CDS pair has also been the target of an unprecedented series of interventions carried by a central bank within the European context. With the aim of injecting liquidity in the sovereign bond market and restore the trust in the economy and the private sector the ECB intervened directly in the sovereign bond market primarily through the Securities Markets Programme (SMP), as well as indirectly through the Long-Term Refinancing Operations (LTROs). 77

In reality, these two technical terms differ slightly. On January 1, 1999, all 15 EU countries were members of EMU, however only 11 became members of the Eurozone.

75 As stipulated in the legislative act, naked is the purchase of CDSs “without having a long position in underlying sovereign debt or any assets, portfolio of assets, financial obligations or financial contracts the value of which is correlated to the value of the sovereign debt”. More details can be found in Regulation (EU) No 236/2012.

76 The difference between the bond yield over the LIBOR/swap rate should be approximately equal to the CDS spread (assuming equal maturities); if it is more than this, arbitrageurs profit by buying the bond and buying protection. More information is provided in Section 2.3 and in Appendix 5.A

77 A presentation of the ECB's non-standard monetary policy measures is provided in Section 2.6.1.
Thus, the ECB interventions should inevitably have affected the liquidity mechanics between the European sovereign bond and CDS markets.\textsuperscript{78} However, the European sovereign debt crisis is not the only case where monetary policy has been employed to restore liquidity in the financial markets. In response to the US-originated liquidity crunch, the Federal Reserve unleashed its Quantitative Easing (QE) programme, which involved the purchase of long-term securities through an increase in reserve balances; since reserve balances are a more liquid asset than long-term securities, QE aimed at increasing liquidity in the hands of investors, thereby decreasing the liquidity premium on the most liquid bonds (Krishnamurthy and Vissing-Jorgensen, 2012).\textsuperscript{79}

Therefore, the examination of the sovereign bond-CDS liquidity dynamics within the US context is of particular relevance, especially when considering that QE2 (November 2010 - June 2011) targeted specifically the government bond market, by involving only Treasury purchases, thus exerting a substantial impact on Treasury rates (ibid).\textsuperscript{80} Furthermore, the ECB has also introduced (effective from March 2015) its massive €1.1 trillion QE programme, which primarily involves the purchase of euro area central government bonds, so a firm understanding of the mechanisms affecting market liquidity in the sovereign debt and credit derivatives markets is essential. This understanding is also required given that ultimately the unconventional monetary policy measures of the ECB and the Fed will cease, giving their place to conventional measures.

The results of this chapter's empirical analysis suggest that sovereign bond liquidity exerts a stronger and longer-lasting impact on the liquidity of the sovereign CDS market than the reverse. Liquidity linkages are found to be stronger in the European North, where shocks to the liquidity of the CDS market also appear able to induce movements in bond illiquidity (even of a limited size), while in the European South, liquidity shocks stemming from the CDS market appear to exert a rather

\textsuperscript{78} For an analysis of how non-standard monetary policy is transmitted to financial markets see Section 2.6.2

\textsuperscript{79} Additional information about the Federal Reserve's QE programmes can be found in Section 2.6.1.

\textsuperscript{80} According to the October 8 2010 Federal Open Market Committee (FOMC) statement “... the Committee intends to purchase a further $600 billion of longer-term Treasury securities by the end of the second quarter of 2011.”
insignificant impact on the level of bond liquidity. This asymmetric relationship between the two assets grants sovereign bonds a more direct and efficient role in pricing sovereign credit risk - especially in countries under fiscal strain - relative to sovereign CDSs, which may have been disassociated from the underlying fundamentals. This is in contrast to the nature of sovereign CDS contracts, which by construction are thought to be the most accurate reflectors of sovereign default risk, while also points to the fact that - in line with Longstaff et al. (2011) - sovereign CDSs are driven primarily by systematic rather than idiosyncratic risk.

Liquidity in the European sovereign bond market is found to exert a significant impact on the CDS-bond basis; this owes to the illiquidity and liquidity risk in the bond market (in terms of the mean and volatility of the quoted bid-ask spread) being greater relative to those in the CDS market. Hence, bond illiquidity in Europe appears to be the major driver of the deviations from the theoretical one-to-one no-arbitrage relationship between bonds and CDSs, thereby supporting the arguments that the most illiquid asset acts as a limit to arbitrage (see Roll et al., 2007; Gârleanu and Pedersen, 2011; Nashikkar et al., 2011). The analysis also provides evidence that the ECB interventions during the Eurozone crisis have affected these liquidity dynamics and relieved the pressure on the CDS-bond basis exerted by bond illiquidity; this result not only verifies the predictions of the preferred habitat theory, but also provides a solid argument for the ECB's large-scale government bond purchases adopted in early 2015.81 It further resembles the US case, where the Fed's QE2 programme appears to have strengthened the impact of the bond market over the CDS market. The chapter's findings further question Beber and Pagano's (2013) predictions and lend support to the EU's decision to ban the purchase of uncovered CDS protection, since in the period after the ban's implementation, a deterioration in the CDS market's liquidity leads to an improvement in the liquidity of the bond market in most EMU countries.

The main novelty of this chapter pertains to the understanding of the effectiveness of non-standard monetary policy with regards to the relief of tensions in the European sovereign bond and

CDS markets. This is an issue of intense interest to policy makers, since to this date the effectiveness of non-standard monetary policy was judged only against the predictions of theoretical foundations.\footnote{The theoretical foundations for the transmission of non-standard monetary policy are presented in Section 2.6.2.} However, the adoption of non-standard measures was neither governed by theoretical foundations nor was the outcome of intellectual fermentation. It was rather the logical response to the exceptional conditions prevailing during the financial and Eurozone crises. Within the European context, non-traditional monetary policy was employed in order to address the liquidity shortage in the sovereign financial markets. However, due to the unique character of those measures no evidence exists with regards to the outcome of these central bank interventions. Hence, this chapter conducts the first empirical investigation of the impact of non-standard monetary policy on sovereign financial market liquidity. It does so, by assessing the ability of those measures to enhance the liquidity transmission between the sovereign bond and CDS markets. It further evaluates the success of central banks to promote the efficient pricing of sovereign bonds and CDS contracts by limiting the price distortions between the two assets.

Thus far, traditional monetary policy was firmly based on empirical evidence on how changes in the official central banks rate are transmitted to financial asset prices; the understanding of this transmission implied that interest rate setting was based on reaching the appropriate level of interest rates expected to produce the desirable outcome (Joyce et al., 2012). The transition to an era of non-traditional policy interventions however, such as asset purchases and liquidity providing operations, gave rise to the need of understanding the impact of this transition. It is imperative that central banks incorporate and capitalize on information from the recent crises in order to evaluate whether this shift in monetary policy stance can provide future guidance on the optimal conduct and formulation of non-standard policy actions. The empirical analysis conducted in the present chapter fills exactly this gap.

This chapter's contribution further concerns the examination of the intertemporal association between sovereign bond and CDS market liquidity and the CDS-bond basis thereby highlighting an additional driver of liquidity. Through this examination it provides a further reason why liquidity is
important for financial theory, i.e., to guarantee the equilibrium between assets linked by a no-arbitrage condition and limit the cross-asset price distortions. In this respect, this chapter's analysis constitutes the first empirical investigation of whether sovereign bond and CDS market liquidity affects and is affected by the CDS-bond basis, and how liquidity is related to the deviations from the CDS-bond equilibrium price.

The chapter also contributes on the regulatory front by evaluating the implications of the EU’s naked CDS ban for sovereign bond liquidity. On the practical front, the evaluation of this regulatory change is hampered by the simultaneous causality between the bond and CDS liquidity measures, and between the liquidity measures with the ban itself. The isolation of the ban from previous periods and its examination within a VAR framework identified by Cholesky decomposition, enables for the identification of the ban’s occurrence, while addresses simultaneity concerns. It further addresses the asymmetric impact of the ban, by differentiating between countries. Thus, the analysis offers an evaluation of the validity of the IMF’s arguments according to which, deteriorating CDS liquidity in the post-ban period will affect negatively bond market liquidity. The following section discusses how these contributions relate to previous studies and how they extend those studies' findings.

The remainder of this chapter is organized as follows: Section 4.2 sets the hypotheses and discuss related studies. Section 4.3 describes the liquidity measures and the methodological framework. Section 4.4 performs the vector autoregression (VAR) analysis. Section 4.5 concludes.

4.2. Literature Review and Hypotheses

This study is related to the literature on liquidity comovements and spillovers between different markets. So far the empirical evidence is scarce and restricted mainly to the stock-bond relationship: Chordia et al. (2005) document covariation in liquidity and volatility between the stock and Treasury bond markets, while De Jong and Driessen (2012), find that liquidity risk from the stock and Treasury bond markets exerts an impact on corporate bond returns. They are followed by Goyenko and Ukhov (2009), who report a cross-market effect of liquidity affecting returns in both markets; they further establish a link between monetary policy and financial markets illiquidity and document that central
bank reserves are an important driver of financial market liquidity. In a joint examination of credit and liquidity risk by Calice et al. (2013), liquidity linkages are also observed between a number of European government bonds and CDSs during the early phase of the Eurozone sovereign debt crisis, with the CDS market being the driver in most cases. Their findings also include a positive and significant lagged transmission from the CDS market's liquidity spread (proxied by the bid-ask spread) to the credit spread in the bond market.

The analysis in this chapter goes even further and examines assets that are linked via a no-arbitrage condition providing evidence that deviations from that equilibrium matter for cross-asset liquidity interaction and vice versa. It additionally considers the effect of central bank interventions, and most importantly the asset purchase interventions within the ECB's SMP and the Fed's QE2. In this respect, it supplements Goyenko and Ukhov (2009), by showing that extreme central bank interventions are effective in changing the cross-asset liquidity interactions in the financial markets. An additional differentiation from the previous studies concerns the impact of a regulatory change (i.e., the European short-selling regulation) that specifically targeted the two assets included in the analysis; the empirical results suggest that a potential fall (due to the regulation) in sovereign CDS liquidity is not detrimental to sovereign bond liquidity, thereby justifying the EU's decision to enact the regulation. The examination further reveals that - in contrast to Calice et al. (2013) - liquidity (and price) movements in the sovereign bond market are more important for the periphery of the Eurozone compared to the core.

This chapter also extends the literature on the CDS-bond basis, as well as the relative price discovery mechanism in the bond and CDS markets. These studies suggest that overall, the no-arbitrage relation holds fairly well. However when the equilibrium breaks down, the market in which the price discovery takes place is state dependent, citing as one of the important determinants the

83 Studies on price discovery include those by Blanco et al. (2005), and Norden and Weber (2009) for the corporate bond and CDS markets, and Fontana and Scheicher (2010), Calice et al. (2011), and Arce et al. (2012), for the sovereign bond and CDS markets. Blanco et al. (2005), and Bai and Collin-Dufresne (2011), examine the CDS-bond basis. These studies are discussed in more detail in Sections 2.3. to 2.3.3.
relative liquidity in these markets, although without including any liquidity proxies in their empirical examination. The present chapter specifically includes the CDS-bond basis in conjunction with liquidity in the empirical analysis and provides evidence that bond illiquidity prevents the basis from converging to its equilibrium value.

This work is also related to the studies examining the relationship between CDS and the issuer of the underlying security on which the CDS contract is written. At the corporate level, liquidity in the bond market appears unaffected by the beginning of the CDS trading in Das et al. (2013), while in Massa and Zhang (2012) and in Shim and Zhu (2014), the CDS market results in an increase in bond market liquidity. This chapter provides evidence for the sovereign market, where the liquidity of the underlying bond matters more for the liquidity of the derivative written on it, rather than the reverse; however, in times of heightened uncertainty the CDS appears to increase its influence on the underlying security for debt-distressed issuers.

In what follows, certain hypotheses are developed to explore the liquidity dynamics between the sovereign bond and CDS markets, and how these dynamics relate to central bank interventions and the CDS-bond basis. The first hypothesis concerns the nature of the liquidity transmission between the two markets and states that this transmission is not limited to a mere comovement between them. The other two hypotheses specify how illiquidity and central bank interventions affect the equilibrium relationship between the sovereign bond and CDS markets.

\textit{Hypothesis 1: Liquidity in one market spills over to the other market.}

There are reasons to expect the existence of liquidity linkages between the bond and CDS markets; since theoretical and empirical studies confirm the role of liquidity as a risk factor priced in each market, and since liquidity conditions in each market depend on- as well as reflect systematic risk factors arising from a common source (e.g., macroeconomic developments, monetary conditions, demand and/or supply shocks, market frictions, investor beliefs), this leads us to expect a bidirectional interaction of liquidity in the two markets (Amihud et al., 2005; Goyenko and Ukhov, 2009; Karolyi et al., 2012; Cespa and Foucault, 2014).\textsuperscript{84} This in turn might have implications for the

\textsuperscript{84} The sources and mechanisms of liquidity propagation are discussed in detail in Section 2.4.
nature of the relationship between liquidity conditions in the two markets; we expect this relationship not to be limited to the comovement of liquidities, but also that liquidity spills from one market over to the other, i.e., current CDS liquidity is affected by past bond liquidity, and vice versa. This dual nature comprises the main hypothesis to be examined in this chapter.

**Hypothesis 2: Central bank interventions drive the CDS-bond basis towards its equilibrium (zero) value.**

More specific, the asset purchases under the ECB’s SMP targeted the bonds of the EMU South and aimed at lowering the illiquidity yield premium required by investors due to the absence of trading activity in situations of high credit risk (Fontana and Scheicher, 2016). The SMP’s sizable purchases resulted in a windfall gain for the periphery countries due to an immediate increase in their bond prices and thus are expected to have - at least temporarily - increased the CDS-bond basis (Acharya et al., 2016). This is further motivated by the long-term horizon of the SMP’s portfolio and the fact that the bond purchases were not reversed through the repo market (Corradin and Maddaloni, 2015). Furthermore, during periods of market stress asset purchases are anticipated to reduce the costs faced by short-sellers for borrowing the bond in the reverse repo channel, and through that to decrease the associated net liquidity premium (see Banerjee and Graveline, 2011). To this end, the ECB interventions are likely to have alleviated short-selling pressures, thereby limiting the negative basis in the EMU periphery.

Central bank interventions are further expected to limit funding problems and "slow-moving capital" which are considered to be leading to asset pricing distortions (see Duffie, 2010) and giving rise to price gaps (i.e., the CDS-bond basis) due to causing securities with nearly identical cash flows, but different margins, to trade at a different price (Gârleanu and Pedersen, 2011). In addition, monetary policy contributes to the transmission of information during periods of heightened market stress by increasing market liquidity and enabling the efficient pricing of assets through a reduction in the risk aversion of market-makers and traders. This is attained through the ability of monetary policy to affect investor sentiment (broadly defined as the propensity to speculate and which is usually
negatively correlated with the market-wide risk aversion), as well as through the restoration of the inventory channel (Brunnermeier and Pedersen, 2009).\textsuperscript{85}

**Hypothesis 3:** It is the less liquid asset that prevents the basis from converging to its equilibrium value.

The motivation for this hypothesis is derived from earlier studies where arbitrage activities in the cash and futures contracts may be affected by those contracts' liquidity (see Kumar and Seppi, 1984). Furthermore, if the mispricing is extensive then a negative shock to liquidity may exert a persistent impact on the cash-futures basis as investors attempt to exploit this mispricing and drive the basis to zero: this persistency in turn prevents the exploitation of the arbitrage opportunity (Roll et al., 2007). When the reverse direction is considered, market-wide order imbalances arising from arbitrage trades due to a wide basis may have a contemporaneous, as well as a lasting impact on liquidity (Stoll, 1978; O'Hara and Oldfied, 1986; Chordia et al., 2002). Most importantly, the effect of illiquidity on arbitrage activities is stronger in the relatively less actively traded longer-term contracts (Roll et al., 2007; Gärleanu and Pedersen, 2011; Nashikkar et al., 2011). This is particularly relevant for the sovereign bond and CDS contracts which are primarily employed in the context of long-horizon strategies and therefore their equilibrium relationship is likely to be affected by their liquidity.

The hypothesis about the link between market liquidity and the level of the basis is further based on the trading traits of the bond and credit derivatives contracts. The CDS-bond basis is used in a basis strategy - as is frequently the case with hedge funds - which is part of a number of different strategies that depend on bonds and CDSs and cause an allocation of funds between them. These

\textsuperscript{85} It is reasonable to expect this relationship to be firm, since for example, accommodative monetary policy may favourably affect liquidity through its effect on volatility (Harvey and Huang, 2002) and interest rates (Kuttner, 2001). Of course falling liquidity might also induce the central bank to ease its monetary stance, thereby highlighting the possibility of reverse causality. Monetary policy may have a different effect on liquidity in the bond and CDS markets due to fundamental differences between those assets. Bond prices are affected through expectations of future short rates and potentially the term premium, and CDS spreads through the discount rate and possibly through the probability of default.
strategies mainly include dynamic hedging and are further promoted by the changes in the contractual features of the CDSs, which make the trading and closing out of positions considerably easier.86 Along these lines, the greater CDS-induced trading activity during the crisis is an additional driver of movements in the level of the basis: speculating on the variation of the basis in a short leg of time (the so called “convergence-trading”) is considered to have led to a negative basis during the post-2008 period (Fontana and Scheicher, 2016). The negative basis in the EMU South during the best part of this period and the assertions at the EU level about the speculative actions targeting that bloc’s countries further reinforce this argument.

Following these ideas, this chapter explores the liquidity spillover between the sovereign bond and CDS contracts. It further examines the intertemporal associations between central bank interventions and market liquidity on the one hand, and the divergence of the sovereign bond and CDS markets from their no-arbitrage relationship (i.e., the CDS-bond basis) on the other.

4.3. Data and Methodology

The data employed is comprised of daily and weekly bid-ask spreads for on-the-run sovereign bonds and CDSs with 5 years to maturity. On-the-run issues are the most frequently traded securities of their maturity, and although on-the-run bonds constitute only a small fraction in some markets, e.g., that of Treasury bonds, they account for the largest portion of the activity in the interdealer market. These issues trade at higher prices (lower yields) than more seasoned securities with similar cash flows, with these higher prices thought to be reflecting a liquidity premium. This superior liquidity of the on-the-run securities also makes them as ideal securities for market intermediaries who are interested in creating short positions, due to the fact that they are particularly easy to borrow and sell when initiating a short position, and also to repurchase when closing one out.87

86 From May 2009 onwards, CDS prices consist of an upfront payment and a regular fixed coupon (Barclays Capital, 2010).
The time to maturity chosen for sovereign CDSs is based on the fact that the 5-year tenor consists the most liquid and frequently quoted part of the credit curve and therefore, the most traded maturity for CDS contracts. Daily bid-ask quotes are from the Bloomberg Generic Quote (BGN) and Composite Bloomberg Bond Trade (CBBT) pricing sources. The sample consists of all the EMU member countries at the time of the introduction of the euro, i.e., Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, and Spain; it further includes the USA. Sovereign bond and CDS bid-ask spreads are available since 31 January 2006, therefore the examination covers the period from January 2006 to June 2014.

In contrast to the ECB’s and the Fed’s asset purchases programmes under the SMP and the QE2 respectively, the UK’s QE did not target government bond yields. The Bank of England (BoE) designed its asset purchase operations with the aim of affecting the yields (or prices) on a wide range of private sector assets, especially on bonds issued to finance lending to corporations and households (Joyce et al., 2012). Contrary to the non-standard operations in the Eurozone and the US, the BoE’s operations were not concerned with restoring a liquidity problem within the banking system or easing the pressures on the government’s sovereign bond issues. Hence, due to this differences in the objectives of the BoE’s non-standard policy operations, the UK is not included in the analysis.

Since the bid-ask spread, due to being based on widely available data, is highly correlated with price impact (Fleming, 2001), the analysis in this chapter follows Chordia et al. (2000) and

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88 BGN prices are computed as a weighted average of quotes from participating dealers and include indicative and executable quotes. CBBT also provides average bid-ask quotes; it is only based on executable quotes that are listed on Bloomberg’s trading platform. BGN spreads are further employed in the literature by inter alia Chen et al. (2007), Longstaff et al. (2005), Bao et al. (2011). As in the previous studies the analysis in the present chapter employs executable quotes.

89 The euro was introduced on January 1, 2002. Data for Luxembourg is unavailable, thus the country is not included in the examination despite being an EMU member on that date. Due to the Greek debt restructuring deal in March 2012, data on Greek bonds and CDSs is not available for the major part of the post-March 2012 period.
Goyenko and Ukhov (2009), and employs the quoted bid-ask spread as the primary liquidity measure for the bond market, which is computed as:

\[
QS = \frac{\text{ASK} - \text{BID}}{\frac{1}{2}(\text{ASK} + \text{BID})}
\]  
(4.1)

where ASK and BID are ask and bid prices respectively for the security on a given day.\(^{90}\) A higher value of this measure is associated with less liquidity (i.e., greater illiquidity). For the CDS market, the absolute bid-ask spread is employed (i.e., ask price - bid price), since CDS premiums are already expressed in basis points per annum of the notional amount of the contract; thus, further dividing the CDS bid-ask spread by the denominator in equation (4.1) might bias the liquidity comparison between different securities. An intuitive example provided by Pires et al. (2015) can help illustrate this point.\(^{91}\)

Assume that bond A trades at €99.50 - €100.50 (i.e., bid price at €99.50, and ask price at €100.50). The absolute spread is thus €1.00, the denominator in equation (4.1) is €100.00, and the quoted bid-ask spread is 1%, or 100 basis points (bps). An investor buying that bond at €100.00 and immediately selling it back to the market maker, suffers a transaction cost of (99.50 - 100.50)/100.50, which is approximately equal to 1% of the initial €100.00. Bond B that trades at €199.00 - €201.00, has a larger absolute spread (€2.00), but the same quoted spread (1%, or 100bps). The same roundtrip transaction would again cost to the investor approximately 1% of €200.00. These two bonds have the same liquidity costs and this cost is captured by their identical quoted bid-ask spreads. Hence, a comparison by means of absolute spreads would provide misleading results; in this regard it is appropriate to use quoted bid-ask spreads to examine liquidity in the bond market.\(^{92}\)

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\(^{90}\) Section 5.6.2 includes a discussion on alternative liquidity measures.

\(^{91}\) This example is taken from Pires et al. (2015) and adjusted for the purposes of the present chapter.

\(^{92}\) The same argument can be employed to justify the use of the relative bid-ask spread, which is expressed as (ask price - bid price)/mid price.
The fact that CDS premiums are already expressed in basis points, reverses the above example when the CDS market is concerned: Assume that the CDS contract on bond A trades at 95.00bps - 105.00bps, i.e., the absolute bid-ask spread is 10 bps, and the quoted bid-ask spread is 10%, or 1000bps. A roundtrip transaction for one CDS contract would entail a cost of 105.00 - 95.00 = 10.00 (for ease of comparisons, the premium is assumed to be paid annually). The CDS on bond B that trades at 190.00 - 210.00, has a larger absolute spread of 20bps, but the same quoted spread of 10%, or 1000bps. Thus, the same roundtrip transaction would result in a larger annual cost of 210.00 - 190.00 = 20.00. Therefore, while the quoted bid-ask spreads of both CDS contracts are equal, these liquidity measures fail to provide an accurate representation of the incurred transaction costs; the latter are only captured by the absolute bid-ask spread, which in turn qualifies as the most precise measure of liquidity in the CDS market.

The difference in the information reflected in the two liquidity measures can further lead to ambiguous results in the context of the statistical examination of liquidity. Adopting the same example - and assuming a number of CDS contracts large enough to conduct the analysis - the regression of the CDS premia on quoted bid-ask spreads would produce a horizontal slope, since the rise in the CDS premia leaves quoted bid-ask spreads unchanged (Pires et al., 2015). In reality however, there is a positive relationship between CDS premia and absolute bid-ask spreads, since higher CDS premia (in the same example) are associated with higher transaction costs and deteriorating liquidity. Since, the focus of this study is the interaction between liquidity in the sovereign bond and CDS markets, a regression of bond quoted spreads on CDS quoted spreads (and vice versa) could yield the same misleading results. This provides an additional justification for the

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93 As Pires et al. (2015) point out, in the event where the absolute bid-ask spread does not grow faster than the CDS premium on a contract (the mid quote, or in our case the denominator in Equation (4.1)), a regression of the CDS premium on the quoted (or the relative) bid-ask spread will be biased towards producing a zero or negative slope. They further attribute some of the negative relations evidenced in Acharya and Johnson (2007) and Tang and Yan (2007) to the choice of liquidity measures.
employment of the absolute bid-ask spread as liquidity measure for the CDS market. As is the case with the quoted bid-ask spread, a higher value of this measure is associated with greater illiquidity. Since there is evidence that asset return and volatility affect liquidity in the given asset, they are included as additional variables along with the liquidity measures. These variables include the sovereign bond returns and CDS spread changes (denoted as BONDRET and CDS respectively), and the volatility of bond returns and CDS spread changes (denoted as BONDVOL and CDSVOL respectively) computed as the standard deviation of daily returns (spread changes) over each week. The data used to calculate the CDS-bond basis for Europe are the daily (and weekly) series of the 24-months Eonia swap rate obtained from Datastream, which are extrapolated to match the maturity of the bond and CDS data (5-year), while for the US the series used is the 5-year interest-rate swap obtained from the Federal Reserve (Hull et al., 2004; Choudry, 2006).

Panels A and B of Table 4.2 present country-specific summary statistics for bond returns, CDS spread changes, bond quoted spreads, CDS absolute spreads, and the CDS-bond basis at the daily frequency. As expected, CDS liquidity is higher than the liquidity of the bond market, with CDS bid-ask spreads ranging from approximately 3.7 to 18.5 basis points in all EMU countries. At the same time, bond quoted spreads are significantly wider, assuming very large and negative values in the case of Greece, Ireland, Italy, Portugal, and Spain that range from minus 932.3 to minus 108.1 basis points. In this same group of countries, both liquidity measures exhibit the higher volatility, a pattern also evident when looking at bond returns and CDS spread changes.

With regards to the difference between the CDS spread and the excess of the bond yield over swap rate, this difference is relatively greater in France and Germany, owing to the very low yields offered by the bonds of these countries. On the contrary, the skyrocketing yields of the Greek, Irish, and Portuguese bonds cause this difference to be negative. In terms of volatility, again the highest standard deviation is observed in the countries of the European South, suggesting greater possibilities of observing a movement of the basis away from, or towards to its equilibrium value.

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94 See inter alia Amihud and Mendelson (1986), Longstaff et al. (2005), Chen et al. (2005;2007), Yang and Tan (2007), and Bai et al. (2011).
According to the earlier arguments about liquidity comovement and spillovers, we expect a bidirectional movement and causality of present and past values of liquidity in the two markets. Therefore, the following five-equation vector autoregression model is adopted for each of the 11 EMU countries and the US:

\[ Y_t = c + \sum_{i=1}^{p} \Pi_i Y_{t-i} + \epsilon_t \]  \hspace{1cm} (4.2)

Where \( Y_t = (Y_{1t}, Y_{2t}, Y_{3t}, Y_{4t}, Y_{5t})' \), is the vector of endogenous variables in the VAR. These variables are respectively the return in the sovereign bond market (BONDRET), the quoted bid-ask spread in the sovereign bond market (BONDLIQ), the change in the spread of the sovereign CDS market (CDS), the quoted bid-ask spread in the sovereign CDS market (CDSLIQ), and the CDS-bond basis (BASIS). Two additional endogenous variables are included at the weekly frequency, namely volatility in the bond and CDS markets, denoted as BONDVOL and CDSVOL respectively. The vector \( c \) is a \((5 \times 1)\) vector of intercept terms, \( \Pi_i \) is a \((5 \times 5)\) coefficient matrix, and \( \epsilon_t \) is a \((5 \times 1)\) vector of innovations following a multivariate normal distribution with variance \( \Sigma \), and \( t = 1, \ldots, T \).

The identifying assumption in the VAR is that if a variable \( Y_1 \) appears earlier in the system than a variable \( Y_2 \), then \( Y_1 \) is weakly exogenous with respect to \( Y_2 \) in the short-run. The lag structure and the maximum lag order \( p \) have been determined using the Akaike Information (AIC) and the Hannan-Quinn Information (HQIC) criteria.

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95 On the one hand there are arguments about placing the CDS market first since it is the most liquid market (in the present analysis the CDS market) that induces movements in the other market (the bond market) in the short-run (see inter alia Blanco et al., 2005; Fung et al., 2008; Norden and Weber, 2009; Corzo et al., 2012). However, since the price of the CDS contract is by construction derived from the value of the underlying bond issues, it is changes in the bond yield that induce changes in the spread of the CDS contract (Duffie, 1999; Hull and White, 2000; 2001). Both orderings however provide identical results.

96 Since, the number of observations is greater than 120, preference is given to HQIC; in any case, the smallest of the number of lags suggested by the two criteria is chosen.
4.4. Vector Autoregression Analysis

This section includes the examination of liquidity dynamics between the sovereign bond and CDS markets at the country-level. Table 4.3 reports the Granger causality tests between the endogenous variables in the VAR at the daily frequency.\(^\text{97}\) Looking at Austria in Table 4.3, the value in the cell (2,4) is 43.665 and significant at the 1% level, thereby indicating that liquidity in the bond market Granger causes liquidity in the CDS market. The results suggest a two-way relationship between bond liquidity and CDS liquidity in Austria since CDS liquidity also Granger causes bond liquidity; the value in the cell (4,2) is 19.091 and statistically significant at the 1%. The remaining coefficients from the Granger causality tests in Table 4.3 are interpreted similarly. Overall, it appears that country-specific liquidity dynamics present substantial differences when we move from the countries of the European South (i.e., Greece, Ireland, Italy, Portugal, Spain) to the countries that belong to the core of the Eurozone. These differences are further present when the interaction of liquidity with the rest of the endogenous variables are considered.

[Insert Table 4.3 about here]

The stronger liquidity linkages between the sovereign bond and CDS markets are mainly observed in the countries hit the most by the European sovereign debt crisis, such as Greece, Ireland, Italy, Portugal, and Spain. In these countries liquidity is transmitted bidirectionally between CDSs and bonds, since bond liquidity Granger causes CDS liquidity and vice versa. In the rest of the Eurozone however, it appears that liquidity only stems from the bond market, as it is bond liquidity that Granger causes CDS liquidity and not the reverse. The only European country in which there is cross-asset liquidity interaction is the Netherlands, a pattern also evident in the US, where bond liquidity is disassociated from liquidity in the CDS market.

\(^\text{97}\) For the null hypothesis that variable \(x\) does not Granger-cause (the dependent) variable \(y\) variable \(y\), is regressed on its own lagged values and on lagged values of \(x\) in order to test whether the lagged coefficients of \(x\) are jointly zero. The cell associated with the \(i_{th}\) row variable and the \(j_{th}\) column variable shows the \(\chi^2\) statistics and the level of statistical significance.
Considerable differences are observed between the European South and North with regards to the interaction of liquidity with the other endogenous variables in the VAR, as well as between bond returns and CDS spreads. Again, bond liquidity is evolved into a major determinant of not only CDS liquidity, but of the level of CDS spreads as well, since bond liquidity Granger causes movements in the CDS spreads in all 11 EMU countries. Similar to the cross-asset liquidity examination earlier, the CDS market appears to play a greater role in the countries that triggered or affected the most by the debt crisis, i.e., in Greece, Ireland, Italy, Portugal, and Spain; in these countries, along with Germany, - besides being affected by bond liquidity - CDS spreads also induce movements in the liquidity of the bond market. On the other hand, CDS liquidity is not a significant factor for bond returns, as there is no interaction between liquidity in the CDS market and returns in the bond market; the only exception being Greece, Germany, and Italy. Hence, it appears that the return provided by a sovereign's bond is not a prerequisite for an active and liquid sovereign CDS market.

Overall, findings suggest a unidirectional, and bidirectional in some cases, transmission of liquidity between the two markets. Liquidity is also found to interact with the other endogenous variables in the system, with a distinctive pattern being that movements in CDS liquidity (spreads) contain information for movements in bond returns (liquidity) only in the Eurozone periphery. In the Eurozone core however, bond liquidity (returns) are more important for the evolution of CDS spreads (liquidity). To obtain a clearer picture impulse response functions (IRFs) are computed, which depict the reaction of one variable to a one-time, unit standard deviation, positive shock to another variable in the system (termed simply a “shock” or “innovation”).

Graphs 1 to 12 of Figure 4.1 present the IRFs for each of the 11 EMU member states and the USA. For the sake of brevity the figure presents the response of illiquidity in one market to a positive

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98 Since the actual variance-covariance matrix of the errors is unlikely to be diagonal, the errors need to be orthogonalized in order to isolate shocks to one of the variables in the system. The usual practice is to use standard Cholesky decompositions of the VAR residuals keeping the ordering of the endogenous variables unchanged, thus allocating any correlation between the residuals of any two elements to the variable placed first in the ordering. The ordering of the endogenous variables remains the same as in the Granger causality tests.
shock to illiquidity (represented by an increase in the bond quoted bid-ask spread or in the CDS absolute bid-ask spread) in the other market, and the response of CDS spreads (bond returns) to a shock to illiquidity in the bond (CDS) market.  

[Insert Figure 4.1 about here]

According to the graphs, there is evidence of cross-market liquidity dynamics. It appears that a positive shock to illiquidity in one market results in the comovement of illiquidity in the other market. As a general result, cross-market illiquidity shocks are significantly greater in size and duration when they are transmitted from the bond market to that of CDSs. However, in the countries of the Eurozone core, CDS illiquidity shocks also appear able to induce movements in bond illiquidity (albeit of a lower magnitude compared to the case where the shocks have the opposite direction, i.e., from bonds to CDSs); this is in contrast to the Eurozone periphery, where an exogenous shock to the level of CDS illiquidity has a rather minor impact on the level of illiquidity in the bond market.

Certain patterns are evident from the impulse response analysis. First, there is an inverse relationship between illiquidity in the one market and illiquidity in the other, i.e., a deterioration in liquidity conditions in the bond (CDS) market results in an improvement in the liquidity of the CDS (bond) market. Second, and most important, illiquidity shocks stemming from the bond market exert a considerably greater (negative) impact on the illiquidity of the CDS market. This is particularly the case in the European North, where shocks to bond illiquidity appear able to induce large movements in the illiquidity of the CDS market. These movements are between 1 to 1.5 standard deviations of their sample means (such as in Austria, Belgium, France, Germany), and can be as high as 2.5 standard deviations (in Finland). In the European South and Ireland however, CDS illiquidity is less dependent on bond illiquidity, since the impact of the latter on the former is in the 0.3 to 0.6 range (in units of standard deviation).

99 Therefore the IRFs are presented with the following ordering: The response of Bond Liquidity to CDS Liquidity, the response of Bond to CDS Liquidity, the response of CDS Liquidity to Bond Liquidity, and the response of CDS to Bond Liquidity.
On the other hand the impact of CDS illiquidity shocks on the level of bond illiquidity is limited, and (as is the case regarding the impact of bond illiquidity on CDS illiquidity) primarily concentrated in the countries of the Eurozone core, where the response of bond illiquidity to a positive CDS illiquidity shock ranges from approximately 5% of standard deviation (in Belgium, Finland, and Germany) to as high as half of standard deviation in Austria. In the rest of the EMU countries, the same response is again significantly weaker, with only Ireland, and Italy reacting somewhat (by about 5% of standard deviation).

In the US, bond illiquidity is evolved into a major determinant of movements in CDS illiquidity, causing a response of about 1 standard deviation, however the response of the bond quoted spreads to illiquidity shocks stemming from the CDS market is insignificant. Illiquidity shocks also exert a cross-market impact on returns and spreads. In particular an increase in bond illiquidity is associated rising CDS spreads, which suggests that less activity in the bond market is considered as a negative prospect for the sovereigns' debt.

However, while a rise in bond illiquidity leads to higher CDS spreads in all EMU countries, the impact of CDS illiquidity shocks on bond returns is dependent on the bloc that each EMU country belongs. In specific, countries in the core of the Eurozone see their bond returns falling in response to a positive illiquidity shock in their CDSs. On the other hand, worsening liquidity in the Eurozone periphery countries, leads to rising bond returns, suggesting that an active and liquid CDS market is perceived as a good sign by investors considering to gain exposure in those countries' bonds. This is further derived from the fact that, in contrast to the impact of CDS illiquidity shocks on bond illiquidity, these illiquidity shocks now cause a significantly greater reaction to bond returns in the periphery countries than in the Eurozone core. While in the latter countries, the bond return's reaction is generally within the 1 to 1.5 range (in standard deviations units), in the periphery, bond returns overreact to CDS-originated illiquidity shocks and assume values as high as 3 (see Italy, Spain) or even 6 (see Ireland).

100 The only exception is Austria, where bond returns exhibit a surprising positive response of almost 2 standard deviations.
Overall, there is evidence of liquidity comovement, and particularly of liquidity spillover, between the two markets, with illiquidity shocks exerting a greater cross-market impact when they are generated in the sovereign bond market. This highlights the importance of analyzing sovereign bond and CDS market liquidity, and also brings attention to the importance of bond liquidity for price movements in the European sovereign debt and credit derivatives markets. In addition, it points to the different role played by the sovereign CDS market in countries under increased fiscal strain compared to countries with sound public finances, as was the case with the Southern and the Northern European countries respectively during the recent sovereign debt crisis.

4.4.1. Robustness

The analysis so far suggests the interaction of liquidity across the sovereign bond and CDS markets, with the nature of this interaction exhibiting considerable differences when moving from the Eurozone periphery to the core. To test the robustness of those findings the VAR examination is conducted by employing weekly series. The VAR specification of equation (4.2) is augmented into a seven-equation model with the order of endogenous variables being: BONDRET, Bond Liquidity, BONDVOL, CDS, CDS Liquidity, CDSVOL, Basis. The results are roughly the same when compared to those from the daily-level examination.

In particular, movements in bond liquidity continue to be the main drivers of movements in CDS liquidity, with the impact of bond market-stemming illiquidity shocks being greater in the EMU. Asset liquidity also appears responsive to that asset's return (or spread in the case of CDSs) and volatility. Bond illiquidity remains the variable exerting the stronger influence on the CDS-bond basis. The order of the VAR is also changed, by placing the CDS market variables in front of the bond market variables, thus accounting for the possibility that the liquidity of the bond market (as measured by other measures, e.g., volume of trades, and/or number of contracts outstanding) is greater than that of the CDS. However, results do not present significant variations compared to the initial VAR ordering.
An additional robustness test includes the assessment of the ability of each market in one country to forecast movements in the other market in the same country.\textsuperscript{101} To this end, an in-sample forecasting exercise is performed by estimating the same VAR of Section 4.4 for the daily series and calculating the predicted series for each market over the last year of the estimation period, i.e., from 20/06/2013 to 20/06/2014. In Figure 4.2, the predicted series of bond (CDS) liquidity from the VAR (red line) is plotted against the actual bond (CDS) liquidity series (blue line) in each country.\textsuperscript{102}

According to the graphs, the evolution of the predicted series for the CDS bid-ask spreads matches closely that of the actual series for the total of the EMU countries and the US. This finding is consistent with that of Section 4.4 where sovereign bond liquidity appears informative for movements in sovereign CDS liquidity. On the other hand, the forecasted series of the bond liquidity although directionally similar to the actual series, they nevertheless exhibit considerable difference with regards to their size. These differences are in turn particularly evident in the countries of the EMU South, since in the EMU North the difference between the two series is of a relatively weaker magnitude.

Therefore, the results of the previous section where liquidity in the CDS market incorporates limited information for movements in bond market liquidity are further confirmed by the forecasting exercise. In addition, this deviation between the predicted and the actual series in the Eurozone periphery is in line with the weak impact exerted by CDS liquidity on bond liquidity that is observed in the IRFs of Section 4.4. Common feature in all graphs of Figure 4.2 is that the predicted series is relatively more volatile than the actual ones in all countries, thereby posing some limitations on the forecasting ability of the model when short-run movements are considered. In the long-run however, the behaviour of the predicted series is similar to the actual evolution of the liquidity measures in each market, suggesting that the dynamics of the actual series are well-captured by the VAR.

\textsuperscript{101} I am grateful to the examiners for the suggestion of this test.

\textsuperscript{102} Bid-ask spreads for Greece are not available for the total of the forecasting period and therefore Greece is omitted from Figure 4.2.
4.4.2. Arbitrage Activities

This section focuses on the role of arbitrage activities in the liquidity dynamics between the sovereign bond and CDS markets by analyzing the results of the VAR estimation in the previous section. The main variable of interest is the CDS-bond basis (henceforth the basis), which represents the arbitrage opportunities created by the pricing discrepancy between sovereigns bonds and CDSs. The aim is to determine whether the level of liquidity impacts on the basis and hence, creates opportunities for arbitrageurs. Only the results at the daily frequency are considered, since any arbitrage opportunities are likely to be diminished at lower frequencies.

Figure 4.3 presents the response of the basis to a positive shock to illiquidity (represented by a widening of the quoted bid-ask spread or the absolute bid-ask spread) in the sovereign bond and CDS markets for each of the 11 EMU member states and for the US. Similar to the cross-asset liquidity examination of the previous section, the results of the IRFs point to a distinction between the Southern and the Northern EMU member-states. Thus, in the European South, illiquidity shocks generated in the bond market appear to be exerting a greater impact on the basis, compared to the case where the same shocks are generated in the CDS market. The former type of shocks induce a reaction in the basis that is double in magnitude compared to the reaction induced by the latter type of shocks, with the strongest reaction being observed in Greece, where the basis responds by approximately 1 standard deviation to any bond illiquidity shock. In these countries, bond illiquidity shocks lead to an increase of the basis (or to a decrease in the cases where the average value of the basis is negative, such as in Greece, Ireland, and Portugal), forcing it away from its zero equilibrium value.

This behaviour is not verified for the rest of the EMU countries, where (with the exception of Finland) those countries basis' response to CDS illiquidity shocks is at the same level with the response to bond illiquidity shocks (e.g., France), or greater (e.g., Austria, Belgium, Germany, Netherlands); in this last group of countries, the difference in the magnitude of the basis' response to the two type of shocks is again about double in size. However, while in the Eurozone periphery countries the greater impact of bond illiquidity shocks relative to CDS illiquidity shocks cause a widening of the basis and thus act as limits to arbitrage, in the Eurozone core countries the CDS
illiquidity shocks' greater impact move the basis towards - and not away of - its equilibrium value (the same is true for Finland, while Austria is the only country where CDS illiquidity acts as a limit to arbitrage by leading to a widening of the basis).

Thus, it might be the case that illiquidity in the periphery countries' bond market leads to an overpricing of credit risk in the CDS market (or an underpricing in the bond market) and hence, to a positive basis in countries such as Italy, and Spain. However, credit risk might be underpriced in the CDS markets (or overpriced in the bond markets) of Greece, Ireland, and Italy, thus leading to a negative basis, instead of a positive basis. In those cases where a widening of the basis is observed, approximately 6 to 8 days are required before the basis' reaction is stabilized, suggesting that price deviations are persistent and need time to correct. This in turn prompts arbitrageurs to act and restore the basis (near) to its equilibrium value during the following days. In the US, bond illiquidity appears to act as a limit to arbitrage, however CDS illiquidity causes a greater, and negative, impact on the basis thus, causing a tightening of the basis and a move towards its zero market-clearing value.

[Insert Figure 4.3 about here]

The implications of these findings can be better understood from an investor perspective. The large (in absolute terms) values of the basis in the countries of the EMU South are associated with the higher volatility and greater illiquidity in both the sovereign bond and CDS markets of that bloc's countries. This combination of higher volatility and illiquidity on the one hand, and the large deviations from the no-arbitrage price on the other indicates that a part of the CDS-bond basis is compensation for this higher volatility and illiquidity. In other words, the exploitation of the widening of the mispricing between the sovereign bond an CDS contracts carries a volatility and illiquidity premium. This in turn dictates that the horizon of the trading strategy adopted in order to profit from this mispricing must be long enough for two reasons: a) to account for the liquidity and volatility risk of the sovereign assets, since holding costs can have disproportionately large effects when they are incurred by a sequence of short-horizon arbitrageurs (see Tuckman and Vila, 1992,1993; Dow and Gorton, 1994) and b) in the case of a negative basis (such as in Greece, Ireland, and Italy) to withstand the fire-sales from a potential deterioration of the fiscal position of the underlying issuer
and the resulting increase in the issuer’s sovereign default risk (see Gromb and Vayanos, 2002). In any case the long-horizon condition must be met for the strategy to be profitable.

This latter case where the basis assumes persistently negative values is further important from a monetary policy perspective. When the basis is negative, the exploitation of arbitrage requires a strategy of buying the bond (at price \( B \)) and buying insurance (the CDS contract) on the bond. The purchase of the bond is funded via the repo market where investors are faced with a haircut \( h \) on the bond; this in turn means that the buyer of the bond (and prospective arbitrageur) will have to provide \( hB \) dollars of “risk-capital” funded at Libor\(+f\), where \( f \) is the funding spread over Libor that the buyer faces (Bai and Collin-Dufresne, 2011). The level of this haircut is central for achieving equilibrium: if the haircut is too large it deters investors from stepping in and eliminating the pricing discrepancy. Thus, the central bank by lowering the haircuts on the bonds that accepts for its reverse repo transactions can encourage investors to exploit the arbitrage opportunity and restore equilibrium in the market. These large deviations of the basis from its equilibrium value further prompt for intervention - through liquidity providing operations - by the central bank, an option that is examined in the following section.

4.4.3. Central Bank Interventions

To examine whether central bank interventions affect the relationship between liquidity in the sovereign bond and CDS markets, the VAR analysis is conducted by employing the autoregressive model of equation (4.2) and including the same endogenous variables employed in the initial analysis of Section 4.4. In Europe, the panel starts from September 30 2008, i.e., shortly after the Lehman Brothers default and the Irish government guarantee provided to six large Irish banks; these events mark the beginning of a significant re-pricing of European sovereign debt by international investors.

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103 This strategy will be further unprofitable in the case of an eventual default of the issuer.

104 In a reverse repo transaction the holder of cash agrees to purchase the asset (e.g., bond) and concurrently agrees to resell the asset for an agreed price in the future. That way the seller can obtain short-term funding.

105 The analysis in this section follows that of Pelizzon et al. (2015) for the Italian sovereign bond market.
The panel is further split in three samples, with the first cut-off date being May 10 2010, which represents the onset of the ECB's SMP, and the second is on December 21 2011, i.e., the introduction of the LTROs.\footnote{The Bai and Perron test for structural change breaks gives roughly similar cut-off points for the European and US markets.} Thus, in Europe, the first period of examination represents the onset of the 2008 financial crisis and also includes the build-up and the first stage of the European sovereign debt crisis. It is also a period free of large-scale central bank interventions, similar to those observed in the other two examination periods, when the SMP and the LTROs programmes were implemented respectively. In the US, the cut-off point is on November 3 2010, which corresponds to the announcement of the Fed's QE2 and the purchase of Treasury securities. To control for the EU short selling ban, a dummy variable equal to one (otherwise zero) is included for all the observations after the adoption of the ban, i.e., after November 1 2012. The resulting IRFs are presented in Figure 4.4.

An initial interpretation of the graphs is that cross-market liquidity dynamics exhibit certain differences between the three periods of examination in Europe. Differences are also observed with regards to the impact of asset illiquidity shocks on the no-arbitrage relationship between the European sovereign bond and CDS markets. In particular, during the pre-ECB interventions period, we can see signs of the imminent (when being back in late 2008) Eurozone debt crisis in the significant impact exerted by bond illiquidity on the illiquidity of the CDS market in the countries later hit the most by this crisis. This is in contrast to the picture observed in the Northern European countries, where the illiquidity of the CDS market exhibits a rather weak response to bond illiquidity shocks, which lies around the 0.2 to 0.6 level (in units of standard deviation). This is observed in Finland, France, Germany, and the Netherlands, and is considerably lower than their full-sample response (where it was between 1 and 1.5 standard deviations).

However, this is not the case in the weaker economies of the European North, such as Austria, and Belgium. In these countries, along with the Southern European countries, and Ireland, shocks to bond illiquidity induce movements in CDS illiquidity significantly higher than their full-sample
values. These movements increase from the range of 0.3 to 0.6 standard deviations in the full panel to 1, 1.7 and 2.5 in Spain, Italy, and Greece respectively (or rise from 1 to 2 in Austria, and Belgium), thus pointing to a period of extreme bond market influence and/or increased sensitivity on the part of the CDS market. There is also an increasing influence of the CDS market in all EMU states, since CDS-originated illiquidity shocks exert a greater impact on the basis relative to bond illiquidity shocks. The increasing pressure and the repricing on the European sovereign debt is evident in the Eurozone periphery countries and Germany, where bond and CDS illiquidity shocks act as a limit to arbitrage (bond illiquidity widens the basis in Italy, Germany, and Spain, while CDS illiquidity in Greece, and Portugal).

When moving to the period during which the ECB's SMP programme was being implemented, the cross-market liquidity dynamics are relatively weaker; both the impact of CDS illiquidity on bond illiquidity, as well as the reverse, are now relatively weaker compared to the period before the ECB' interventions. The impact of cross-market illiquidity shocks is still stronger when these shocks are generated in the bond rather than in the CDS market, however they are not able to induce movements in CDS illiquidity above 0.2 and 0.5 standard deviations in the Eurozone's core and periphery respectively, i.e., less than half in magnitude compared to the pre-interventions period.107

The transition from the SMP to the LTROs is marked by an increase in the cross-market influence of both the bond and CDS market illiquidity shocks in the periphery, as well as in the core countries. However, as it is also the case in the previous two periods, illiquidity shocks stemming from the bond market continue to exert the stronger cross-market impact on illiquidity relative to those shocks that stem from the CDS market. The size of this impact generally lies between the values assumed during the pre-interventions and the SMP period.

107 Due to the fact that the Greek government bonds have not been trading for the major part of the period following the LTROs, the results for Greece during the particular period should be interpreted with caution. In addition, from September 2011 to February 2012 only €7 million of Greek bonds changed hands.
The same pattern is further observed with regards to the impact of illiquidity shocks on the CDS-bond basis: their impact weakens during the SMP period, and strengthens with the introduction of the LTROs. This pattern however, only concerns the core countries, those in the periphery follow the reverse course with regards to the illiquidity shocks that originate in the bond market. This difference in the effect of bond and CDS market illiquidity when moving from the core to the periphery becomes apparent in the LTROs period. In particular, while in the former bloc of countries, this effect is stronger than in the SMP period, in the latter bloc, the basis is less responsive to bond and CDS illiquidity shocks.

The SMP programme also appears to have affected the pricing in the European sovereign debt markets and to have also corrected certain price discrepancies. In specific, bond illiquidity's role as a limit to arbitrage in the periphery is counter acted by CDS illiquidity, which appears to drive the basis towards the exact opposite direction. Thus, the impact of illiquidity shocks that stem either from the bond or the CDS market on the basis not only has generally decreased relative to the pre-SMP period, their net effect on the basis is also smaller. The transition to the LTROs period, although has further limited the pressure on the basis exerted by illiquidity shocks in the countries of the EMU South, it nevertheless coincided with a significant increase in the same pressure exerted by illiquidity shocks in the EMU North. Furthermore in the same bloc, the cases where the widening of the basis is caused by CDS illiquidity shocks have increased in number.

In the US, the distinction concerns the periods before and after the onset of the QE2 programme, however the general characteristics are unchanged during both periods: Bond illiquidity shocks are the major determinants of movements in CDS illiquidity and the basis, and further act as limits to arbitrage during the pre- and post-interventions periods. However the cross-market impact of both bond and CDS illiquidity shocks, as well as their impact on the basis is relatively greater after the

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108 Bond illiquidity continues to cause a widening of the basis in the periphery countries, as well as in France, Germany, and the Netherlands, however in these latter countries CDS illiquidity also appears to cause a widening of the basis.
Fed's QE2. This suggests that the purchase of Treasury securities resulted in a stronger connection between the liquidity of the two assets examined.

These findings are consistent and extend those of Brunnermeier (2009) and Pedersen (2009), who illustrate the role of insufficient liquidity in aggravating the financial crisis: the analysis of this section reveals that insufficient liquidity constitutes a negative factor for the Eurozone crisis as well. It does so by showing that liquidity injection improves the cross-asset information transmission, while also moves the CDS-bond basis towards its equilibrium value, thereby contributing to the efficient pricing of sovereign bonds and CDS contracts. Thus, the role of central bank as liquidity provider is successful in limiting the price discrepancies where it is most needed, i.e., in the stressed markets of the EMU South.

Overall, two implications arise with regards to the ability of central bank interventions to affect the cross-asset liquidity dynamics. First, bond market-stemming illiquidity shocks have a weakening impact not only on CDS illiquidity, but most importantly on the CDS-bond basis during the SMP's implementation period. This acts as supporting evidence about the favourable effect of asset purchases on restoring the information transmission during crises. It further provides a rationale for the massive purchases of public sector securities under the ECB's quantitative easing from January 2015 onwards. Second, this effect appears to be somewhat reversed following the end of the SMP and the transition to the LTROs. This implies that the provision of loans by the central bank should be accompanied by the simultaneous intervention in the cash market through the purchase of government bonds. Otherwise, the fiscal stress and the rise in the borrowing costs - especially in the periphery - is likely to crowd out the provision of cheap credit through the refinancing operations.

Hence, according to this section's analysis the central bank purchases of government bonds are qualified as the preferred means for injecting liquidity and facilitating the efficient pricing in the European sovereign credit and derivatives markets. This is further implied for the US, where the bond market leads liquidity discovery and also exerts the stronger impact on the CDS-bond basis. Therefore although the QE mainly targeted private sector securities, that portion of the QE series that included the purchase of government bonds appears to have restore equilibrium between the bond and CDS
markets. In this case however, the impact of US monetary policy on the convergence of the basis is transmitted through the CDS rather than the bond market.

4.4.4. Uncovered CDS Ban

Under the suspicion that sovereign CDSs aggravated serial European debt crises, EU regulators banned uncovered positions in sovereign CDSs; the ban was effective November 2012. However, this ban was opposed by IMF on the grounds that a liquid sovereign CDS market, will react faster and incorporate information quicker in times of financial market stress compared to the bond markets. This was further reinforced by the “covered” CDS notion: the availability of CDS protection for the investors' sovereign bond holdings is likely to attract traders in the sovereign bond market and thus, cause an increase in sovereign bond market liquidity. Hence, the IMF's argument was based on the hypothesis that the increase of CDS liquidity due to naked CDS trading, acts as an indirect channel for the increase in bond market liquidity.

To examine in practice the validity of the above arguments and identify the nature of the relationship between the European sovereign bond and CDS market liquidity after the introduction of the ban, the VAR model in equation (4.2) is employed, splitting the panel in two samples, one for the period after the ban, i.e., after November 1 2012, and one for the period before. A dummy variable equal to one (otherwise zero) is additionally used for all observations for which the ECB's unconventional policy measures analyzed in Section 4.4.3 (the SMP and the LTROs) were effective, i.e., from May 10 2010 onwards.

The IRFs in Figure 4.5 provide evidence of an inverse relationship between shocks to the illiquidity of the CDS market and movements in bond illiquidity for most of the EMU member-states in the sample. In particular, a deterioration in the liquidity of the CDS market increases the liquidity in

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109 The EU's decision was formed on the basis that by allowing investors to bet on and profit from a sovereign default without even owning the underlying government bonds, the sovereign debt market was prone to speculation and overshoot; this in turn discourages investors and accelerates bailouts and/or sovereign defaults.

110 Greece is omitted from the examination due to the non-availability of bid-ask spreads in the post-ban period.
the bond market. The only case where a positive CDS illiquidity shock leads to an increase in bond illiquidity is in Ireland, the Netherlands, and Spain; however, in the last two countries the effect is rather small and insignificant.

[Insert Figure 4.5 about here]

In the rest two of the periphery countries, which may have been the target of speculative attacks, there is no evidence of CDS illiquidity exerting a positive impact on bond illiquidity: in Italy a widening of its CDS absolute bid-ask spreads leads to a significant tightening of its bond quoted bid-ask spreads that reaches the 4 basis points (or about 0.4 standard deviations). The same is true for Portugal where bond liquidity improves by about 2 basis points (or 0.1 standard deviations) following an increase in the illiquidity of the Irish CDS. In the EMU’s two largest economies, i.e., Germany, and France, CDS liquidity is also inversely (albeit weakly) related to bond liquidity. Finally, in the least strong economies of the Eurozone's core, such as in Austria, and Belgium, which the analysis thus far has shown that in some cases behave like the debt-laden countries of the periphery, a rise in CDS illiquidity also leads to an improvement of liquidity in the bond market by approximately 0.3 and 0.6 standard deviations.

4.4.5. Discussion

The econometric analysis of Sections 4.4 confirms the existence of liquidity linkages between the sovereign bond and CDS contracts. Results suggest that the sovereign bond market leads liquidity discovery relative to the SDS market in all EMU member-states and the US, since cross-market illiquidity shocks are significantly greater in size and duration when they are transmitted from the bond market to that of CDSs. This persistency in the transmission of sovereign bond liquidity is in line with the expectation about the cross-asset liquidity dynamics stipulated in Hypothesis 1. The analysis further provides evidence of an asymmetric interaction between liquidity developments in the European sovereign bond and CDS markets. In particular, while in the countries of the European North, CDS illiquidity shocks also appear able to induce movements in bond illiquidity (even of a
limited size), in the European South, CDS illiquidity has a rather insignificant impact on the level of illiquidity in the bond market.

One interpretation for this varying relationship is that before the crisis the cash market was considerably more liquid than the CDS market for most European sovereigns (see BIS 2010; Delatte et al., 2012). The onset of the Eurozone crisis however was marked by a significant increase of outstanding CDSs, especially for those member-states under market pressure, and by a consequent increase in the liquidity of those sovereigns' CDS contracts, that might have led to a disassociation between (liquidity) movements in the sovereign bond and CDS markets. This disassociation might have further been exacerbated by the use of CDSs as a speculative tool, a use that could have driven their prices and liquidity up, and thus weakened their link with the underlying fundamentals and/or actual risks.

This significant responsiveness of CDS liquidity to liquidity movements in the periphery's bonds verifies the notion about a prominent liquidity effect - in this case stemming from the sovereign bond market - being exerted on sovereign CDSs, especially during periods of tightening financial conditions (see Gomez-Puig, 2006; Beber et al., 2009). One major implication for policy makers and investors is that during periods of market stress, sovereign bond markets appear to incorporate information faster and more accurately than sovereign CDS markets for countries under fiscal strain. This suggests that bond yields can perform better as indicators of those countries' credit risk than their respective CDS spreads, which might contain an element of exaggeration.

When the role of arbitrage activities is taken into account, sovereign bond liquidity appears to exert the largest influence on the basis. The impulse response analysis suggests that a positive shock to bond illiquidity generally leads to a widening of the basis. Hence, bond illiquidity appears to be the major driver of the deviations from the theoretical one-to-one no-arbitrage relationship between bonds and CDSs, thereby confirming Hypothesis 3. The analysis also confirms that the no-arbitrage condition is not affected in a uniform manner during the different phases of the European sovereign debt crisis. During the evolution, as well as the main stage of the crisis, bond illiquidity emerges as the variable exerting the strongest pressures on the basis. This is a rather unsurprising result,
considering the funding constraints, i.e., the limited ability of financial institutions to borrow against their securities, and the mispricing in financial markets, which is a direct consequence of the 2008 financial crisis (Brunnermeier and Pedersen, 2009; Gârleanu and Pedersen, 2011).

The central bank purchases during the main stage of the crisis however, appear to have limited the price deviation caused by bond illiquidity, a result in line with the preferred habitat theory (Vayanos and Vila, 2009; Greenwood and Vayanos, 2010; Gromb and Vayanos, 2012). During the same period the presence of CDS illiquidity as an additional factor affecting (albeit moderately) the basis is also explained by the vast changes in the information set during that period that are primarily manifested through the CDS market. The ECB's large-scale liquidity facilities and loose collateral policy in the later period of the crisis seem to have further relieved the pressures on the basis, especially with regards to the EMU periphery countries. These findings confirm Hypothesis 2 and are also supportive of a more expansionary monetary policy on the part of the ECB, such as the €1.1 trillion government bond purchases programme, in order to further improve sovereign bond market liquidity with the goal of restricting its role as a limit to arbitrage and thus, helping the CDS-bond basis converge (near) to its equilibrium value.

When notable focus is given to the periods during which the ECB interventions have taken place, the nature of the liquidity dynamics between the sovereign bond and CDS markets exhibit considerable differences with regards to the “non-interventions” period. In specific, sovereign bonds continue to retain a lead in liquidity discovery, however their impact of illiquidity shocks are considerably contained during the SMP period, and relatively stronger thereafter. It appears that the ECB's open market purchases have exerted the intended impact on the cash market, since when these type of interventions target a specific security (e.g., sovereign bonds), they are expected to affect the price of those securities when market stress and capital constraints are high. These results are not only consistent with the recent predictions of the revised preferred habitat theory, but also supportive of the arguments that in periods of financial crises and interbank lending stoppage, the central banks - through open market purchases - are more efficient in injecting (and transferring liquidity) in the market (Vayanos and Vila, 2009; Acharya et al., 2012; Gromb and Vayanos, 2012).
To this end, they might have been effective in inducing a strong enough (positive) shock to primary dealer funding liquidity in order to force market-makers to increase their inventories and thus provide more liquidity to the markets, which would further result in a consequent increase in market liquidity.\(^{111}\) The end result is that, shocks to the bond market have ceased to induce excessive movements in the liquidity of the CDS market during the period of the open market purchases. In this point it should be noted that bond and CDS markets exhibit varying sensitivity to different factors; CDS contracts tend to be more dependent on institutional factors, such as specific settlement procedures, and most importantly, on differing definitions of credit events (debt restructuring or outright defaults).\(^{112}\) Since the likelihood of credit events occurring has been significantly greater for the periphery countries during the initial and the main stage of the crisis, this likelihood might have been better reflected in the increase in the impact of CDS illiquidity shocks on the level of bond liquidity during the respective periods (although this impact is weaker than that of bond liquidity on CDS liquidity).

The inverse relationship between bond and CDS market liquidity in most EMU countries during the post-ban period lends support to the ECB's decision to stop the trading in uncovered CDS protection. The fact that after the ban, the fall in CDS illiquidity can lead to an improvement - rather than to a deterioration - in bond liquidity, challenges the dissidents who oppose the EU’s decision on the grounds that the ban could negatively affect sovereign bond market liquidity, as well as cause dislocation in other markets.\(^{113}\) It further casts doubt on the view that bans on short selling are generally viewed as merely reducing market liquidity and hindering price discovery (Beber and Pagano, 2013).

\(^{111}\) For a detailed analysis of the mechanics see Brunnermeier and Pedersen (2009).

\(^{112}\) Such settlement procedures include cash or physical settlement, with or without “cheapest-to-deliver” options for protection buyer. In fact, on March 9 2012, Greece agreed to a restructuring deal with 95.7% of private holders of Greek government bonds; this percentage increased to 96.9% on April 20 2012.

\(^{113}\) The critique on the ban on naked sovereign CDSs was originated by the IMF (see inter alia IMF Global Financial and Stability Report, April 2013).
Overall, the strong influence of the sovereign bond market is consistent with the fact that a liquidity shock that comes solely from funding constraints or from central bank interventions, will likely move from the cash to the derivative market (Pelizzon et al., 2015). On the other hand, a change in liquidity that is due to a change in the information set available to investors, will probably move from the derivatives market to the cash market. This last proposition is compatible with the relative increase in the sovereign CDS market's influence during the main stage of the sovereign debt crisis. However, the ample availability of central bank-provided liquidity combined with the easing in the ECB's collateral policy managed to contain the impact of sovereign CDSs, and contributed to the already substantial lead of the sovereign bond market in liquidity discovery.

4.5. Conclusion

This chapter analyzes the joint dynamics of sovereign bond and CDS liquidity in Europe and the US from January 2006 to June 2014. The choice of the particular assets and markets is not arbitrary, since bonds and CDSs are linked by arbitrage and are also employed in a number of different trading strategies, with this trading occurring in considerably liquid markets. Furthermore, the European and US markets were subject to numerous informational shocks, primarily, due to the fiscal developments in the Eurozone. To this end, they were the target of an unprecedented intervention by the central banks as the crux of an attempt to inject liquidity and ease market stress. They have further been the subject of a heated debate initiated by the IMF with regards to the decision of European authorities to prohibit uncovered purchases of sovereign CDS protection and the resulting consequences of this prohibition for the liquidity of the underlying sovereign bond market.

The findings of this chapter suggest that sovereign bonds and CDSs are linked via liquidity. The liquidity linkages are found to be stronger in the EMU North, where liquidity is primarily transmitted from the bond market to that of CDSs, although shocks in the latter also appear able to induce movements in bond illiquidity (even of a limited size). The opposite situation is evident in the EMU South, where liquidity shocks stemming from the bond market are the only determinants of cross-market liquidity interaction. Overall, sovereign bond liquidity exerts a stronger and longer-
lasting impact on the liquidity of the sovereign CDS market than the reverse. Hence, the sovereign bond market appears to have replaced the SCDS market as the most efficient indicator of sovereign credit risk, especially in countries under significant fiscal strain. It might be the case that SCDSs might have over-reacted to underlying fundamentals, thereby suggesting that are driven primarily by idiosyncratic rather than systematic risk (an argument in line with Longstaff et al., (2011)).

Liquidity in the European sovereign bond market is found to exert a significant impact on the difference between the spread of the sovereign bond over the swap rate and the spread of the CDS contract written on it; this is due to the higher illiquidity and liquidity risk in the sovereign bond market (in terms of the mean and volatility of the quoted bid-ask spread) relative to that in the CDS. This greater illiquidity imposes a limit to the arbitrage mechanism between sovereign bonds and CDSs, with a consequent impediment on the frictionless transmission of liquidity from one asset to the other, that is expected to occur in any assets linked by arbitrage. This in turn verifies in practice the arguments that between any two assets, it is the less liquid one that acts as a limit to arbitrage (see Roll et al., 2007; Gârleanu and Pedersen, 2011; Nashikkar et al., 2011).

The empirical analysis suggests that the ECB interventions, and in particular the asset purchases under the SMP, have affected the bond-CDS liquidity dynamics and most importantly, relieved the pressure on the CDS-bond basis exerted by bond illiquidity. This is in line with the prediction of the preferred habitat theory and provides a justification for the large-scale government bond purchases under the ECB's quantitative easing programme. Of particular importance is also the finding that the period following the naked CDS ban in Europe, a deterioration in the CDS market's liquidity leads to an improvement in the liquidity of the bond market in most EMU countries. This is in contrast to Beber and Pagano's (2013) predictions and additionally implies that the purchase of credit derivatives without owning the underlying security has a destabilizing effect on the liquidity of the underlying market.

The implications of the present study further concern the ability of monetary policy to affect the sovereign bond-CDS equilibrium relationship, and through this relationship the efficient pricing of sovereign bonds and CDS contracts. Despite that expansionary monetary policy shocks prevents
illiquidity from acting as a limit to arbitrage, as Section 4.4.2 revealed these limits to arbitrage are
present in the long run, especially in the countries of the EMU South. This points to the need that the
quantity of the government securities purchased under the ECB's QE be increased and specifically
target the debt-laden countries of the Eurozone periphery. It thus, provides an argument in favour of
the ECB's imminent 1.1€ trillion asset purchases programme. Second, since the European sovereign
CDS contracts are denominated in US dollars, the ECB could adjust the provision of US dollars
through its US dollars standing swap arrangement, i.e., a bilateral swap line with the Federal Reserve.
By increasing the frequency and maturity of these US dollar liquidity-providing operations, the ECB
can provide the necessary funding liquidity in US dollars and re-establish the no-arbitrage condition
across the European sovereign credit and derivatives markets.

On the regulatory front and still within the ECB's scope of responsibility, the ECB through
the Single Supervisory Mechanism (SSM) has assumed the supervision of the euro area banking
system. In this respect, new regulatory proposals - along with an increase in the level of
countercyclical capital buffers - should entail the upward revision of the current requirements for
holding liquid assets and extend these requirements to the sovereign issues of the Southern EMU
countries regardless of their credit rating. This would stimulate demand, and consequently trading, for
those countries' government securities and thus increase their liquidity. Lastly, the positive impact of
CDS illiquidity on sovereign bonds serves as supporting evidence of the EU's decision to ban the
purchase of uncovered CDS protection. It further constitutes a guide for the future regulatory
treatment of the disequilibrium between financial assets linked by arbitrage.
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<td>The quoted bid-ask spread for the 5-year on-the-run sovereign bond. Calculated by collecting the bid price and the ask price for the on-the-run bond. To compute the quoted bid-ask spread we subtract the bid price from the ask price and we divide it by the half of the sum of the ask price plus the bid price. The ratio is the quoted bid-ask spread for the bond.</td>
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<tr>
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<td>Daily/Weekly</td>
<td>BLOOMBERG</td>
<td>The quoted bid-ask spread for the 5-year sovereign CDS contract. Calculated by collecting the bid price and the ask price for the CDS. To compute the quoted bid-ask spread we subtract the bid price from the ask price and we divide it by the half of the sum of the ask price plus the bid price. The ratio is the quoted bid-ask spread for the CDS.</td>
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<td>The return on the 5-year on-the-run sovereign bond. Calculated by collecting the mid price for the on-the-run bond. To compute the return we subtract the price on day (week) ( t ) from the mid price on day (week) ( t-1 ) and we divide it by the mid price on day (week) ( t ). The ratio is the return on the bond.</td>
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<td>Daily/Weekly</td>
<td>BLOOMBERG</td>
<td>The change in the spread on the 5-year CDS contract. Calculated by collecting the spread on the CDS contract.</td>
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<td>The volatility of the return on the 5-year on-the-run sovereign bond. Calculated as the standard deviation of the daily returns on the bond during the week.</td>
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<td>The CDS-bond basis. Calculated by collecting the 24-month Eonia swap rate from Datastream. The swap rate is extrapolated to match the maturity of the bond and CDS data, i.e. 5-year. To compute the basis we subtract the swap rate from the yield on the bond, this is the spread of the bond. Then we subtract the spread of the bond from the spread on the CDS.</td>
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<td>Basis (US) Daily/Weekly</td>
<td>The CDS-bond basis. Calculated by collecting the 5-year interest-rate swap from the Federal Reserve. To compute the basis we subtract the swap rate from the yield on the bond, this is the spread of the bond. Then we subtract the spread of the bond from the spread on the CDS.</td>
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Table 4.2
Descriptive Statistics

Table 4.2 reports daily means, standard deviations, minimums, and maximums of Bond Return, CDS Spread Change, Bond Quoted Bid-Ask Spread, CDS Bid-Ask Spread, CDS-Bond Basis. Bond Return is the return on 5-year on-the-run sovereign bonds. CDS Spread Change is the spread change in 5-year sovereign CDSs, Bond Quoted Bid-Ask Spread is defined in Equation (4.1), CDS Bid-Ask Spread is the ask price minus the bid price for 5-year sovereign CDSs, CDS-Bond Basis is the 5-year sovereign CDS spread minus the excess of the 5-year on-the-run sovereign bond yield over the 5-year interest rate swap. The sample includes Austria, Belgium, Finland, France, Ireland, Italy, Germany, Greece, the Netherlands, Portugal, Spain, and USA, for the period between January 2006 and June 2014. Bond and CDS bid-ask quotes, bond returns, and CDS spreads are from the Bloomberg Generic Quote (BGN) and Composite Bloomberg Bond Trade (CBBT) pricing sources. 24-month Eonia swap rates are from Datastream and US 5-year interest rate swaps are from the Federal Reserve.

Panel A. Daily Data

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Table 4.3

Granger Causality Tests. Daily Data

Table 4.3 presents country-specific $x^2$ statistics (row 1) and the corresponding $p$-values (row 2) of pair-wise Granger causality tests between endogenous VAR variables at the daily frequency. Null hypothesis is that row variable does not Granger cause column variable. The ordering of the VAR endogenous variables is BONDRET, Bond Liquidity, BONDVOL, CDS, CDSLIQ, CDSVOL, BASIS. BONDRET is the daily return on 5-year on-the-run sovereign bonds. BONDLIQ is the daily change in the quoted bid-ask spread (Equation 4.1) for 5-year on-the-run sovereign bonds. CDS is the daily change in the spread on 5-year sovereign CDSs. CDSLIQ is the daily change in the absolute bid-ask spread for 5-year sovereign CDSs. BONDVOL. BASIS is the daily change in the value derived from the 5-year sovereign CDS spread minus the excess of the 5-year on-the-run sovereign bond yield over the 5-year interest rate swap. The sample includes Austria, Belgium, Finland, France, Ireland, Italy, Germany, Greece, the Netherlands, Portugal, Spain, and USA, for the period between January 2006 and June 2014. Bond and CDS Bid-ask quotes, bond returns, and CDS spreads are from the Bloomberg Generic Quote (BGN) and Composite Bloomberg Bond Trade (CBBT) pricing sources. European swap rates are from Datastream and US swap rates are from the Federal Reserve.


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| BONDRET   | 0.1185  | 13.223*** | 14.569*** | 14.659*** | 71.635*** | 7.8488* |
| BONDLIQ   | 0.9124  | 31.572*** | 36.035*** | 36.370*** | 32.792*** | 19.559*** |
| CDS       | 1.722   | 2.1279 | 9.7952*** | 12.673*** | 38.504*** | 15.965*** |
| CDSLIQ    | 0.3352  | 2.2279 | 3.7511*** | 12.968*** | 13.133*** | 353.25*** |
| BASIS     | 0.7106  | 4.557*  | 0.7113 | 4.8477 | 4.8477** | 6.9757 |

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| BONDLIQ   | 0.8379   | 24.431*** | 4.8242* | 18.505*** | 124.24*** | 62.867*** |
| CDS       | 9.7952*** | 10.274*** | 5.9113* | 8.203**  | 61.02***  | 29.443*** |
| CDSLIQ    | 3.7511   | 3.3619   | 1.0744 | 2.9387   | 213.51*** | 318.41*** |
| BASIS     | 0.7113   | 0.6065   | 6.9261**| 2.3877   | 30.959*** | 149.13*** |

| BONDRET   | 71.635*** | 32.792*** | 6.5999* | 30.701*** | 7.6138   | 25.561*** |
| BONDLIQ   | 17.386*** | 135.22*** | 23.169*** | 12.651*** | 251.97*** | 82.97***  |
| CDS       | 38.504*** | 44.542*** | 13.036*** | 8.7052** | 22.183*** | 39.189*** |
| CDSLIQ    | 13.133*** | 9.4454**  | 4.6028  | 2.9152   | 7069.1*** | 661.41*** |
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Figure 4.1
Country-specific Response to Endogenous Variables (Full Sample)

Graph 1. Austria.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Bond to CDS illiquidity.

Response of CDS to Bond illiquidity.

Graph 2. Belgium.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Bond to CDS illiquidity.

Response of CDS to Bond illiquidity.
Graph 3. Finland

- Response of Bond illiquidity to CDS illiquidity.
- Response of CDS illiquidity to Bond illiquidity.

Graph 4. France.

- Response of Bond illiquidity to CDS illiquidity.
- Response of CDS illiquidity to Bond illiquidity.
Graph 7. Ireland.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Graph 8. Italy.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.
Graph 11. Spain.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Graph 12. USA.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS to Bond illiquidity.

Response of Bond to CDS illiquidity.

Response of Bond illiquidity to CDS illiquidity.
Figure 4.2
Country-specific Forecasts of Illiquidity (Daily Series)

Graph 1. Austria.
Forecast of Bond illiquidity

Graph 2. Belgium.
Forecast of Bond illiquidity

Graph 3. Finland
Forecast of Bond illiquidity
Figure 4.3
Country-specific Response of CDS-Bond Basis to Bond Illiquidity and CDS Illiquidity (Full Sample)

Graph 1. Austria.

Graph 2. Belgium.

Graph 3. Finland

Graph 4. France.
Graph 5. Germany.

Graph 6. Greece

Graph 7. Ireland.

Graph 8. Italy.
Graph 9. Netherlands.

Graph 10. Portugal.

Graph 11. Spain.

Graph 12. USA.
Figure 4.4
Country-specific Response to Endogenous Variables in the Periods
Before and During the Central Bank Interventions

1. PRE-ECB INTERVENTIONS PERIOD: 30 SEPTEMBER 2008 - 10 MAY 2010

Graph 1. Austria.

Graph 2. Belgium.
Graph 3. Finland

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to CDS illiquidity.

Response of Basis to Bond illiquidity.

Graph 4. France.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.

Graph 5. Germany.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to CDS illiquidity.

Response of Basis to Bond illiquidity.
Graph 6. Greece

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.

Graph 7. Ireland

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.
Graph 8. Italy.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Graph 9. Netherlands.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Graph 10. Portugal.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.
Graph 11. Spain.

Graph 12. USA. (Pre-QE2 Period: 31 January 2006 - 3 November 2010).
2) SMP PERIOD: 10 MAY 2010 - 21 DECEMBER 2011

Graph 1. Austria.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Bond illiquidity to CDS illiquidity.

Graph 2. Belgium.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.
Graph 6. Greece.

Graph 7. Ireland.
Graph 8. Italy.
Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.

Graph 9. Netherlands.
Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.

Graph 10. Portugal.
Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.
Graph 11. Spain.

Graph 12. USA (QE2 Period: 3 November 2010 – 20 June 2014).
3) LTROs PERIOD: 21 DECEMBER 2011 - 20 JUNE 2014

Graph 1. Austria.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.

Graph 2. Belgium.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.
Graph 3. Finland

Graph 4. France.

Graph 5. Germany.
Graph 6. Greece.
Response of Bond illiquidity to CDS illiquidity.

Graph 7. Ireland.
Response of Bond illiquidity to CDS illiquidity.
Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.

Graph 11. Spain.

Response of Bond illiquidity to CDS illiquidity.

Response of CDS illiquidity to Bond illiquidity.

Response of Basis to Bond illiquidity.

Response of Basis to CDS illiquidity.
Figure 4.5
Country-specific Response to Endogenous Variables in the Period After the Ban

Graph 1. Austria.
Response of Bond illiquidity to CDS illiquidity.

Graph 2. Belgium.
Response of Bond illiquidity to CDS illiquidity.

Graph 3. Finland.
Response of Bond illiquidity to CDS illiquidity.

Graph 4. France.
Response of Bond illiquidity to CDS illiquidity.

Graph 5. Germany.
Response of Bond illiquidity to CDS illiquidity.

Graph 6. Ireland.
Response of Bond illiquidity to CDS illiquidity.

Graph 7. Italy.
Response of Bond illiquidity to CDS illiquidity.

Graph 8. Netherlands.
Response of Bond illiquidity to CDS illiquidity.
Graph 9. Portugal. Response of Bond illiquidity to CDS illiquidity.

Graph 10. Spain. Response of Bond illiquidity to CDS illiquidity.
Chapter III

Volatility and Integration in the European Sovereign Bond and CDS Markets
5.1. Introduction

In times of crisis, one might expect a larger than usual number of information-related shocks to hit all assets simultaneously, generating volatility and covariation in asset prices, and further translating mechanically into an increase in those assets' realized correlations (Aït-Sahalia et al., 2009; Aït-Sahalia and Xiu, 2016). The increase in the correlation and interconnectedness of financial asset-markets during crises is in turn more evident when markets are more volatile: the dependence of cross-market correlation coefficients on market volatility causes estimates of correlation coefficients to increase and bias upward (Forbes and Rigobon, 2002). Thus, consistent with a “risk-off” scenario, asset correlation improves due to investors decreasing their exposure across all asset classes when the environment turns negative (Aït-Sahalia and Xiu, 2016). Such a negative environment has emerged in the context of the European sovereign financial markets. The virulent transmission of negative shocks during the evolution of the Eurozone crisis coincided with a) the fiscal developments in the debt-laden European periphery countries that resulted in those countries' sovereign bond yields remaining at an elevated level for the best part of the crisis, and b) the arguments that speculation via the sovereign CDS market is additionally responsible for the skyrocketing borrowing costs across the European periphery, and that eventually led to the EU regulatory authorities' ban on uncovered positions in SCDS contracts.

This chapter examines the dynamic bilateral volatility spillovers for 11 EMU sovereign bond and CDS markets during the 2007-2014 period. The examination is conducted by calculating a volatility spillover measure on the basis of Diebold and Yilmaz's (2009, 2012) generalized decomposition of the forecast error variance of a vector autoregressive (VAR) model. In line with Bernanke et al. (2005) and Claeyts and Vašíček (2014) the VAR is augmented with two common factors reflecting developments at the EMU level that affect concurrently the sovereign bond and CDS markets. Considering the theoretically grounded (strong) relationship between volatility and correlation (see Forbes and Rigobon, 2002; Andersen et al., 2003 Aït-Sahalia et al., 2009; Aït-Sahalia and Xiu, 2016) the analysis is extended in order to examine the conditional correlation between the

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114 A discussion of the sources and channels of volatility is provided in Section 2.5.
sovereign bond and CDS markets which further constitutes a measure for the level of integration between them. This is done by means of an asymmetric generalized dynamic conditional correlation (AG-DCC) model (see Cappiello et al., 2006) that enables the calculation of the conditional correlation between each pair of sovereign bonds and CDSs in a given country. This in turn provides information on the extent to which volatility spillover leads to improved conditional correlation and whether this improved correlation restores the no-arbitrage relationship between the two assets, as reflected in the level of the CDS-bond basis.

However, the issue of financial market interconnectedness and integration has broader implications. A greater degree of market integration results in more welfare gains due to the efficient transmission of monetary policy. This is especially important when different countries are involved, since integrated markets facilitate monetary policy pass-through, thereby enabling central bank policy to exert a homogeneous impact on all countries; that way these countries can reap the gains from the coordination of monetary policy (see Oudiz et al., 1984; Oudiz and Sachs, 1985; Rogoff 1985; Benigno, 2002). Therefore, central banks have an interest in the level of market integration. This is further the case within the confines of a currency union, where according to the optimum currency area (OCA) theory (see Mundell, 1961; McKinnon, 1963) as well as previous empirical studies (Fratzscher, 2002; Baele, 2005; Kim et al., 2005, 2006a, 2006b; Hardouvelis et al., 2006) the process towards monetary convergence is expected to contribute towards a greater degree of market integration. To this end the present analysis employs a number of variables from the OCA theory along with a set of variables that proxy for the ECB's monetary policy stance in order to assess the impact of monetary convergence and of the ECB's monetary policy on the level of European sovereign bond-CDS integration.

Despite its implications for the implementation and transmission of monetary policy the importance of the examination lies in the fact that when movements in the European sovereign bond and CDS markets deviate from underlying macroeconomic and fiscal fundamentals or from idiosyncratic risk factors, such as liquidity and credit premia, they are still driven by international

115 For more information on the relationship between volatility and asset correlation see Section 2.5.
market risk factors or shocks common to the sovereign credit and derivatives markets. International factors and shocks must in turn be the outcome of developments within a country or group of countries, thereby impacting on their macroeconomic and fiscal fundamentals and inducing movements in their sovereign bonds and/or CDSs that consequently spill over to other countries, before eventually returning to the initial transmitter(s). These spillovers (primarily within the context of intra-asset examination) are found to be time-variant and state-dependent, with potential states including either the level of financial market stress (with contrasting volatility behaviour between quiet and turbulent periods), or the degree of integration between domestic markets (with improved integration enhancing similarity in volatility behaviour); they further exhibit differences in their size and direction when moving across domestic markets (see Diebold and Yilmaz (2009) and Engle et al. (2012) for international and East Asian equity markets respectively, Skintzi and Refenes (2006), Christiansen (2007), and Claeys and Vašíček (2014) for the European sovereign bond markets, and Diebold and Yilmaz (2012) for the equity, bond, foreign exchange and commodities markets).

No evidence exists so far for the European sovereign debt and credit derivatives markets, which have constituted the field of the severest tensions in the history of a currency union. These tensions not only intensified, but ultimately extended across all EMU member states and transformed into broader economic consequences, thereby resulting in the crowding out of private-sector financing and the further decline in the level of economic activity. In addition, bond and credit derivatives instruments are the ideal candidates for examining the relation between volatility behaviour and the level of integration between different asset-markets, since their integration is - theoretically - guaranteed by their no-arbitrage relationship.\textsuperscript{116} It is therefore imperative that European policy makers are provided with all available information on the nature and evolution of linkages between and within the respective asset-markets in order to formulate their monetary and macroprudential policies accordingly and thus, manage systemic risk and reduce negative spillovers across, or even beyond the Eurozone.

\textsuperscript{116} The no-arbitrage relationship between bonds and CDS contracts is discussed in Section 2.3.
Results from the VAR analysis indicate a unidirectional volatility spillover from the sovereign bond to the CDS market in all EMU countries within the context of both cross- and intra-country analysis. Germany emerges as the main transmitter of bond volatility to the CDS markets of the Eurozone core, while Ireland and Italy further assume a central role in the European financial markets framework, since they appear as significant bond and CDS volatility contributors to the rest of the European CDS markets. Thus, despite the surge in the size and importance of the SCDS market, the present analysis identifies sovereign bond markets as the most powerful vectors of information particularly during the 2010-2012 period. This constitutes government bonds as the most efficient indicators of sovereign risk, and further establishes the cash market as the means through which information is filtered and transmitted to the derivatives market.

The examination of the conditional correlation between the sovereign bond and CDS markets under the AG-DCC GARCH analysis reveals that the increase in the level of bond-CDS integration in each of the countries of the EMU South coincides with an increase in the volatility spillover between sovereign bonds and CDSs in the same countries. This provides support to the arguments about volatility being a major driver of cross-asset correlation (see Aït-Sahalia and Xiu, 2016). Interestingly the analysis points to the existence of two blocs across the Eurozone, depending on the evolution of bond-CDS integration in each bloc: while in the EMU South (Greece, Ireland, Italy, Portugal, Spain) the integration between sovereign bonds and CDS has weakened after the late 2008 and the Lehman Brothers collapse, in the rest of the EMU it has followed the reverse track. When the bond-CDS volatility interaction is examined against the CDS-bond basis capital flights emerge as the primary reason for the persistently positive CDS-bond basis in Austria, Finland, France, Germany, and the Netherlands for the duration of the main stage of the sovereign debt crisis, i.e., until late 2011-early 2012. It further documents an inverse relationship between bond-CDS conditional correlation (and therefore integration) and the CDS-bond basis in the EMU South and Belgium: post-2009, an improvement of this integration, which further suggests that sovereign bonds and CDSs are driven to a large extent by the same fundamentals, causes the basis to become negative. In the same bloc,
illiquidity and volatility appear to act as limits to arbitrage, since they coincide with the large and persistent negative values of the CDS-bond basis observed during the late 2011-mid 2012 period.

Lastly, the ECB’s monetary policy is found to be a major determinant of the degree of cross-market integration, since an easing in the ECB’s monetary policy stance exerts a strong positive impact on the level of bond-CDS conditional correlations. Thus, in times of heightened market activity such as those during the Eurozone crisis, an expansion of the central bank’s balance sheet might contribute towards greater cross-asset integration and therefore facilitate the transmission of monetary policy within each country. Along the same lines, the process towards real and monetary integration across the Eurozone emerges as an additional factor contributing to improved integration in the European sovereign debt and derivatives markets.

The main contribution of the present chapter pertains to the methodological approach adopted. Thus far empirical studies ascribe movements in the European sovereign financial markets to the conditions prevailing in international financial markets (Skintzi and Refenes, 2006; Christiansen, 2007; Claeys and Vašíček, 2014). However, the assignment of asset movements to international developments, although highlighting the importance of market correlation and integration, it is nonetheless unable to provide additional insight on the roots of these developments (Kaminsky and Reinhart, 2000; Claeys and Vašíček, 2014). Still, these developments might be ultimately generated by developments in a domestic market and consequently being transmitted to other markets, before feeding back to the originator market (Claeys and Vašíček, 2014). When these external risks are proxied with an aggregate measure that is assumed to be exogenous to developments in the domestic markets, it is further assumed that these risks affect domestic markets symmetrically; this is in turn an implausible assumption, especially when considering that volatility linkages are not equally strong between all asset-markets and/or countries (Kaminsky and Reinhart, 2000; Claeys and Vašíček, 2014). The effect exerted by large volatility shocks on the domestic markets could be different from the effect that is due to smaller volatility shocks (asymmetric response).

The employment of the generalized VAR addresses specifically the above issues. The generalized decomposition extracts all available information on the relative importance of domestic
and foreign sources of sovereign bond and CDS market dynamics across the EMU, while it further enables the examination of the size and direction of the spillover effects between and within the respective asset-markets (Diebold and Yilmaz 2009, 2012). Thus, the decomposition differentiates between domestic and foreign drivers of sovereign bond and CDS market dynamics, thereby providing an accurate measure of the bilateral spillover between the two markets. In addition, the augmentation of the VAR with common factors allows for the inclusion of an additional feedback channel from common shocks to the EMU sovereign debt and derivatives markets. Most importantly, the inclusion of those shocks in the VAR specification treats those shocks as endogenous to the system. The shocks' endogenous nature is a more plausible assumption within the context of volatility spillover since - compared to the assumption of exogeneity - allows for the simultaneous feedback between domestic markets.

Along these lines, and in consistency with Diebold and Yilmaz (2009, 2012), the adoption of the generalized impulse-response framework of Koop et al. (1996) and Pesaran and Shin (1998) accounts for the correlation of shocks to all domestic markets by means of their historically observed distribution. Hence, the factor augmented version of the generalized VAR not only provides a causal direction of volatility spillover across and within the sovereign bond and CDS markets, but further excludes simultaneity due to the employment of the common factors (Bernanke et al., 2005; Diebold and Yilmaz, 2009, 2012; Claeys and Vašíček, 2014). The recursive examination of the factor-augmented VAR through the employment of rolling windows yields dynamic estimates that further allows the analysis to deviate from the static picture that summary measures provide. To this end, the time-dependent nature of the new spillover measure provided by the recursive estimations enables the monitoring of the cross- and intra-market linkages' evolution throughout the examination period, while revealing the existence of potential breaks in those linkages' evolution.

An additional contribution of the present chapter relates to the examination of the sovereign bond-CDS integration per se. Thus far, the (extreme) comovements between the bond and CDS markets have been examined in a lead-lag framework, with a focus on the price discovery process.
between the two markets.\footnote{These studies are presented in Sections 2.3.1 to 2.3.3.} When asset prices move together this constitutes an indirect evidence on the expectations of markets participants and how they respond to changes in the information set (Kim et al., 2006b). However, while this type of examination identifies the asset market in which information is reflected first and then transmitted to the other asset market (which asset market provides more timely information), the issue of integration examines the entire picture, that is, the degree of overall correlation between asset markets (Blanco et al., 2005; Kim et al., 2006b). This is an important distinction, since one market might lead the other in terms of price discovery, but the market lagging the price discovery process might be affected by other exogenous factors that could cause overall movements in that market to be disassociated with movements in the former market. Existing studies have examined bond and CDS comovements within a lead-lag framework, or treated them as time-invariant correlations or covariances, but not from the perspective of bond and CDS market integration. To this end, the modelling of these comovements through an AG-DCC GARCH model is able to capture the dynamic and time-varying nature of the bond-CDS relationship, while allowing for the “asymmetric volatility” phenomenon, according to which financial asset volatility increases more following a negative rather than a positive shock of the same magnitude. This is in turn necessitated by the negative financial and fiscal shocks that have characterized the ongoing European debt crisis. The consideration of these shocks’ impact on market integration as well as the impact of non-standard measures adopted by the ECB as a response to these shocks is an issue that remains unexplored.

The analysis of this chapter further constitutes the first empirical assessment of the link between the integration of any two assets (through their conditional correlation) and those assets' equilibrium relationship. When two assets are linked by arbitrage - such as in the case of a derivative instrument and the underlying cash contract - any change in their correlation will cause a deviation from the prices that guarantee their equilibrium relationship and thus, give rise to arbitrage opportunities. The efficient markets approach to arbitrage dictates that these arbitrage opportunities should be eliminated by the actions of a large number of investors, each with limited additional
exposure to any of the two assets. However, the assets prices' diversion away from their fundamental values, renders arbitrage ineffective, with the consequent mispricing reflecting not some exposure to difficult-to-measure macroeconomic risks, but rather, high idiosyncratic volatility risk (Shleifer and Vishny, 1997). This in turn leads to a paradox, in that - at least theoretically - high volatility is linked to more frequent extreme mispricing, and therefore to continuous opportunities for earning a riskless profit. This paradox is explained by the fact that it is the combination of both volatile and illiquid assets, that causes arbitrageurs to avoid extremely volatile “arbitrage” positions, since - despite the likelihood of excess returns - volatility further exposes professional arbitrageurs to increasing losses and the need to liquidate the portfolio under pressure from the investors in the fund (Shleifer and Vishny, 1997). Since this combination of excess volatility and illiquidity is the case in a number of European sovereign bond and CDS markets, especially those in the EMU South, this provides us with the opportunity to identify in practice whether these factors are indeed associated with mispricing between those asset-markets, and therefore with a status away from equilibrium.

The remainder of the Chapter proceeds as follows. Section 5.2 provides the empirical method for the calculation of the volatility spillover measure based on the Diebold and Yilmaz's (2009, 2012) VAR. Section 5.3 analyzes the empirical findings at the intra- and cross-country level. Section 5.4 presents the AG-DCC GARCH model employed for the analysis of sovereign bond-CDS integration. Section 5.5 assess the link between bond-CDS integration and the CDS-bond basis, and Section 5.6 examines the role of monetary policy. Section 5.7 concludes.

5.2. Factor-augmented VAR

5.2.1. Cross- and Intra-asset Spillovers

Since the objective of this chapter is to measure the cross- and intra-market spillovers between the European sovereign bond and CDS markets, the method employed is the Diebold and Yilmaz (2009, 2012) generalized VAR framework for measuring directional spillovers, based on the forecast error variance decomposition of the VAR. This method further eliminates the possible dependence of
results on ordering and hence, is the most appropriate for the large number of endogenous variables employed in this study. The covariance-stationary $N$-variable VAR($p$) is:

$$x_t = \sum_{i=1}^{p} \Phi_i x_{t-i} + \epsilon_t$$  \hspace{1cm} (5.1)

where $\epsilon \sim (0, \Sigma)$ is a vector of independently and identically distributed disturbances, the moving-average representation of which is:

$$x_t = \sum_{i=0}^{\infty} A_i \epsilon_{t-i}$$  \hspace{1cm} (5.2)

with some regulatory conditions being imposed on the $A_i$ matrices.

These moving average coefficients (or transformations such as variance decompositions) are the key to understanding the VAR dynamics, since the decomposition of the variance of the $H$-step ahead forecast error on one of the asset prices $x_i$ represents the percentage of the variance attributed to shocks in the asset price $x_j$ ($\forall j \neq i$, for each $i$).

Diebold and Yilmaz (2009, 2012), define own variance shares to be the fractions of the $H$-step-ahead forecast error variances in forecasting $x_i$ due to shocks to $x_i$, for $i = 1, 2, \ldots, N$, and cross variance shares (or spillovers) to be the fractions of the $H$-step-ahead forecast error variances in forecasting $x_i$ due to shocks to $x_j$, for $i, j = 1, 2, \ldots, N$, where $i \neq j$. In order to use the information in the variance decomposition matrix for the calculation of the spillover index, the $H$-step-ahead forecast error variance decompositions $\theta^\theta_{ij}(H)$, are normalized by the row sum as:

$$\tilde{\theta}^\theta_{ij}(H) = \frac{\theta^\theta_{ij}(H)}{\sum_{i=1}^{N} \theta^\theta_{ij}(H)}$$  \hspace{1cm} (5.3)

where by construction $\sum_{j=1}^{N} \theta^\theta_{ij}(H) = 1$ and $\sum_{i,j=1}^{N} \theta^\theta_{ij}(H) = N$. The term $\tilde{\theta}^\theta_{ij}(H)$, is essentially the own variance shares when $i = j$, or the cross variance shares when $i \neq j$. The cross variance shares are employed by Diebold and Yilmaz (2009, 2012) to measure the spillover from $x_i$ to $x_j$, and in our case represent: a) the percentage contribution of a change in a country's bond yield to

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118 Diebold and Yilmaz (2009, 2012), set the $N \times N$ coefficient matrices $A_i$ to obey the recursion $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \ldots + \Phi_p A_{i-p} A_0$, with $A_0$ being a $N \times N$ identity matrix and $A_i = 0$ for $i < 0$. 

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the variation in the another country's CDS spread, i.e., the intra-asset contribution, and b) the percentage contribution of a change in a country's bond yield (CDS spread) to the variation in another country's bond yield (CDS spread), i.e., the cross-asset contribution. This can be more comprehensible with the help of the matrix $\Theta$ below, where the off-diagonal elements represent all bilateral linkages to and from two assets $x_i$ and $x_j$, while the main diagonal represents the own linkage of asset $x_i$.

$$\Theta = \begin{bmatrix}
\bar{\theta}_{11}(H) & \bar{\theta}_{12}(H) & \cdots & \bar{\theta}_{1N}(H) \\
\bar{\theta}_{21}(H) & \bar{\theta}_{22}(H) & \cdots & \bar{\theta}_{2N}(H) \\
\vdots & \vdots & \ddots & \vdots \\
\bar{\theta}_{N1}(H) & \cdots & \cdots & \bar{\theta}_{NN}(H)
\end{bmatrix}$$

(5.4)

In this case, $\bar{\theta}_{12}(H)$ represents the contribution from a shock in country 1’s bond yield or CDS spread, to country 2's bond yield or CDS spread (depending on which country-specific asset characterizes row 2 and which column 1), otherwise stated, the spillover from country 1’s asset to country 2’s asset. Similarly, $\bar{\theta}_{21}(H)$ represents the contribution of a shock accounting for the country 1's own asset price movements.

This in turn forms the basis for the calculation of a total spillover index, which measures the contribution of spillovers of volatility shocks across all country-specific assets in the generalized VAR to the total forecast error variance:

$$S^\theta(H) = \frac{\sum_{i|j=1}^N \bar{\theta}_{ij}(H)}{\sum_{ij=1}^N \bar{\theta}_{ij}(H)} \cdot 100 = \frac{\sum_{i|j=1}^N \bar{\theta}_{ij}(H)}{N} \cdot 100$$

(5.5)

The normalized elements of the generalized variance decomposition matrix are further employed to calculate the directional spillovers, which display the direction of the spillover of a country's asset being transmitted to the rest $N$-1 assets in the system. These are simply defined as the sum of the column-elements of the matrix $\Theta$ minus the own asset contribution, or:

$$S^\theta_i(H) = \frac{\sum_{j=1}^N \bar{\theta}_{ij}(H)}{\sum_{i|j=1}^N \bar{\theta}_{ij}(H)} \cdot 100$$

(5.6)

In a similar respect, the directional spillovers received by a country's asset from the rest $N$-1 assets in the system, is defined as the sum of the row-elements of the matrix $\Theta$ minus the own asset contribution, namely:
This set of directional spillovers is essentially the decomposition of total spillovers into two categories: those being transmitted to- and those received from a particular asset. The net directional volatility from asset to all other N-1 assets in the VAR, which indicates whether an asset is a transmitter or receiver of volatility, is consequently defined as the difference between equations (5.6) and 5.(7), or:

\[ S^\theta(H) = S^\theta_{ij}(H) - S^\theta_{ji}(H) \]  

Finally, the calculation of the net pairwise volatility spillovers reveals the extent to which each asset \( i \) contributes to the volatility of asset \( j \) in net terms. This is simply the difference between the gross volatility shocks transmitted from asset \( i \) to asset \( j \) and those transmitted from asset \( j \) to asset \( i \):

\[ S^\theta_{ij}(H) = \left[ \frac{\theta^\theta_{ij}(H)}{\sum_{k=1}^{N} \theta^\theta_{ik}(H)} - \frac{\theta^\theta_{ji}(H)}{\sum_{k=1}^{N} \theta^\theta_{jk}(H)} \right] \cdot 100 \]  

Since directional spillovers and pairwise spillovers are derived from the forecast error variance decomposition of the generalized VAR, some additional economic information might not be captured by the system. This is due to the fact that, by construction, these variance decompositions can be observed only for the included variables, which in turn might constitute only a subset of the variables researchers and policymakers care about, especially with regards to the examination of sovereign bonds and CDS comovements, which pertains to both monetary policy, as well as to financial markets analysis (Bernanke et al., 2005). To additionally control for the possibility of shocks that are exogenous to the VAR system, we follow Bernanke et al. (2005) and Claeys and Vašíček (2014) and augment the system with two variables that represent the common response of bond yields and CDS spreads respectively to those exogenous shocks. The Bernanke et al. (2005) factor-augmented VAR (FAVAR) assumes that the informational time series \( X_t \) are related to the unobservable factors \( F_t \) and the observed variables \( Y_t \) by the following equation:

\[ X_t = \Lambda^f F_t + \Lambda^Y Y_t + \varepsilon_t \]  

\[ 100 \]
where $A_f$ is a $N \times K$ matrix of factor loadings, $A_v$ is a $N \times M$, and $\varepsilon_t$ is a $N \times 1$ vector of zero mean innovations.\footnote{Bernanke et al. (2005), assume that the innovations are either normal and uncorrelated or display a small amount of cross-correlation, depending on whether estimation is by likelihood methods or principal components.} To construct these additional variables factor analysis is employed in order to extract the common factors that account for the greatest amount of variance among the observed variables. The Kaiser criterion is used to determine the number of factors to be retained and that consequently enter the principal factor analysis for the estimation of the factor loadings. Then the scores from the factor analysis conducted for the bond yields and the CDS spreads are included separately as endogenous variables in the FAVAR in addition to the initial set of observable variables. This allows for the identification of direct linkages between any two assets $i$ and $j$, as well as of indirect linkages via the common bond and/or CDS factors.

An advantage of the Diebold and Yilmaz (2009, 2012) VAR framework over partial equilibrium regression approaches is the address of the contemporaneous nature characterizing the movements between different financial asset prices. By construction, any change in the value of an endogenous variable in the VAR feeds into the other endogenous variables and through them to the overall co-movement of endogenous variables in the system. Furthermore, since the contemporaneous correlation between financial assets forms the basis for the analysis of the linkages between them, it would be preferable to calculate a spillover measure invariant to variable ordering.

However, the resulting forecast error variance decompositions - that rely on the Cholesky factor identification - are dependent on VAR ordering, therefore imposing diagonal block restrictions on this contemporaneous feedback between the variables in the system (Claeys and Vašíček, 2014). The Diebold and Yilmaz's (2009, 2012) exploitation of the generalized VAR framework of Koop et al. (1996) and Pesaran and Shin (1998), accounts for correlated shocks through the employment of the historically observed distribution of the errors, thus producing variance decompositions invariant to
variable ordering.\textsuperscript{120} Hence, the employment of the generalized VAR framework along with the augmentation of the VAR with common factors guarantees the identification of the actual causal direction of the linkages between different assets, while also addresses simultaneity issues that might influence the direction and size of those linkages.

5.2.2. Sovereign bond and CDS data

The dataset consists of bond yields and CDS spreads for sovereign bonds and sovereign CDSs (SCDSs) with 5 years to maturity from August 8 2007, to June 20 2014. The starting date marks the onset of the US financial crisis which further led to an era characterized by increasing volatility in all European sovereign bond and CDS markets, and that lasts until the time of the writing.\textsuperscript{121} The sample includes all EMU member-states at the time of the introduction of the euro, i.e., Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, and Spain.\textsuperscript{122} The consideration of the 5-year time to maturity is due to the fact that constitutes the most liquid and traded maturity for CDS contracts, while it is further employed as a reference for the level of spreads in the sovereign CDS market. Daily bond yields are from Thomson Reuters Datastream and daily CDS spreads are from Markit. Since the augmented Dickey-Fuller tests reveal the non-stationarity nature of the time series, first differences are employed. The change in bond yields is further converted into basis points (bps), due to the CDS spread changes (calculated as $\Delta S_{it} = S_t - S_{t-1}$).

\textsuperscript{120}Due to the shocks to each variable not being orthogonalized, the sum of contributions to the variance of forecast error, i.e., the sum of the row-elements of the variance decomposition matrix, is not necessarily equal to one (Diebold and Yilmaz, 2009).

\textsuperscript{121}Only bond yields are employed and not bond spreads, i.e., the difference between a country's government bond yield and the yield on the government bond of Germany (equal maturities are assumed), since Germany (as evidenced by the results in sections 5.3 and 5.5) performs a pivotal role in the analysis of the cross- and intra-asset spillovers between the EMU periphery and the EMU core.

\textsuperscript{122}Data for Luxemburg is available from February 2009 onwards, except for the period from January 2010 to February 2011, and therefore not included in the sample.
being already in basis points. The motivation for the chosen data frequency (daily) is motivated by the fact that comovements in the bond and CDS markets often change on a rapid basis as investors shift their domestic asset. In addition arbitrage opportunities, which are a significant driver, as well as consequence, of these comovements are likely to be diminished at lower frequencies.

Figure 5.1 presents the evolution of the daily time series of the bond yields and the CDS spreads for two different blocs of countries, i.e., the EMU periphery (Greece, Ireland, Italy, Portugal, and Spain) and the EMU core (Austria, Belgium, Finland, France, Germany, and the Netherlands). Bond yields in the former bloc follow a skyward trend since late-2009 and in any case after mid-2010 when Greece reached an agreement with the European Union and the International Monetary Fund (IMF) for a €110 billion financing package in order to recover from its debt crisis and modernize the economy. This has been the case until approximately mid-2012 when bond yields appear to return close to their pre-2010 levels. Among these debt-laden countries, Greece, Ireland, and Portugal have seen their government bonds to be (negatively) affected the most by the Eurozone crisis. Bond yields in the EMU core follow the exact opposite course, since they fall during the best part of the post-2008 period (with only a slight rise occurring in the first half of 2011), thus appearing to have benefited from the skyrocketing borrowing costs of the periphery countries. CDS spreads in the EMU periphery match closely the upward trend exhibited by the periphery bond yields pointing to a close association between the two asset-markets. However, CDS spreads also increase in the EMU core, indicating an overall rise in the sovereign default probabilities across the entire Eurozone.

Considering the evidence that since the onset of the Eurozone crisis, bond yields are dependent not only on the underlying macro-fundamentals but also on international risk factors (Arghyrou and Kontonikas, 2013), and that the EMU periphery CDS spreads overpriced the prevailing values of fiscal space and other macro variables (Aizenman et al., 2013), factor analysis is applied in order to extract common factors from the 11 EMU countries' sovereign bond yields and CDS spreads respectively. The Kaiser criterion selects three factors as common drivers, hence the first three principal factors are used to compute the scores that form the two additional variables, each of them representing the sovereign bond (CDS) market's response to common shocks.
The evolution of the two factors at the daily level is presented in Figure 5.2. Although exhibiting a relatively contrasting course until about the mid-2008 period which coincides with the intensification of the US-credit crunch, thereafter, movements in both factors parallel each other. Bond and CDS factors rise following the onset of the Eurozone crisis and remain at elevated levels before beginning to revert back to their pre-crisis levels from mid-2012 onwards. Interestingly, the respective breakpoint, i.e., mid-2012, signifies a period of recession with regards to the level not only of the two factors, but also of the bond yields and CDS spreads across both EMU blocs, thereby designating a potential de-escalation of the European sovereign debt crisis, at least from the perspective of financial market participants.

The following sections include the estimation of the intra- and cross-asset linkages across the EMU sovereign bond and CDS markets. Following Diebold and Yilmaz (2009), a FAVAR of order 2 is estimated and generalized variance decompositions of 10-day-ahead volatility forecast errors, a period long enough to encompass all available information on the occurrence of these spillovers.

5.3. Empirical Results from the FAVAR

5.3.1. Cross- and intra-asset linkages

This section presents the results for all bilateral cross- and intra-asset linkages across the EMU sovereign bond yields and CDS spreads (as well as the two common factors) from the estimation of the generalized FAVAR specified in equation (5.10). Table 5.2 includes a 28 × 25 matrix, where the off-diagonal elements represent all bilateral volatility linkages between any two assets \( i \) and \( j \) (for \( i \neq j \)), i.e., the cross variance shares, and where the main diagonal elements represent the contribution of an asset's volatility to its own volatility, i.e., the own variance shares. The first two rows following the cross and intra-bilateral linkages sum the contribution of shocks to asset \( i \) on all other assets excluding (i.e., \( i \neq j \)), and including its own contribution respectively. The penultimate row (and the first right-hand column) sums the contribution that an asset \( i \) receives from all other
assets, while the last row represents the net spillover, i.e., the difference in the size of shocks that an asset contributes to and receives from all other assets (excluding its own contribution).

[Insert Table 5.2 about here]

According to Table 5.2, the total spillover between all assets (including the two common factors) is 53%, revealing that half of the variation in the European sovereign bond and CDS markets is attributed to volatility shocks in other countries' bonds and CDSs, while the other half is caused by domestic factors, among them the lagged level of own volatility. These domestic factors present considerable differences when moving between the same, as well as across different asset-markets. The values for the own variance shares (i.e., the main diagonal elements in the total spillover matrix) reveal that the relation between current and past volatility shocks is stronger in the bond rather than the CDS market. They therefore suggest that European sovereign bond markets appear considerably less integrated, with shocks to bond yields being mainly idiosyncratic, a result in line with the non-uniform evolution of bond yields outlined in Figure 5.1. In particular, the percentage of bonds' variation attributed to domestic developments is in the 45.00-60.00 range in most cases, while it reaches the 77.00-86.00 range for countries such as, Greece, Ireland, Italy, and Germany. This result is not surprising, since it verifies the earlier studies' findings about the level of the respective market's dependence on country-specific factors (see Codogno et al., 2003; Longstaff et al., 2011; Favero and Missale, 2012, Claeys and Vašíček, 2014).

On the other hand, the dependence of the CDS market on idiosyncratic shocks is generally smaller than the same dependence of the bond market, thereby pointing to a close relationship between movements across the European sovereign CDS markets. This offers an explanation for the almost identical evolution of all EMU CDS spreads depicted in Figure 5.1, where spreads follow an upward trend throughout the Eurozone crisis. However, in countries such as Greece, Ireland and Germany CDS spreads exhibiting strong dependence on own volatility shocks (which is 2 to 4 times the dependence exhibited by the rest sovereign CDSs). This is in turn new evidence with regards to the sovereign CDS market, and stands in contrast to the previous studies' conclusions that idiosyncratic country-specific volatility represents only a secondary fraction of the total volatility in
SCDS spreads, the volatility of which is mainly related to global and regional risk premia. This conclusion is derived for a large sample of developed and emerging economies for the pre-2007 period (see Longstaff et al., 2007), and for emerging economies during the 2007-2011 period (see Fender et al., 2012).

Moving from the idiosyncratic shocks to bilateral spillovers (i.e., the off diagonal elements in the total spillover matrix), we observe that the cross-country linkages between sovereign bond yields and CDS spreads exhibit differences depending on whether the source of transmission lies in the bond or the CDS market. Bond volatility shocks are transmitted to a considerably greater extent to CDS volatility, than when the reverse path is considered. Among the domestic bond markets with the strongest contribution to the rest of the European CDS markets are those of Germany, Italy, Ireland, Spain and France (ordered by the size of the contribution). In Germany, which is by far the greatest transmitter of bond volatility shocks, around a third of these shocks is (evenly) transmitted to the CDS spreads of the rest EMU countries. The same is further observed for Italy (the second largest bond volatility contributor) and Ireland, where a fourth and a third of their bond volatility shocks respectively are directed to the other countries' CDS spreads (Italy affects evenly all European CDSs, while Ireland's effect is mainly concentrated in the periphery). These latter two periphery countries also appear to be the main transmitters of CDS volatility shocks, however only a limited fraction of these shocks is directed to the domestic bond markets across the Eurozone. Interestingly, although Spain appears as the fourth largest contributor of bond volatility shocks, its contribution mainly pertains to the bond factor, thus elevating the respective country into a barometer for the overall level of volatility in the European sovereign bond markets.

We can therefore deduce that in terms of cross-asset linkages, Germany appears as the main transmitter of volatility to the domestic markets of the Eurozone core, when the direction of transmission is from the bond market to that of CDSs. German government bonds act as benchmarks, thereby affecting prices across European financial markets, while they also constitute the highest-quality collateral within the European sovereign bond market context. It is not surprisingly therefore,
that any movements in their yields have wide repercussions across the Eurozone sovereign debt and derivatives markets

However, the role of the key country within the context of the European sovereign bond and CDS markets, is jointly assumed by Ireland and Italy, since the two countries emerge not only as bond volatility contributors to the other domestic CDS markets, but also as the main contributors of CDS volatility shocks to the volatility of the rest European CDSs. The bi-fold contribution of Ireland and Italy to the sovereign CDS volatility across Eurozone is in turn directed to both the EMU periphery and the core. This systemic importance of the two periphery countries is due to Italy being the EMU's 3rd largest economy with its post-2008 public debt to GDP ratios being constantly above 115%, while Ireland experienced an increase in its public debt to GDP ratio by 62.9 percentage points during the 2007-2010 period (by 96.3 during the 2007-2012 period), and by 25 percentage points alone between 2009 and 2010 as a consequence of the recapitalization and nationalization of its large banks; it has further been the first Eurozone country to enter a recession (Acharya and Sascha, 2012; Acharya et al., 2014).

Furthermore, the Italian along with the Belgian and Spanish banks' mutual accumulation of large government debt holdings, not only adds to the systemic risk importance of Italy, but in combination with the Spanish banks' exposure to problems in the domestic financial sector which could be transmitted to their foreign branches, further explains the emergence of the Spanish government bond market as a determinant of the overall European bond market volatility (Claeys and Vašíček, 2014).

It should also be noted that a considerable fraction of sovereign bond volatility in the core is attributed to volatility shocks originating in the sovereign bond markets of France and Belgium. The former, as the euro area's second largest economy, presents several similarities with Germany, since they both display relatively high exposure to the Eurozone periphery, while French government bonds further act as benchmarks in the fixed-income market. In addition, during the 2010-2011 period French and Belgian banks (in particular Dexia S.A., Crédit Agricole S.A. and Société Générale) have risen to the top of Europe’s systemic financial institutions, a fact also reflecting the Belgian
internationally developed banking system's strong exposure to the periphery sovereigns (Acharya and Sascha, 2012; Claeys and Vašíček, 2014).

Focusing on the intra-country volatility spillovers between sovereign bond yields and CDS spreads there is a moderate interaction when the shocks are transmitted from the former to the latter, since only in half of the EMU countries bond-originated volatility shocks spill over to CDSs. These countries include the periphery countries of Ireland, Italy, and Spain, and the core countries of Belgium and Germany. However, when the reverse order of this transmission is considered, the interaction is even more narrow and observed only for some of the periphery countries, i.e., for Ireland, Portugal and Spain. To get a clearer picture of these cross-asset linkages in each EMU member state, the next section examines their dynamic evolution.

Shocks to common factors exert only a marginal impact on sovereign bonds and CDS volatility indicating that EMU-wide (and international non-EMU-wide) developments have been limited in number and/or size during the Eurozone crisis. It appears that all shocks originate within the domestic markets and transmitted from their source of origin directly - rather than indirectly - not only to the rest of the countries, but also to the common factors. In this respect, domestic developments in Spain (primarily) and Italy (secondarily) emerge as the main determinants of common bond market developments, since they jointly account for approximately three fourths of bond factor volatility (45.91 and 22.86 respectively). Most importantly, half of the effect of the Spanish and Italian bond market developments is also transmitted indirectly to the EMU-wide CDS market through the significantly strong contribution of bond factor to CDS factor (i.e., 37.50). Hence, although overall movements in the EMU-average CDS spreads appear to be disassociated with developments in the domestic CDS markets, they are nevertheless strongly related to the average level of European sovereign bond yields.

Results so far reveal a unidirectional volatility spillover from the sovereign bond to the SCDS market, suggesting that new information is mainly transmitted from the former to the latter, while further pointing to the two markets having a different degree of dependence on underlying fundamentals. Thus, a repetition of a wake-up call similar to the homonym hypothesis of Goldstein
(1998) may have been the case across the Eurozone, where the debt crisis provided new information, thereby prompting investors to reassess the vulnerability of other market segments or countries, and thus leading to a rediscovering and/or repricing of macroeconomic and fiscal fundamentals in sovereign bond pricing (Goldstein, 1998; Goldstein et al., 2000; Bekaert, 2014, Claeys and Vašíček, 2014). This, in combination with the potential launch of speculative attacks via the European SCDS market - that could have raised SCDs' spreads and volatility and consequently weakened their link with the underlying fundamentals - might have resulted in a prominent volatility effect being transmitted from the sovereign bond market to that of SCDSs.

5.3.2. Dynamic bond-CDS linkages

Section 5.3.1 estimated the total cross- and intra-asset spillovers between the European sovereign bond and CDSs. Clearly, many changes occurred during the 2007-2014 period, the European sovereign debt crisis probably being the most notable among them, thereby altering the strength and direction of these spillovers. As seen in Figure 5.1 above, the onset of the Eurozone crisis resulted in the European sovereign bond yields following divergent paths depending on whether these bonds belong to the EMU periphery or the EMU core. It further resulted in the periphery CDSs' rise being significantly greater in size than the corresponding rise in the CDSs of the core. Given this period of extreme stress and heightened market activity within the European financial market context, it is unlikely that any single fixed-parameter model would pertain to the entire examination period. Hence, in order to assess the unidimensional and/or cyclical movements in cross- and intra-market spillovers that cannot be captured by the total spillover index, the analysis follows Diebold and Yilmaz (2009, 2012) and examines the dynamic evolution of these spillovers by estimating the FAVAR over a 200-day rolling window.

[Insert Figure 5.3 about here]

The daily time-series for the net spillover between sovereign bond yields and CDS spreads in each EMU country are presented in Figure 5.3. The graphs confirm the existence of two periods of moderate and significant volatility spillover respectively. The common conclusion is that, in both
periods and in all countries, volatility is transmitted from the sovereign bond to the CDS market (the only exception being Portugal during the second period). The respective periods consist of the late 2008-early 2009 period, where spillover is of a moderate size and duration and pertains to only half of the Eurozone countries, and of the main stage of the European sovereign debt crisis, i.e., from 2010 to 2012, where spillover is considerably stronger and occurs in almost each country. The former period corresponds to the post-Lehman Brothers' bankruptcy period, which was associated with a repricing of European sovereign credit risk due to the an increase in global uncertainty, that further led to a rise in the demand for low-risk German government bonds.

The reassessment of country-specific fundamentals and the consequent correction in sovereign credit risk was probably more immense - as implied by the volatility transmission from sovereign bonds to CDSs - in the sovereign bond markets of the weakest periphery economies, i.e., Ireland and Greece (partly evident in the movements of their bond yields in Figure 5.1), as well as Portugal. This repricing in the EMU periphery triggered diametrically opposite movements in the bond yields of the safer EMU economies, a fact primarily evident from the bond-CDS volatility spillover occurring in Germany (the main recipient of flights-to-safety) and secondarily in the Netherlands. However, the period where is evidence of excessive cross-asset volatility spillover within each EMU country is the one starting from mid 2010, and in any case from early 2011, until mid 2012. The only exception appears to be Finland, where the spillover is rather limited and close to the pre-crisis level, while in Austria the spillover, although greater than pre-2010, is relatively weak compared to the other EMU countries.

Hence, it appears that the European sovereign debt crisis have resulted in an increase in the transmission of volatility from sovereign bonds to SCDS contracts in each EMU country. At first glance, this appears contradictory to the remarkable increase in the size and trading activity, and consequently in volatility, of - particularly - the periphery countries' sovereign CDS markets as entering the Eurozone crisis. However, according to Figure 5.4, this surge in the periphery SCDS market's size and volatility is mainly transmitted at the intra-asset level, i.e., to the SCDS markets in the core, rather than to the sovereign bond markets in any of the periphery or the core.
As the next section (i.e., Section 5.6) reveals, the Eurozone crisis marked a significant increase in the integration (reflected in the bond-CDS conditional correlations) between the sovereign bonds and SCDS contracts in each EMU periphery country and Belgium. This improved integration however appears to be driven by information provided by the sovereign bond market. It therefore seems that even though the escalation of the Eurozone crisis prompted investors to heightened perceptions of the sovereign credit risk of most EMU member-states, these corrections in sovereign risk pricing was fuelled from the reassessment of fundamentals in the sovereign bond market. In each of the economies of the EMU core, the evolution of their (declining) sovereign bond yields in each country is diametrically opposite to the evolution of their (rising) CDS spreads, which (according to Section 5.6) further leads to a limited level of integration between them. Nevertheless, similar to the periphery countries' case, this moderate rise in the core countries' CDS spreads is largely affected by information transmitted from their sovereign bonds, as the direction of volatility is from the latter to the former.

This is further verified by the evolution of the net bond-CDS spillover between the two EMU blocs in Figure 5.4. The sovereign bond market in one bloc, remains the principal transmitter of volatility to the SCDS market of the other bloc regardless of whether the sovereign bond market is located in the periphery or the core. The only period where this transmission appears to be weak is from 2013 onwards, when the rising sovereign bond yields and CDS spreads in the European core begin to recede, thus signifying a potential containment of the Eurozone crisis.

Thus, despite the surge in the size and importance of the SCDS market, the results identify sovereign bond markets as the most powerful vectors of information - through - volatility during the 2010-2102 period. Therefore, the results of Section 5.3.1 according to which volatility was found to be transmitted from the sovereign bond to the CDS market at both the cross-country and the EMU-wide level, are further verified in the context of the intra-country analysis.
5.3.3. Robustness checks

To ensure the robustness of these results a VAR is estimated consisted solely of the country-specific bond yield and CDS spread series and excluding the bond and CDS factors. Results in Table 5.3 suggest that the total spillover is approximately 9% lower, thus verifying Section's 5.3.1 assumption about the interaction of the common factors with each of the bond and CDS markets respectively. The differences between the two total spillover indices are mainly concentrated in the bond market, pointing to the fact that the latter market constitutes the laboratory for the amplification of volatility shocks to an EMU-scale, as well as the channel for these shocks' transmission across the Eurozone. Contribution to - as well as from other assets is significantly weaker in the case of the European periphery bond yields, further suggesting that common EMU developments have different explanatory power when moving between the two EMU blocs. Also evident from the comparison of the diagonal elements in the two total spillover matrices is the greater size of own country linkages in the omitted factor-VAR; this owes to the effect of common shocks being incorporated in the country-specific bond yields and CDS spreads.

Hence, the inclusion of the common bond and CDS factors in the VAR reverses the underestimation of the cross- and intra-asset spillovers stemming from and being directed to the bond markets of the European periphery. It further corrects for the upward trend in the own variance share, which is otherwise the case when the simple VAR is considered. To further confirm the appropriateness of the initial VAR's chosen specification the spillover index is calculated for orders 2 to 4, and with forecast horizons varying from 8 to 10 days. Overall, the results appear to be insensitive to the choice of the order of the FAVAR or the choice of the forecast horizon, a fact also evident in Diebold and Yilmaz (2009).

5.3.4. Implications

A quite important conclusion derived from this chapter's analysis is the increased capacity of the sovereign bond market to transmit information to that of CDSs, a fact observed at both the country-
and the EMU-level. This points to the need that the management of sovereign credit risk within the macroprudential framework is conducted with reference to the sovereign bonds rather than the CDS contracts. It further highlights the importance and verifies the selection of the European sovereign bond market for the targeted central bank interventions carried out at the European level with the scope of minimizing the spillover to the CDS market and restoring investor trust in the periphery countries’ financial soundness as reflected by the level of their CDS spreads. On the other hand, the capacity of the CDS market to transmit information to the bond market is rather limited; CDS volatility is only transmitted at the intra-asset level, with majors transmitters the CDS markets of Ireland, Italy and Spain, suggesting that during the Eurozone crisis information is generated by countries with deteriorating fiscal and macroeconomic fundamentals. The emergence of the Spanish and Italian CDS spreads as predominant volatility contributors to the “common bond factors” variable emphasizes the importance of the two countries for the overall level of Eurozone bond yields.

Thus, policies - such as fiscal-consolidation measures and/or structural reforms - aiming at ensuring the solvency of the respective countries and thereby reducing their default probabilities might be a contributing factor for the containment of yields across the European sovereign bond markets. This pivotal position of Italy and Spain further draws attention to the issue of the sovereign-bank nexus. This issue concerns the increased holdings of domestic government bonds by those countries' banks and the dangers that the banks' exposure to problems in the domestic financial sector can be transmitted to their branches across the Eurozone. The revision of the current regulatory framework should aim at exactly limiting even further the exposure of banks to a single counterparty and placing an even lower cap on the ratio of domestic bond holdings to the banks' total assets. This in turn should minimize the possibilities that insolvent or imprudent banks downgrade the solvency of their sovereigns and vice versa and therefore increasing the systemic risk across the Eurozone.

5.4. AG-DCC GARCH

Following the examination of volatility spillovers between the European sovereign bond and CDS markets and considering the theoretical propositions that volatility is a major driver of asset-
correlation, the second part of this chapter assesses whether bond-CDS volatility spillovers are associated with stronger integration between sovereign bonds and CDSs in each EMU country.\textsuperscript{123} It additionally evaluates whether the shift in the ECB's monetary policy stance and the process towards monetary and economic integration has impacted on the degree of this integration. Since theoretical and empirical studies attribute cross-market integration and comovement to informational linkages, and following Ross's (1989) arguments that in a no-arbitrage economy changes in conditional variances are directly related to the rate at which information flows to the market, the examination of the information flow between the sovereign bond and CDS markets is plausible through the modelling of their conditional volatility interdependence and correlation. To this method, contributes the argument that market integration should affect the conditional return-generating process (Bekaert and Harvey, 2003).

Due to the time-variance and clustering exhibited by the conditional volatilities and the conditional correlation of multivariate financial time-series, the multivariate generalized autoregressive conditional heteroskedasticity (MGARCH) model developed by Bollerslev et al. (1988) emerges as a natural candidate for the modeling of these stylized facts. This is especially the case in the context of the analysis of financial return comovement, an essential component of which is the construction, estimation, and forecasting of the joint volatility dynamics of financial asset returns in a given portfolio; it further pertains to the derivative pricing of correlation sensitive products. The dependence of conditional volatilities and conditional correlation on their past values is also addressed by the MGARCH (also called VEC model). This dynamic nature of conditional volatilities, further led to the development of more sophisticated MGARCH models, such as the principal component GARCH model by Ding (1994), the BEKK model of Baba et al. (1995), the asymmetric dynamic covariance (ADC) model of Kroner and Ng (1998), and the dynamic conditional correlation (DCC) model of Engle (2002).

\textsuperscript{123} The theoretical arguments about the relationship between volatility and correlation are discussed in detail in Section 2.5.
Each of the above models imposes different restrictions on the conditional covariance matrix, therefore providing different variance and covariance estimates; among them, BEKK and DCC are the two most widely used models, and are employed as forecasting tools, especially during periods of “heightened” market activity, where significant changes in the correlation dynamics are likely to occur. For the purposes of the analysis conducted in the present chapter a DCC model is selected. This selection is not arbitrary and is based on the DCC model's clear computational advantages over BEKK. In specific, the non-linear optimization required under the maximum likelihood fit of the BEKK model's parameters involves heavy computations due to several matrix transpositions, while the model is further difficult to converge in high-dimensions. On the other hand the number of DCC parameters to be estimated in the correlation process is independent of the number of series to be correlated, making feasible the estimation of potentially very large correlation matrices (Engle, 2002). Most importantly, the estimation of the DCC model involves dynamic parameters, in contrast to BEKK, where the values of the model's parameters are assumed to be constant; thus, the DCC is better able to capture the dynamic and time-varying nature of the financial conditions, especially when the frequency of the observations increases (Engle, 2002; Cappielo et al., 2006).

The choice of the DCC is further necessitated by the “asymmetric volatility” phenomenon, where financial asset volatility increases more following a negative rather than a positive shock of the same magnitude (Cappielo et al., 2006). This is important when considering the existence of numerous negative shocks in the European sovereign credit markets during the recent Eurozone crisis, e.g., the post-2008 banking crisis in Ireland, Greece's upward revision of government deficit in late 2009, or the numerous credit rating announcements during the 2009-2012 period.\textsuperscript{124} The possibility that these negative shocks exerted an asymmetric impact on the current and - due to the dynamic nature of conditional correlation - in the future asset conditional correlation, serves as a motivation to follow Cappiello et al. (2006) and model the joint return generating process of sovereign bond and CDS markets with a bivariate DCC-GARCH model.

\textsuperscript{124} During the 2009-2012 period the number of published downgrades for the Eurozone countries by Standard and Poor's, Moody's Ratings and Fitch Ratings were 35, 32 and 29 respectively.
The estimation of the DCC-GARCH consists of two stages. The first stage accounts for the conditional heteroskedasticity and involves the derivation of the standardized residuals, which are further used as inputs in the DCC-GARCH model. This derivation is feasible through the estimation of the GJR-GARCH model of Glosten et al. (1993), a procedure also known as “de-GARCHing” (Engle, 2002).\(^{125}\) The conditional variance \(\sigma_t^2\) at time \(t\), under the uni-variate GJR-GARCH\((p,q)\) is modeled according to the following specification:

\[
\sigma_t^2 = \omega + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{q} \gamma_i \varepsilon_{t-i}^2 I[\varepsilon_{t-i} < 0] + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2
\]

(5.11)

and is a function of the lagged positive and negative squared residuals \(\varepsilon_t^2\) (the ARCH, and GARCH terms respectively), and the lagged conditional variance \(\sigma_t^2\). \(I(\cdot)\) denotes the indicator function which equals 1 if \(\varepsilon_{t-i} < 0\) and 0 otherwise. The GARCH parameters are estimated through maximum likelihood estimation.

In the second stage, the standardized residuals of the bond returns and CDS spreads changes in each EMU country and the EMU-average are used as inputs in the DCC-GARCH model for the calculation of the conditional correlations. Under the DCC, the conditional covariance matrix \(H_t\) of the standardized residuals is decomposed as:

\[
H_t = D_t R_t D_t
\]

(5.12)

where \(D_t\) is a \(n \times n\) matrix of time-varying standard deviations from the uni-variate GJR-GARCH model of equation (5.11), and \(R_t\) is the time-varying correlation matrix.

The log likelihood of the DCC estimator is expressed as:

\[
L = -\frac{1}{2} \sum_{t=1}^{n} (n \log(2\pi) + \log(|D_t|^2) + \log(|R_t|) + \varepsilon_t' R_t^{-1} \varepsilon_t)
\]

(5.13)

where \(\varepsilon_t \sim N(0,R_t)\) are the standardized residuals from the first-stage estimation of the GJR-GARCH. The log likelihood can further be written as the sum of a volatility part and a correlation part, namely:

\[
L(\theta, \varphi) = L_v(\theta) + L_c(\theta, \varphi)
\]

(5.14)

\(^{125}\) A Threshold ARCH (TARCH), and an Absolute Value GARCH (AVGARCH) are employed as alternatives to the GJR-GARCH for robustness purposes.
the volatility component is

\[ L_{\sigma}(\theta) = -\frac{1}{2} \sum_{t=1}^{n} \left( n \log(2\pi) + \log(|D_t|^2) + r_t D_t^{-2} r_t \right) \]  

(5.15)

and the correlation component is

\[ L_{\rho}(\theta, \varphi) = -\frac{1}{2} \sum_{t=1}^{n} \left( \log|R_t| + \varepsilon_t R_t^{-1} \varepsilon_t - \varepsilon_t^{'} \varepsilon_t \right) \]  

(5.16)

The DCC model as formulated in Engle (2002) has the following non-linear GARCH specification:

\[ Q_t = (1 - \alpha - \beta) \bar{Q} + \alpha \varepsilon_{t-1}^{'} \varepsilon_{t-1} + \beta Q_{t-1} \]  

(5.17)

where \( Q_t = (q_{i,j,t}) \) is an \( n \times n \) conditional variance-covariance matrix of standardized residuals, \( \alpha \) and \( \beta \) are non-constant negative scalars causing the model to be mean-reverting as long as \( \alpha + \beta < 1 \) (or integrated if \( \alpha + \beta = 1 \)), and \( \bar{Q} = E[\varepsilon_t^{'} \varepsilon_t] \) is the unconditional time-invariant variance-covariance matrix of the standardized residuals. According to Engle (2002), the modelling of the conditional covariance of the standardized returns is equivalent to the modelling of the returns’ conditional correlation; hence the time-varying conditional correlations \( q_{i,j,t} \) are normalized and then used in the estimation of the conditional correlation \( \rho_{i,j,t} \) between any two assets at any instant of time \( t \), according to the equation:

\[ \rho_{i,j,t} = \frac{q_{i,j,t}}{\sqrt{q_{i,i,t} q_{j,j,t}}} \]  

(5.18)

The mechanics of the DCC are such, that when new information causes the assets to move in the same (opposite) direction, the coefficient \( \alpha \) will cause the conditional correlations \( q_{i,j,t} \) to increase (decrease) above (below) their average level and remain at this level for a short period of time, before the coefficient \( \beta \) forces them to revert back to their long-run average direction.

Since a fundamental assumption of Engle's (2002) DCC is that the conditional correlations follow the same dynamic structure, in the presence of structural breaks, such as those during the 2007-2008 financial crisis and the European sovereign debt crisis, the conditional correlations may lead to an over- or under-estimation of asset risk. For that reason, the asymmetric generalized DCC (AG-DCC) specification of Cappiello et al. (2006) is employed. Compared to the conventional DCC, the asymmetric generalized extension on the one hand allows for asset-specific news and smoothing
parameters and on the other hand permits conditional asymmetries in correlations (Cappielo et al., 2006). Furthermore, the AG-DCC models’ modification of the univariate volatility parameterizations of standard models allows for the accommodation of conditional asymmetries. The combination of these two approaches results in a specification that is flexible and also feasible when more than one assets are considered, as is the case in the present analysis of sovereign bond yields and CDS spreads. Lastly, the evolution of the original DCC estimator is modelled according to a process that assumes identical news impact and smoothing parameters for all pairs of variables; since this is a rather strong assumption to hold for high-dimensional models, the employment of the AG-DCC estimator is more efficient in capturing the heterogeneity present in the financial data (Cappielo et al., 2006).

Under the AG-DCC, the correlation evolution of equation (5.17) is modified as:

$$Q_t = (\bar{Q} - A'\bar{Q}A - \Gamma'\bar{N}\Gamma - B'\bar{Q}B) + A'e_{t-1}e'_{t-1}A + \Gamma'\nu_{t-1}\nu'_{t-1}\Gamma + B'Q_{t-1}B \quad (5.19)$$

where $A, B,$ and $\Gamma$ are $k \times k$ parameter matrices, $\nu_t = I[\epsilon_t < 0]\epsilon_t$ ($I[.]$ is a $k \times 1$ indicator function which equals 1 if $\epsilon_t < 0$ and 0 otherwise, and $\circ$ is the Hadamard product), and $\bar{N} = E[\nu_t\nu'_t]$.

Re-arranging the terms in the parenthesis, and denoting the unconditional correlation $\bar{Q}$ as $\bar{R}$, the conditional correlations of the DCC-GARCH($p,r,s$) for two assets (i.e., bond returns and CDS spread changes) is estimated as:

- $q_{i,t} = \bar{R}_{i,i}(1 - \sum_{k=1}^{p}\alpha_{k11} - \sum_{m=1}^{r}\gamma_{m11} - \sum_{n=1}^{s}\beta_{n11}) + \sum_{k=1}^{p}\alpha_{k11}(e_{i,t-k})^2 + \sum_{m=1}^{r}\gamma_{m11}(\nu_{i,t-m})^2 + \sum_{n=1}^{s}\beta_{n11}q_{i,i-n} \quad (5.20)$

- $q_{i,j} = \bar{R}_{i,j}(1 - \sum_{k=1}^{p}\alpha_{k12} - \sum_{m=1}^{r}\gamma_{m12} - \sum_{n=1}^{s}\beta_{n12}) + \sum_{k=1}^{p}\alpha_{k12}(e_{i,t-k}e_{j,t-k}) + \sum_{m=1}^{r}\gamma_{m12}(\nu_{i,t-m}\nu_{j,t-m}) + \sum_{n=1}^{s}\beta_{n12}q_{i,i-n}q_{j,j-n} \quad (5.21)$

- $q_{j,j} = \bar{R}_{j,j}(1 - \sum_{k=1}^{p}\alpha_{k22} - \sum_{m=1}^{r}\gamma_{m22} - \sum_{n=1}^{s}\beta_{n22}) + \sum_{k=1}^{p}\alpha_{k22}(e_{j,t-k})^2 + \sum_{m=1}^{r}\gamma_{m22}(\nu_{j,t-m})^2 + \sum_{n=1}^{s}\beta_{n22}q_{j,j-n} \quad (5.22)$

in which the conditional correlation or “quasi-correlation” $q_{i,j,t}$ (where $i$ (j) is the sovereign bond (CDS) market of each of the 11 EMU countries and the EMU-average at time $t$), is a function of
the past symmetric and asymmetric innovations, \( e_t \) and \( n_t \) respectively, and its own past conditional correlations \( q_{i,j,t} \).\(^{126}\)

Under the AG-DCC, the time-varying conditional correlation \( \rho_{B,CDS,t} \) between the bond and CDS markets at time \( t \), is simply the ratio of their conditional covariance \( q_{B,CDS,t} \) at time \( t \), and the individual conditional variances of the bond and CDS markets at time \( t \), i.e., \( \sigma^2_{B,t} \) and \( \sigma^2_{CDS,t} \) respectively, or:

\[
\rho_{B,CDS,t} = \frac{\sigma^2_{B,CDS,t}}{\sqrt{\sigma^2_{B,t} \cdot \sigma^2_{CDS,t}}} 
\]

(5.26)

The value of \( \rho_{B,CDS,t} \) is an indication of the level of the sovereign bond-CDS comovement at any instant of time \( t \), and it is interpreted as reflecting the evolution of the integration process between the sovereign bond and CDS markets, since it considers the effects of common information and volatility shocks between and from the two markets. We would expect this measure to assume a positive value, since no-arbitrage conditions force the spread of the CDS to rise in response to a rise in the yield of the underlying bond, and/or vice versa. Conditional correlation is bounded between \(-1 \leq \rho_{B,CDS,t} \leq 1\), with a high positive value indicating a greater degree of sovereign bond-CDS integration.

5.5. Sovereign bond-CDS conditional correlation and CDS-bond basis

This section analyzes the relationship between the level of conditional correlation between sovereign bonds and CDSs in each EMU country (estimated from the AG-DCC model of equation (5.19)) and

\(^{126}\) According to equations (5.20)-(5.22), the specification of a AG-DCC(1,1,1) is:

\[
q_{i,i,t} = R_{i,i}(1 - \alpha_{11} - \gamma_{11} - \beta_{11}) + \alpha_{11}(e_{i,t-1})^2 + \gamma_{11}(v_{i,t-1})^2 + \beta_{11}q_{i,i,t-1} \tag{5.23}
\]

\[
q_{i,j,t} = R_{i,j}(1 - \alpha_{12} - \gamma_{12} - \beta_{12}) + \alpha_{12}(e_{i,t-1})^2 + \gamma_{12}(v_{i,t-1})^2 + \beta_{12}q_{i,j,t-1} \tag{5.24}
\]

\[
q_{j,j,t} = R_{j,j}(1 - \alpha_{22} - \gamma_{22} - \beta_{22}) + \alpha_{22}(e_{j,t-1})^2 + \gamma_{22}(v_{j,t-1})^2 + \beta_{22}q_{j,j,t-1} \tag{5.25}
\]
the level of the CDS-bond basis in the same country (calculated from equation (5.27)).\textsuperscript{127} Figure 5.5 plots for each of the 11 EMU countries the daily time-series of the bond-CDS conditional correlation against the daily time-series of the CDS-bond basis.\textsuperscript{128}

[Insert Figure 5.5 about here]

As a general conclusion, it appears that the evolution in each of the bond-CDS market integration (proxied by the bond-CDS conditional correlation) and the CDS-bond basis is characterized by two key breakpoints: the first is common for movements in both market integration and the CDS-bond basis across all 11 EMU countries and pertains to late 2008-early 2009, while the second refers to late 2011-early 2012, however is only common for the countries of the EMU core excluding Belgium. In the latter country, as well as in each of the EMU periphery countries emerge considerable time differences between market integration and the CDS-bond basis with regards to the direction of their evolution during the post-2009 period.

The former breakpoint coincides with the bankruptcy of the Lehman Brothers which marked an upward trend in long-term European government bond yields and a disruptive re-pricing of European sovereign credit risk. This reassessment of underlying economic and financial fundamentals (a direct consequence of the associated global uncertainty and flight-to-quality tendencies) increased investor demand for low-risk German government bonds. The following recession and the government announcements of large-scale bail-out programs for banks further prompted investors to heightened perceptions of sovereign credit risk in most Eurozone countries (Fontana and Scheicher, 2016). In particular, during the pre-2009 period, a rather limited degree of cross-market integration is observed, with bond-CDS conditional correlations assuming values within the (-20, 20) range in all

\textsuperscript{127} To account for the fact that the European sovereign bonds are denominated in Euros, while the CDS contracts written on them are denominated in US Dollars, and therefore remove the strong impact exerted by the Euro/US Dollar exchange rate on the level of the CDS-bond basis, the SCDS contracts employed are denominated in Euros.

\textsuperscript{128} The value of the conditional coefficient $\rho_{B,CDS,t}$ is multiplied by 100 for expositional convenience, therefore it is bounded by $-100 \leq \rho_{B,CDS,t} \leq 100$. 

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Eurozone countries. This disintegration between sovereign bonds and CDSs, further coincides with a negative CDS-bond basis in all EMU member states, except the Netherlands.

However, when progressing into the European sovereign debt crisis from early 2009 onwards, we observe the formation of two different blocs within the EMU, according to the degree of bond-CDS integration in each country. The first bloc includes the distressed countries of the EMU periphery, which were characterized by persistent and positive conditional correlations. Belgium is further included in this bloc, since its behavior with regards to both the bond-CDS conditional correlation and the CDS-bond basis resembles that of the periphery countries. The other bloc consists of the EMU core countries (excluding Belgium), where these correlations recede even further from their (negative) pre-2009 values and remain at a moderately negative level for the best part of the Eurozone crisis. During that period we observe a positive basis across the Eurozone, which particularly during the mid 2009-early 2010 period exceeds the 100 basis points level in all countries, while in cases such as of Greece (primarily), Austria, Ireland, and Spain the basis peaks even higher.

5.5.1. Sovereign bond-CDS integration

Therefore, the transition to the Eurozone crisis is associated with an increase in the bond-CDS conditional correlations in each country of the EMU South and also in Belgium. As Section 5.3 reveals this period of rising bond-CDS correlations coincides with an increase in volatility directed from the sovereign bond towards the SCDS market. This consequently points not only to the overall (strong) relationship between volatility and cross-asset correlation (see Andersen et al., 1999, 2003) but further to the importance of volatility for the evolution of cross-asset correlation (Aït-Sahalia and Xiu, 2016). According to the findings of Section 5.3 during - and shortly after - the onset of the Eurozone crisis, information appears to be mainly transmitted from the sovereign bond to the SCDS market, a fact evident in all EMU countries and not just those of the EMU South. However, this period of increased information transmission towards the CDS market results in a stronger bond-CDS correlation only across the EMU South and Belgium. Hence, it appears that up until the Eurozone crisis period, the domestic CDS markets across the latter bloc were not responding to the same
information as that bloc's domestic bond markets. Once the CDS markets started to act as the recipient of bond-stemming volatility and information, the conditional correlations between the sovereign bond and CDS markets experienced a significant increase climbing above the +70 level in most countries (i.e., Greece, Ireland, Italy, and Spain).

As the main stage of the Eurozone crisis evolves we observe a moderate downward shift in the cross-market conditional correlations of the EMU periphery countries and Belgium, which is matched by an also moderate but upward shift in the conditional correlations of the EMU core countries, signifying a return of these correlations close to their pre-crisis levels. A similar (downward) shift is also evident with regards to the CDS-bond basis, the only difference being that this shift is common for the two EMU blocs and results in an almost entirely negative basis in each of the Eurozone countries thereafter.

This change in the strength of market integration occurs between late 2010 and early 2011 in all periphery countries and Belgium, while in the European core the same change takes place with a lag ranging from two to four quarters, i.e., between late 2011 and mid 2012. What is interesting is that the change in each of the core countries' conditional correlations towards less negative values concurs with the large downward shift in their CDS-bond basis. In the periphery however, the transition to a period of weaker cross-asset integration precedes by far the changes in the level of the basis. In particular the time distance between them ranges from two quarters in Italy, to four and six quarters in Spain and Greece respectively. In Portugal, while the basis turns negative in early 2011, the country's bond yields and CDS spreads continue to be moderately integrated until the end of 2013. In Ireland, despite the switch towards a negative basis, the degree of bond-CDS integration, although relatively weaker, is still close to its post-2009 average.

Due to this contradicting behaviour of conditional correlations between the Eurozone countries we can conclude that the European sovereign debt crisis constitutes the breaking point for the considerable improvement in the integration between the sovereign bond and CDS markets in the EMU periphery and Belgium, i.e., the countries - at least those in the periphery bloc - affected the most by this crisis. Even though during the pre-2009 period movements in the respective countries'
bond yields and CDS spreads were relatively uncorrelated, during the initiation and the main stage of the Eurozone crisis this correlation assumes large positive values, thus pointing to a strong association between them.

The diametrically antithetical movements between sovereign bond yields and CDS spreads in the European core during most of the Eurozone crisis depicted in Figure 5.1, are further reflected in the level of bond-CDS conditional correlations in each of the core countries, with the exception of Belgium. Although translating into higher default probabilities, a rise in those countries' CDS spreads is associated with a fall in their underlying government bond yields. Thus, it appears that the aforementioned countries have been the recipients of the so called “safe haven flows”, especially from the first half of 2010 until the second half of 2011, i.e., during the main stage of the Eurozone crisis (Fontana, 2012). The sky-rocketing SCDS spreads and rising sovereign bond yields, as well as the positive correlation between them in the EMU periphery during the same period, verify the argument about the flight-to-quality and flight-to-liquidity phenomena, according to which in times of heightened market uncertainty, investors rebalance their portfolios toward less risky and more liquid securities, especially in fixed-income markets (Beber et al., 2009). This phenomenon is in turn more evident in the case of Finland, France and Germany, as well as in Austria and the Netherlands. In addition, the significantly greater credit quality (reflected in the higher credit ratings) and liquidity (reflected in the tighter bid-ask spreads) of the core countries' government bonds relative to those in the periphery, further points to the fact that these flights into the core countries' sovereign debt markets are due to both safety and liquidity considerations (a fact also documented in Monfort and Renne, 2014 and in Fontana and Scheicher, 2016).

5.5.2. Sovereign bond-CDS integration and the CDS-bond basis

The degree of market integration is in turn essential in explaining the level of the CDS-bond basis in each EMU country. As suggested by the graphs, the onset of the Eurozone crisis resulted in the classification of EMU member states into two blocs: the EMU periphery countries and Belgium, and the EMU core countries excluding Belgium. Each of these blocs exhibit strong and weak sovereign
bond-CDS integration respectively. The same blocs however, are observed with regards to the evolution of the CDS-bond basis, since in the former bloc the transition of the basis towards negative values occurs between two to four quarters earlier than the same transition in the latter bloc (i.e., late 2010-early 2011 versus late 2011-mid 2012). In addition, while in the EMU core this shift to negative basis coincides with a rise in conditional correlations, in the periphery countries and Belgium conditional correlations begin to decrease significantly later than the negative shift in the basis' level.

The negative correlation in the core countries during the main stage of the Eurozone crisis offers the most plausible explanation for the positive basis during the same period. The “safe haven flows” targeting that bloc's constituent countries result in the rise of their SCDS spreads to be matched by a concurrent fall - rather than a rise - in their sovereign bond yields, thereby causing a widening of their basis towards positive values. Along these lines, from late-2011 onwards when the flight-to-quality and flight-to-liquidity phenomena appear to weaken, the basis starts to converge towards zero before eventually turning negative for the remainder of the crisis. This is primarily evident in the EMU's two largest economies and principal recipients of the capital flights from the EMU periphery, i.e., Germany and France, while it is further the case in Austria, Finland and the Netherlands. In these two latter countries, although the basis turns again slightly positive in 2014, its level is considerably lower than the level at which the basis peaked during 2009 and 2010. Even though the contemporaneous rise and fall in the core countries' CDS spreads and bond yields respectively justifies the notably large positive sign of the basis in each of these countries during the 2009-2012 period, in the periphery such a diametrically opposite relationship between the two assets is not observed. Therefore, the positive basis in the periphery and Belgium should be attributed to other factors than the flight-to-safety phenomenon.

A partial explanation is provided by the inherent differences in the exposure of sovereign bonds and CDSs to various risk factors; being cash instruments, bonds are affected by interest rate risk, default risk, and funding risk, while CDSs are mainly affected by default risk and counterparty risk. Since, default probabilities were considerably high for the debt-laden European periphery - as well as for Belgium according to Figure 5.1 - sovereign CDSs in the respective bloc's countries have
been affected asymmetrically relative to the underlying sovereign bonds. This is evident in the pre-2011 period where the basis assumes significantly positive values, pointing to the increase in the CDS spreads being greater than the corresponding increase in the underlying government bond yields. At the same period, the integration between the two assets remains at a moderate level suggesting their sensitivity to different underlying fundamentals. However, from early-2010 onwards, sovereign bonds in the periphery and Belgium appear to integrate with SCDSs, signifying that movements in both asset-markets are driven to a large extent from the same factors. This process towards stronger integration is in turn matched by the process towards a negative basis for the remainder of the period.

Entering the late 2011-early 2012 period we observe the largest negative values of the basis across the EMU South and Belgium. These persistent and negative values coincide with the peak in the level of the CDS spreads during the same period, as well as with signs of extreme illiquidity (as measured by the wide bid-ask spreads) and volatility (as measured by the large standard deviation) in the periphery's CDS contracts. The combination of illiquid and volatile CDS contracts is in turn responsible for the persistence of the negative basis, since it causes professional arbitrageurs to avoid extremely volatile “arbitrage” positions; the exposure to increasing losses due to excessive volatility, as well as the potential need to liquidate the portfolio outweigh the likelihood of earning excess returns from trading the basis (Shleifer and Vishny, 1997). This can further be seen from a different perspective: within Merton's (1974) framework, the CDS is essentially a put option on the underlying bond.129 During the mid 2011-mid 2012, bond yields across the periphery elevated to their highest levels in the short history of the EMU, with CDS spreads also matching this upward trend. The non-negligible likelihood of a sovereign defaulting at the time rendered the put options on these bonds (i.e., the CDS) in the money. Hence, the volatility smile arising or in other words the volatility smirk (since sovereign bonds generally attract passive and/or long-term investors and thus resemble long-term equity options and index options), advocates excessive volatility for SCDS contracts relative to the pre-2012 period when sovereign bond yields were fluctuating within more moderate levels.

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129 More information on Merton's (1974) model is provided in Section 2.2.
Overall, several conclusions are derived from the intra-country analysis of the sovereign bond-CDS integration as well as the analysis of the relationship between bond-CDS integration and the level of the CDS-bond basis. First, the increase in the level of bond-CDS integration in each of the countries of the EMU South coincides with an increase in the volatility spillover between sovereign bonds and CDSs in the same countries, thereby verifying - to an extent - the arguments about volatility being a major driver of cross-asset correlation (see Aït-Sahalia and Xiu, 2016). Second, capital flights emerge as the primary reason for the persistently positive basis in Austria, Finland, France, Germany, and the Netherlands for the duration of the main stage of the European sovereign debt crisis, i.e., until late 2011-early 2012. Lastly, post-2009, when bond-CDS integration in the European periphery and Belgium strengthens, suggesting that sovereign bonds and CDSs are driven to a large extent by the same fundamentals, the basis becomes negative; this in turn renders sovereign bond yields as the most efficient indicators of sovereign credit risk in those countries. In the same countries, illiquidity and volatility appear to act as limits to arbitrage (Shleifer and Vishny, 1997; Roll et al., 2007; Gârleanu and Pedersen, 2011; Nashikkar et al., 2011), since they coincide with the large and persistent negative values of the basis observed during the late 2011-mid 2012 period.

5.6. Monetary conditions and sovereign bond-CDS integration

This section examines the effect of monetary and macroeconomic conditions as reflected in the process of monetary and real economic convergence and in the ECB's monetary policy stance. The examination is motivated by previous studies arguments that the EMU has achieved considerable convergence on the macroeconomic and monetary front, and that financial market integration is dependent, not only on country-specific fundamentals, but on the level of real and monetary convergence between international economies (see Fratzscher, 2002; Baele, 2005). Since the examination is conducted within a monetary union, the theory on optimum currency area suggests that these forms of convergence will have increasing effects on cross-market integration (Mundell, 1961; 130 The analysis in this section follows that of Kim et al. (2005, 2006b) for the stock and bond markets.
McKinnon, 1963). In order to determine the appropriate model for the examination we must first identify the direction of causality between the sample of monetary and macroeconomic variables and the bond-CDS conditional correlations that are employed to proxy for the degree of bond-CDS integration.

To this end, a Granger causality test is performed for each EMU country individually in order to test whether monetary and macroeconomic variables contain information for forecasting the country-specific bond-CDS conditional correlations and vice versa. For the null hypothesis that variable $\chi$ does not Granger cause (the dependent) variable $\gamma$, the variable $\gamma$ is regressed on its own lagged values and on lagged values of $\chi$ in order to test whether the lagged coefficients of $\chi$ are jointly zero. The cell associated with the $i_{th}$ row variable and the $j_{th}$ column variable shows the $\chi^2$ statistics and corresponding $p$-values in parentheses.

[Insert Table 5.4 about here]

Starting from Austria, Table 5.4 reveals that the variable proxying for real economic convergence at the EMU-level Granger causes that country's bond-CDS conditional correlation, since the value of cell (1,1) is 15.545 and significant at the 5% level. However, the reverse does not appear to be the case since the value of cell (5,5) is 7.251 and insignificant at all levels, thereby indicating that the level of bond-CDS integration in Austria is not informative for movements in the real economic convergence variable. The coefficients from the Granger causality tests for the remaining countries in Table 5.4 are interpreted in a similar way. Overall, the results point to a unidirectional transmission of causality stemming from the monetary and macroeconomic variables to the bond-CDS conditional correlations. This implies that by modifying its monetary policy stance, the central banks can affect the bond-CDS integration and thus (in the case of increased integration), enhance the diversification and hedging benefits of investment strategies.

Due to this unidirectional relationship, it is reasonable to treat the monetary and macroeconomic variables as exogenous in relation to the cross-market conditional correlations; however the probability of correlation between those variables - possibly through their innovations - is also allowed. These innovations capture regulatory and institutional features, political factors, and
any other information that could be omitted in ordinary least squares regressions (Kim et al., 2006b).

For these reasons a seemingly unrelated regression (SUR) is employed, that is, a system of linear equations that has contemporaneous cross-equation error correlation. Because of the nature of the variables employed to proxy for real economic convergence and monetary convergence, multicollinearity problems arise during the analysis. To address these problems, along the lines of Fratzscher (2002) and Kim et al. (2005, 2006b) principal component analysis is employed in order to form two new variables that proxy for each of these forms of convergence. The model is comprised of 11 separate equations, one for each EMU member-state, and has the following form:

\[
\begin{align*}
\rho_{BCDS,t} &= \alpha_{t1} + \beta_{t1}PCREAL_{t,t-1} + \gamma_{t1}PCMONETARY_{t,t-1} + \sum_{j=0}^p \delta_{t1j}ECB_{t-j} + \\
&+ \sum_{j=1}^2 \zeta_{1ij}\rho_{B,CDS,t-j} + \sum_{j=0}^r \theta_{1ijk(\text{for } k=1:3)}CONTROL_{t-j} + \varepsilon_{it}
\end{align*}
\] (5.26)

where \(\rho_{BCDS,t}\) is the bond-CDS conditional correlation of country \(i\) at time \(t\), \(PCREAL_{t,t-1}\) and \(PCMONETARY_{t,t-1}\) are the variables resulted from the principal component analysis and that employed as proxies for real economic convergence and monetary policy convergence respectively. These variables enter the analysis in their lagged values. The vector \(\sum_{j=0}^p \delta_{t1j}ECB_{t-j}\) is the monetary policy variable. This variable is consisted of a vector containing the present and past values of the interest rate variables (i.e., the EONIA and EURORATE) and the measures of “orthogonalized” reserves held with the ECB (i.e., ERX, RRX, ER/TR, RR/TR). This variable is employed as a proxy for the stance of the ECB’s monetary policy. The equations also include the lagged bond-CDS conditional correlation of country \(i\) at time \(t\), which is represented by the vector \(\sum_{j=1}^2 \zeta_{1ij}\rho_{B,CDS,t-j}\). The vector \(\sum_{j=0}^r \theta_{1ijk(\text{for } k=1:3)}CONTROL_{t-j}\) is a vector of control variables and includes the implied volatility of the CBOE index (VIX) and the economic uncertainty index (UNCERTAINTY).131 The vector of control variables further includes a dummy variable equal to one (otherwise zero) for all observations after the bankruptcy of the Lehman Brothers (i.e., September 15 2008), and a dummy

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131 Table 5.1 provides detailed information on the definition of the variables employed in the analysis of Section 5.6, the sources of these variables and the methods for their construction.
variable equal to one (otherwise zero) for all observations after the onset of the implementation of the short-sales ban (i.e., November 1 2012).\textsuperscript{132} Lastly, $\varepsilon_{it}$ is the error term.

To confirm the appropriateness of dummy variables and verify the results from Section's 5.5 graphs regarding the points where structural changes in the evolution of bond-CDS conditional correlations occurred, the Bai and Perron test is also employed. Only the September 2008 date is chosen as the cut-off point for the dummy variable, since the other changes occurred in a wider time-band (second half of 2010 - first half of 2011); these latest changes are represented by the measures of bank reserves with the ECB, which also experience a significant increase after May 2010, and thus, capture this transition to a period of unconventional monetary policy across EMU. Results in Table 5.5 reveal that independent variables are not uniformly significant as we observe relative differences across EMU member-states, suggesting that the use of measures of “orthogonalized” reserves and the employment of principal components has addressed the issue of multi-collinearity raised previously.

[Insert Table 5.5 about here]

Along the lines of OCA theory, advances in real economic as well as in monetary policy convergence appear to have been successful in driving the European sovereign bond and CDS markets towards greater integration. This is primarily the case with regards to the real economy, where the significant coefficients are greater in number and value, and are observed in the majority of the EMU member-states. The proxy for monetary policy convergence also appears effective in improving cross-market integration, however its importance is mostly concentrated in the less strong and/or the debt-laden economies; this is unsurprising, since predominant economies such as Germany and France are the main determinants of the monetary conditions prevailing in the EMU, and further constitute the benchmarks against which the monetary convergence of individual states is evaluated. The implication of these results is that a greater degree of conformance with the EMU-average in

\textsuperscript{132} This is motivated by the analysis of Section 5.5, which revealed that the changes in the time-varying bond-CDS conditional correlations occurred since late 2008. The analysis further shows that the other period where a significant change in the pattern of these correlations occurred, is from the second half of 2010 until the first half of 2011.
terms of trade openness, productivity growth, and price level adjustments, leads to a tighter association and a more efficient interaction between the debt and credit derivatives markets of an EMU member-state.

Focusing on the variables reflecting the ECB's monetary policy stance, we observe that “orthogonalized” reserves are effective in inducing movements in sovereign bond-CDS integration. Monetary expansion represented by a rise in excess reserves and/or required reserves is generally associated with an improvement in the bond-CDS conditional correlations. Interest rates further constitute a determinant of cross-market integration (although their contribution is relatively weaker than that of bank reserves), with a fall in interest rates generally leading to a rise in the degree of integration between sovereign bonds and CDSs in most of the Eurozone countries. This strong impact of the monetary policy variables provides a strong argument for the expanded asset purchase programme (APP), i.e., the massive purchase programme for marketable debt instruments announced by the ECB in January 2015 in order to intervene more heavily in the European sovereign debt markets. Hence, the further expansion of the ECB’s balance sheet through additional purchases of government bonds can contribute to the restoration of equilibrium between the sovereign bond and CDS markets. The impact of measures of bank reserves is mainly concentrated in the countries of the EMU South (along with the smallest EMU North economies, such as Austria and Belgium), that is the countries that the ECB purported to affect, and whose sovereign markets comprise the primary target of the asset purchase programmes. Among those measures, the excess reserves to total reserves ratio appears to exert the greatest impact on cross-market conditional correlations, suggesting that it can be an efficient tool - and signal - for determining the future level of bond-CDS integration.

We would expect economic uncertainty to affect cross-market integration in different ways, with growing uncertainty (represented by a rise in the uncertainty index and/or the volatility index) improving integration in the strongest EMU economies and favouring segmentation in the less strong and debt-laden ones, due to the flight-to-safety phenomenon. The coefficients on both the uncertainty index and the volatility index are significant, however their sign across countries does not support the above argument. Thus, either the period of market uncertainty in the Eurozone cannot be fully
captured by these measures, or the European sovereign bond and CDS markets are away of their equilibrium values and cannot perform their diversification role. Results are not clear with regards to the influence of the dummy variables, as the coefficients of both variables vary in sign and significance. This is expected when considering the effect of the post-September 2008 period, since following the Lehman Brothers bankruptcy and the re-pricing in the European sovereign debt markets, bond-CDS integration has followed different paths depending on the country of question, a pattern also evident in the AG-DCC GARCH analysis of Section 5.5. However, it cannot be argued with certainty that the short-selling ban has been a contributing factor towards greater integration between the two markets; the coefficients are significant in only half of the EMU member states. A rather expected finding is that the level of bond-CDS conditional correlation is dependent on the past values of this correlation in most countries; this in turn verifies the persistent and dynamic nature of the bond-CDS integration process.

5.7. Conclusion

This chapter measures the bilateral volatility spillovers between the sovereign bond and CDS markets across the EMU during the 2007-2014 period by augmenting the Diebold and Yilmaz's (2009, 2012) generalized VAR model with two common factors to account for the possibility of EMU-wide shocks. Results from the intra-country analysis reveal a unidirectional volatility spillover from the sovereign bond to the SCDS market in all EMU countries, which is further verified within the context of cross-country analysis. Germany emerges as the main transmitter of bond volatility to the CDS markets of the Eurozone core, while Ireland and Italy also assume a central role in the European financial markets framework, since they appear as significant bond and CDS volatility contributors to the rest of the European CDS markets. Thus, despite the surge in the size and importance of the SCDS market, the results identify sovereign bond markets as the most powerful vectors of information particularly during the 2010-2012 period.

The chapter further assess the extent to volatility interaction between sovereign bonds and CDSs within the same EMU country drives the level of integration between them (as reflected in their
level of conditional correlation), and whether this integration is consequently linked to the evolution of the no-arbitrage relationship between the two assets (the CDS-bond basis). This is done by means of the asymmetric generalized DCC of Cappiello et al. (2006). In this regard, the increase in volatility directed from the sovereign bond towards the SCDS market from the onset of the Eurozone crisis onwards coincides with the an increase in the bond-CDS conditional correlations in each country of the EMU South and Belgium. This verifies the theoretical arguments about the strong association between volatility and cross-asset correlation (Andersen et al., 1999, 2003) and most importantly the importance of volatility for the evolution of cross-asset correlation (Aït-Sahalia and Xiu, 2016). The consideration of the role of the CDS-bond basis, reveals the existence of a two-tier Eurozone. In the countries of the North (i.e., Austria, Finland, France, Germany and the Netherlands) capital flights emerge as the primary reason for the persistently positive CDS-bond basis for the duration of the main stage of the Euro debt crisis, i.e., until late 2011-early 2012. In the EMU South and Belgium however, there is evidence of an inverse relationship between bond-CDS conditional correlation (and therefore integration) and the CDS-bond basis: post-2009, an improvement of this integration, which further suggests that sovereign bonds and CDSs are driven to a large extent by the same fundamentals, causes the basis to become negative. In the same bloc, illiquidity and volatility appear to act as limits to arbitrage, since they coincide with the large and persistent negative values of the CDS-bond basis during the late 2011-mid 2012 period.

The present chapter's results carry significant implications for the measurement and transmission of sovereign credit risk. Within this framework the analysis of this chapter identifies sovereign bond yields as the most efficient indicators of sovereign credit risk in the countries of the EMU South. Therefore, macroprudential policies should take into consideration the optimum mix of sovereign bonds and CDSs in the portfolio of financial institutions when calculating the risk in those institutions' portfolio. This is not only due to the capacity of bonds to transmit information to CDSs, but also to the former being the driver of the integration between the two assets. This in turn determines the exposure of a financial institution in a given country since it dictates the amount of domestic debt to be hedged at any instant by assuming offsetting positions in the underlying domestic
sovereign CDS market. In addition, early warning indicators of financial stress should assign more weight to developments in the sovereign bond market in order to forecast developments in that of sovereign CDSs.

Future research could be devoted to measuring the extent to which this increased intra- and particularly cross-country spillover between sovereign bond and CDSs eventually leads to the emergence of contagion phenomena between the two asset-markets. As the analysis in the present chapter reveals, in periods of extreme markets stress there are increased volatility linkages across the Eurozone. Since contagion is defined as a significant increase in cross-market linkages after a shock to one country, or group of countries (see Frobes and Rigobon, 2002), future examination could focus on whether the strength of the linkages documented in this chapter is strong enough to result in contagion.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Frequency</th>
<th>Source</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOND</td>
<td>Daily</td>
<td>Datastream</td>
<td>The yield on the 5-year on-the-run sovereign bond.</td>
</tr>
<tr>
<td>CDS</td>
<td>Daily</td>
<td>Markit</td>
<td>The change in the spread on the 5-year CDS contract.</td>
</tr>
<tr>
<td>BOND FACTOR</td>
<td>Daily</td>
<td>Bloomberg</td>
<td>The common factor from the principal factor analysis of the 11 countries' yields on the 5-year on-the-run sovereign bonds.</td>
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<tr>
<td>CDS FACTOR</td>
<td>Daily</td>
<td>Eurostat</td>
<td>The common factor from the principal factor analysis of the 11 countries' spreads on the 5-year on-the-run sovereign CDS contracts.</td>
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<tr>
<td>PCREAL</td>
<td>Monthly</td>
<td>Datastream</td>
<td>The principal component that proxies for real economic convergence and is formed of the following variables:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Output: The rolling correlations in annual growth rates of seasonally adjusted industrial production (IP) with the average of the Euro Area.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Trade Openness: The ratio of the country's total exports plus imports to the country's annual GDP.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intra-Trade: The ratio of the country's exports to EMU plus imports from EMU to the country's total trade.</td>
</tr>
<tr>
<td>PCMONETARY</td>
<td>Monthly</td>
<td>Eurostat</td>
<td>The principal component that proxies for monetary policy convergence and is formed of the following variables:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Datastream</td>
<td>Nominal short-term rates: The rolling correlations in nominal short-term interest rates (1 month</td>
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<td>Variable</td>
<td>Frequency</td>
<td>Data Source</td>
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</tr>
<tr>
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<td>Monthly</td>
<td>ECB</td>
<td></td>
</tr>
<tr>
<td>RRX</td>
<td>Monthly</td>
<td>ECB</td>
<td></td>
</tr>
<tr>
<td>ER/TR</td>
<td>Monthly</td>
<td>ECB</td>
<td></td>
</tr>
<tr>
<td>RR/TR</td>
<td>Weekly/Monthly</td>
<td>ECB</td>
<td></td>
</tr>
<tr>
<td>EONIA</td>
<td>Weekly/Monthly</td>
<td>ECB</td>
<td></td>
</tr>
<tr>
<td>EURORATE</td>
<td>Daily/Weekly/Monthly</td>
<td>Datastream</td>
<td></td>
</tr>
<tr>
<td>VIX</td>
<td>Daily/Weekly/Monthly</td>
<td>CBOE</td>
<td>The implied volatility of the CBOE index</td>
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<tr>
<td>-----</td>
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<td>----------------------------------------</td>
</tr>
<tr>
<td>UNCERTAINTY</td>
<td>Monthly</td>
<td>Baker et al. 2015</td>
<td>An index constructed from three types of underlying components: The first component quantifies information on policy-related economic uncertainty from newspaper coverage. The second component reflects the number of tax code provisions that are set to expire in the future years. The third component employs disagreement among economic forecasters as a proxy for measuring uncertainty. For more information, see Baker et al. 2015.</td>
</tr>
</tbody>
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## Table 5.2
Total Spillover Index. Factor-augmented VAR

<table>
<thead>
<tr>
<th>BOND</th>
<th>CDS</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GRE</strong></td>
<td>86.11</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>IRA</strong></td>
<td>2.78</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>ITA</strong></td>
<td>2.79</td>
<td>0.40</td>
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<tr>
<td><strong>POR</strong></td>
<td>2.46</td>
<td>0.55</td>
</tr>
<tr>
<td><strong>ESP</strong></td>
<td>2.86</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>GER</strong></td>
<td>0.20</td>
<td>0.13</td>
</tr>
<tr>
<td><strong>FRA</strong></td>
<td>0.73</td>
<td>0.10</td>
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<td><strong>To Others</strong></td>
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<tr>
<td><strong>From Others (+ own)</strong></td>
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<td>104.66</td>
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<tr>
<td><strong>Net Spillover</strong></td>
<td>29.08</td>
<td>4.66</td>
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### Notes
- **Bond CDS** refers to the direct spillover effect from one country's bond market to another's CDS market.
- **To Others** and **From Others** represent the percentage of spillover from or to other countries, respectively.
- **Net Spillover** takes into account both direct and indirect spillovers.
Table 5.3
Total Spillover Index. VAR

| From Others | GRE | IRA | ITA | POR | ESP | GER | FRA | AUS | BEL | FIN | NED |  | From Others |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----| |  |
| GRE         | 98.32 | 0.06 | 0.20 | 0.01 | 0.27 | 0.01 | 0.04 | 0.01 | 0.02 | 0.02 |  |  | 1.68 |
| IRA         | 0.20 | 89.43 | 1.44 | 0.21 | 0.27 | 0.26 | 0.34 | 0.21 | 0.19 | 0.20 | 0.20 |  |  |
| ITA         | 0.22 | 7.31 | 83.92 | 1.20 | 0.25 | 0.28 | 0.27 | 0.40 | 0.36 | 0.06 | 0.25 |  |  |
| POR         | 0.67 | 11.73 | 4.12 | 62.47 | 0.29 | 0.20 | 0.02 | 0.15 | 0.23 | 0.34 | 0.15 |  |  |
| ESP         | 0.29 | 6.72 | 38.90 | 2.15 | 0.39 | 0.30 | 0.28 | 0.17 | 0.14 | 0.06 |  |  |
| GER         | 0.26 | 0.30 | 0.35 | 0.32 | 0.33 | 87.11 | 5.58 | 1.13 | 0.24 | 0.69 | 1.32 |  |  |
| FRA         | 0.08 | 1.18 | 5.10 | 1.11 | 0.46 | 36.25 | 50.05 | 0.87 | 2.07 | 0.10 | 0.58 |  |  |
| AUS         | 0.15 | 0.59 | 3.33 | 1.24 | 0.91 | 24.33 | 7.40 | 56.93 | 2.74 | 0.10 | 0.04 |  |  |
| BEL         | 0.25 | 4.31 | 14.01 | 1.41 | 1.37 | 13.32 | 16.61 | 0.91 | 42.98 | 0.02 | 0.14 |  |  |
| FIN         | 0.11 | 0.23 | 0.70 | 0.34 | 0.34 | 37.56 | 5.13 | 0.97 | 0.72 | 51.13 | 1.45 |  |  |
| NED         | 0.16 | 0.55 | 0.89 | 0.36 | 0.15 | 35.51 | 12.72 | 0.31 | 0.78 | 0.45 | 46.16 |  |  |

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<td>FIN</td>
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<tr>
<td>NED</td>
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<td>AUS</td>
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</tr>
<tr>
<td>BEL</td>
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To Others Net Spillover 44.5% 979.24
Table 5.4
Granger Causality Tests

Table 5.4 presents $x^2$ statistics of pair-wise Granger causality tests between macroeconomic and monetary variables and country-specific conditional correlations endogenous. Null hypothesis is that row variable does not Granger cause column variable. The ordering of the VAR endogenous variables is PCREAL, PCMONETARY, ERX, RRX, EONIA, each of the country-specific conditional correlations. PCREAL is the principal component that proxies for real economic convergence. PCMONETARY is the principal component that proxies for monetary policy convergence. ERX The change in the orthogonalized excess reserves of Euro Area credit institutions with the ECB. RRX The change in the orthogonalized required reserves of Euro Area credit institutions with the ECB. EONIA is the change in EONIA. AT, BE, DE, EL, ES, IE, FI, FR, IT, NL, PT are the country-specific conditional correlations. The sample includes Austria, Belgium, Finland, France, Ireland, Italy, Germany, Greece, the Netherlands, Portugal, and Spain for the period between August 2007 and June 2014. *, **, *** denotes significance at the 10%, 5%, and 1% level respectively.

Panel A. EMU South.

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<th>PCMONETARY$_{t-1}$</th>
<th>ERX</th>
<th>RRX</th>
<th>EONIA</th>
<th>EL</th>
<th>IE</th>
<th>IT</th>
<th>PT</th>
<th>ES</th>
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<td>32.785***</td>
<td>10.445**</td>
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<td>21.361***</td>
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<td>41.230***</td>
<td>47.124***</td>
<td>17.247***</td>
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<td></td>
<td></td>
<td></td>
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<td>19.005***</td>
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<td>23.058***</td>
<td>28.377***</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
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Country Abbreviations:
EL: Greece    IE: Ireland  IT: Italy  PT: Portugal  ES: Spain
Panel B. EMU North.

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<th>( ERX )</th>
<th>( RRX )</th>
<th>( EONIA )</th>
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<td>( PCREAL_{t-1} )</td>
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<tr>
<td>PT: Portugal</td>
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<td>ES: Spain</td>
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252
Table 5.5 presents country-specific results from the seemingly unrelated regressions (equation (5.26)) for sovereign bond returns and sovereign CDS spreads. $P_{CREAL,t-1}$ is the previous period's principal component that proxies for real economic convergence. $P_{MONETARY,t-1}$ is the previous period's principal component that proxies for monetary policy convergence. ERX is the measure of orthogonalized excess reserves, RRX is the measure of orthogonalized required reserves, ER/TR is the ratio of excess reserves to total reserves, RR/TR is the ratio of required reserves to total reserves, EONIA is the Eonia, EURORATE is a set of Euro Area interest rates, $P_{BCDS,t-1} - P_{BCDS,t-2}$ are the lagged conditional correlations at time $t-1$ and $t-2$ respectively, VIX is the implied volatility for the CBOE index, UNCERTAINTY is the economic uncertainty index, POST-2008 is a dummy variable equal to one for all observations after the bankruptcy of the Lehman Brothers (i.e., September 15 2008), POST-BAN is a dummy variable equal to one for all observations after the onset of the implementation of the short-sales ban (i.e., November 1 2012). *, **, *** denotes significance at the 10%, 5%, and 1% level respectively.

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<th>Variables</th>
<th>AT</th>
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<td>-0.5964***</td>
<td>1.1012***</td>
<td>0.7955*</td>
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Country Abbreviations: AT: Austria  BE: Belgium  FI: Finland  FR: France  DE: Germany  EL: Greece  IE: Ireland  IT: Italy  NL: The Netherlands  PT: Portugal  ES: Spain
Figure 5.1
Daily Time-Series of Government Bond Yields and Government CDS Spreads

This Figure presents the daily time-series of government bond yields and government CDS spreads for the EMU Periphery (i.e., Greece, Ireland, Italy, Portugal, Spain), and for the EMU Core (i.e., Austria, Belgium, Finland, France, Germany, the Netherlands) between August 6 2007 and June 20 2014. Bond yields and CDS spreads are expressed in basis points. The CDS spreads for Greece scaled down by 10 to enhance comparability between the countries. Bond yields are from Thomson Reuters Datastream, and CDS spreads are from Markit.
Bond Yields - EMU Core

Time

06.08.2007
15.09.2008
05.11.2009
03.05.2010
09.03.2012
14.08.2013
20.06.2014

Basis Points

Austria
Belgium
Finland
France
Germany
Netherlands
This Figure presents the daily time-series of the scores from the factors analysis for the sovereign bond yields and for the CDS spreads for of Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, and Spain between August 6 2007 and June 20 2014. The scores from the factor analysis for the sovereign bond yields and the CDS spreads are computed by employing factors 1, 2, and 3.
This Figure presents the daily time-series of the net spillover between country-specific sovereign bonds and SCDSs, for Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, between August 6 2007 and June 20 2014. The net bond-CDS spillover for each country is defined as the spillover of that country’s bond to the same country’s CDS minus the spillover of that country’s CDS to the same country’s bond.

**Austria**

![Graph of Austria's net spillover](image)

**Belgium**

![Graph of Belgium's net spillover](image)

**Finland**

![Graph of Finland's net spillover](image)

**France**

![Graph of France's net spillover](image)

**Germany**

![Graph of Germany's net spillover](image)

**Greece**

![Graph of Greece's net spillover](image)

**Ireland**

![Graph of Ireland's net spillover](image)

**Italy**

![Graph of Italy's net spillover](image)
Figure 5.4
Net Spillover Between the EMU Periphery and the EMU Core

Graph I. Intra-asset Net Spillover Between the EMU Periphery and the EMU Core

Graph II. Cross-asset Net Spillover Between the EMU Periphery and the EMU Core
This Figure presents the daily time-series of country-specific conditional correlations between sovereign bonds and SCDSs, against the country-specific daily-time series of the CDS-bond basis, for Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, between August 6 2007 and June 20 2014. Bond-CDS conditional correlation is multiplied by 100 and therefore, is bounded in the range [-100, 100], and the CDS-bond basis is expressed in basis points. The CDS-bond basis for Greece is scaled down by 10 from 14/06/2011 to 07/06/2013 to enhance comparability with the Greece bond-CDS conditional correlation.
Appendix 5.A

More information about the calculation of the CDS-bond basis

For the purpose of this study, the CDS-bond basis (the basis) is defined as the difference between the CDS premium and the maturity matched par asset swap spread, i.e., the difference between the bond yield and the risk-free rate. Therefore, the CDS-bond basis for country $i$ at time $t$ is calculated as:

$$Basis_{it} = CDS_{it} - (Bond_{it} - EoniaSwap_t)$$

(5.27)

where, $CDS_{it}$ and $Bond_{it}$ are the CDS spread and bond yield respectively of country $i$ at time $t$, and $EoniaSwap_t$ is the Eonia swap index at time $t$, which is the measure of risk-free rate (other measures of risk-free rate can include LIBOR, or in the case of the US the overnight indexed swap (OIS) spread).

Essentially, the CDS premium covers the risky component of the bond, i.e., the excess of the bond yield over the risk-free rate. The no-arbitrage condition forces the basis to be zero, since any value different than zero represents an arbitrage opportunity (assuming no transactions costs). In the case of a positive (negative) basis, an investor can buy (short) the bond and sell (buy) CDS protection. In practice however, the no-arbitrage condition is violated, resulting in the basis being either positive or negative.

This is partly attributed to the changes in the mechanics of CDS contracts. In particular, since 2009 CDSs trade with a fixed coupon and an upfront payment. For distressed bonds with a low fixed coupon, a significant component of the protection costs' is paid in advance. Therefore, if the bond's price is added to the cost of the upfront payment for the CDS contract the no-arbitrage strategy costs more than par. In the event of an immediate default this translates into a loss for the investor. Only if the default occurs in some fixed horizon, the investor is able to receive the higher bond coupons and thus, compensate for the potential default of the entity. This feature may consequently account for a non-zero basis since the arbitrage opportunities are difficult to be eliminated.

Most importantly, European sovereign bonds are denominated in Euros, while the standard CDS contracts on these bonds are denominated in US Dollars. Hence, a standard no-arbitrage strategy further depends on the Euro/US Dollar exchange rate. In particular, the portion of the bond that is not
redeemed and, therefore is paid by the CDS contract, is converted into Euros. However, besides the daily changes in the Euro/US Dollar exchange rate, a Eurozone sovereign's default is expected to impact on the exchange rate, possibly forcing the Euro to depreciate against the US Dollar. This in turn is translated into a profit for the Euro-based hedger or arbitrager, while it also presents an opportunity for speculation on a Eurozone sovereign's default. To prevent such speculation the US Dollar-denominated CDS spread should incorporate the future exchange rate at the time of the sovereign's default. Therefore, during periods of extreme market stress where a default is more likely to occur, the spread on the US Dollar-denominated CDS contract is higher than the spread on its Euro-denominated counterpart.

An additional method for calculating the CDS-bond basis is through the “par-equivalent CDS spread” methodology of JPMorgan. The par-equivalent CDS spread is the spread of a par bond that has the same implied default probability as that implied by the CDS contract on the traded bond. Then, the CDS-bond basis is simply the difference between the CDS premium and the par-equivalent CDS spread. However, for most investment grade bonds, the values for CDS-bond basis calculated by the two methods differ by only a few basis points. Since, the analysis in this chapter focuses on the value, but most importantly on the direction of the CDS-bond basis with regards to the level of correlation between sovereign bonds and CDSs in each country, either of the two methods is credible.
6. Conclusion

In this Section I provide an outline of the Thesis. In particular, I summarize the general findings of the Thesis as well as the main findings of each individual empirical chapter and the implications that these findings carry. I additionally discuss the limitations of my empirical analysis which concern the examination of sovereign bond and CDS liquidity. Finally, within the context of the financial asset interaction, I point attention to an issue that arises from the analysis of volatility and integration and that can constitute the subject of future academic research.

6.1. Findings of the Thesis

In the present Thesis I examined the price, liquidity, and volatility interaction between different financial asset-markets. Considering the transition to an era of non-standard monetary policy measures as a response of policy makers to the financial and the Eurozone crises, I further evaluated the success of central banks in affecting this interaction and financial asset-markets in general. My analysis provided new information about the nature and the characteristics of financial markets and was mainly developed along two fronts: the one concerns the link between the sovereign bond and sovereign CDS markets and the other referred to the differences in terms of financial market behaviour between the two EMU blocs, i.e., the EMU North and the EMU South.

On the first front, I provided evidence of the existence of significant differences between the sovereign bond and SCDS markets, regarding their liquidity and volatility interaction. My results revealed that the sovereign bonds constitute the main transmitters of information, and therefore of liquidity and volatility, to the market of sovereign CDS contracts. In addition, through my empirical analysis I showed that the two Eurozone blocs, i.e., the North and the South, do not only differ in structural aspects or in terms of macroeconomic and fiscal fundamentals, but also with regards to the features and behaviour of their sovereign financial markets. In specific, I found that in the EMU South a) the sovereign bond markets are the sole transmitters of liquidity to the sovereign CDS markets and b) that the CDS-bond basis is persistently negative and inversely related to the level of bond-CDS integration. On the contrary, within the Northern EMU bloc, the sovereign CDS market also appears
to transmit - although to a lesser extent - liquidity to the sovereign bond market, while the CDS-bond basis assumes positive values and is positively associated with the level of bond-CDS integration.

My empirical analysis suggests that sovereign bond yields provide indications of sovereign credit risk that reflect different economic fundamentals and market conditions relative to the CDS contracts written on them. This pattern is more evident in countries under significant fiscal stress, such as those of the European South, since the transmission of information appears to be directed solely from the sovereign bonds to CDSs and not the reverse. In addition, when their performance as market indicators is considered, sovereign bonds appear to adjust more rapidly to new information, particularly during periods of heightened market activity. Therefore, I argue that sovereign CDS spreads cannot constitute an efficient hedge to offset sovereign credit risk, therefore hampering the diversification of funds and posing a threat to financial stability. My results about the persistently negative (positive) in the EMU South (North) CDS-bond basis further point to the fact that sovereign CDS spreads cannot entirely replicate the cash flows on the underlying obligations, thereby giving rise to arbitrage opportunities. I further showed that these opportunities are in turn associated with the level of integration between the sovereign bond and CDS markets in each country. From the perspective of policy implementation, my analysis supports the recent EU’s decision on prohibiting the purchase of naked CDS contracts: I found that greater sovereign CDS illiquidity positively affects sovereign bond liquidity in most EMU countries, thereby indicating that the sovereign CDS market might be the means for the launch of speculative attacks against the sovereign bond markets of the EMU South.

My results further carry significant implications for the identification and monitoring of systemic risk in financial markets as well as for the current global and EU regulatory frameworks. As a general rule the sovereign-related exposures should be treated with reference to the sovereign bond market rather than that of CDSs except for the cases where the latter are employed as collateral. In specific, a) low or zero capital requirements on certain sovereign exposures should be redefined, since even risk-free sovereigns such as Germany are susceptible to negative spillovers from large but high-debt economies such as Italy and Spain, which consequently emerge as primary determinants of the
EMU-wide financial stability, b) low capital requirements for government bond collateralised exposures due to lower haircuts for high-rated sovereigns should be readjusted upwards when this collateral include CDS contracts written on those bonds, due to the less than perfect hedging capacity of CDSs at least in countries under fiscal stress. Along the same lines, the construction of broader and more forward-looking systemic risk indicators should assign more weight to sovereign bonds.

I additionally show that the existence of differences in the timing and quantity of the reflected information is not a feature of cross-asset interaction only at the sovereign level. At the corporate level, my examination of the information transmission between the stock, bond and CDS market indices supports the ‘‘friction-based’’ and ‘‘sentiment-based’’ theories of co-movement according to which index co-movement is delinked from the underlying fundamentals. I show that the stock index in both Europe and the US is the asset where information is reflected first before being transmitted to the corporate bond and CDS indices. This lead of the stock market is particularly relevant in the context of passively managed mutual funds and exchange-traded funds: on the one hand, it highlights the importance of monitoring the stock index for predicting movements in the bond and CDS indices, while on the other hand, the lag in the information transmission between the market indices reduces the efficiency of price information and consequently the benefits of diversification across the stock, bond and CDS markets.

On the monetary policy front, my analysis suggests that the expansion of the central bank’s balance sheet through the supply of bank reserves constitutes an effective tool for affecting financial markets during exceptional monetary conditions. These conditions refer to periods where the interest rate is at the zero or even negative level and thus the central bank is deprived of its principal monetary policy tool. It further confirms the transition in central bank practice from an interest rate policy to that of quantitative easing (QE). By providing evidence that the financial market movements induced by QE are of a greater magnitude and duration in the US rather than in Europe and also post- rather than pre-crisis: a) I draw attention to the fact that central bank-conducted asset purchases are more effective in lowering asset returns when the markets are not functioning normally, a fact that

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133 The ‘‘friction-based’’ and ‘‘sentiment-based’’ theories of co-movement are presented in Section 2.2.
empirically verifies the “portfolio balance” channel of monetary policy transmission and further confirms the models of market segmentation and the theories of preferred habitat, b) I lend support to the adoption of non-standard measures by the Federal Reserve following the 2007-2008 credit crunch. The effectiveness of the Fed-adopted measures and their consistency with the escalation of the US crisis additionally serves as a guide for the ECB, since during the onset and the main stage of the Eurozone crisis its monetary policy was primarily exercised by means of interest rate setting.

6.2. Limitations

One of the issues that have been at the core of this Thesis’ empirical analysis was that of cross-asset liquidity, acknowledging the fact that liquidity constitutes one of the main channels for the interaction between financial assets. In this respect, Chapter II (Section 4) examined the liquidity interaction between the sovereign bond and CDS markets. The primary measure of liquidity employed in the examination was the bid-ask spread, i.e., the difference between the ask price and the bid price. This measure was used to measure liquidity in the sovereign CDS market and was also employed to construct the effective bid-ask spread which was the preferred liquidity measure for the sovereign bond market. However, other liquidity measures have been employed in the literature to study aspects of intra- or cross-asset liquidity.

These measures which were initially constructed to measure the liquidity of individual stocks include the Amihud measure of illiquidity, a price impact measure that captures the “daily price response associated with one dollar of trading volume” (see Amihud, 2002), the Roll estimator, an estimator of the effective spread based on the serial covariance of the change in price (see Roll, 1984), the LOT measure, an estimator of the effective spread based on the assumption of informed trading on non-zero-return days and the absence of informed trading on zero-return days (see Lesmond et al., 1999), the transaction price impact measured as the price response to signed order flow (see Brennan and Subrahmanyam, 1996), the probability of information-based trading, a measure estimated from

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134 An analysis of the “portfolio balance” channel of monetary policy transmission along with a discussion of the models of market segmentation and the theories of preferred habitat is provided in Section 2.6.2.
intra-daily transaction data (see Easley et al., 2002), and the Gibbs measure, a Gibbs sampler estimation of the Roll model using prices from all days (see Hasbrouck, 2004).

To construct the above liquidity measures certain information is needed, such as trading volume, intra-day transaction prices, order flow, and buy/sell indicators for last trades. Due to its nature, this information was not accessible from the available databases on sovereign bonds and CDSs at the time of the writing. For that reason, the examination of sovereign bond and CDS liquidity in Chapter II was conducted by employing the bid-ask spread. Nevertheless, despite the popularity of the bid-ask spread, the consideration of additional liquidity measures would enhance the empirical analysis. These measures could be used either to confirm the robustness of the empirical findings or to enable a comparison between the predicted abilities of different liquidity measures.

6.3. Future Research

My examination in the previous empirical chapters focused on the most important forms of the interaction and comovement between financial asset-markets. These forms refer to the comovement and interaction with regards to their price, liquidity and volatility. The latter two forms, i.e., liquidity and volatility, additionally constitute the primary channels through which asset-markets are connected. However, the prices of different assets frequently follow the same path due to contagion. Financial market contagion is closely related to the issue of volatility analyzed in Chapter III (Section 5). According to the findings of Chapter III, as well as to theoretical propositions (see Forbes and Rigobon, 2002; Andersen et al., 2003 Aït-Sahalia et al., 2009; Aït-Sahalia and Xiu, 2016), volatility is a strong driver of cross-asset correlation. In specific, increased volatility linkages cause an increase in conditional correlations. This increase in conditional correlations might in turn result in the emergence of contagion phenomena, since contagion is defined as a significant increase in cross-market linkages after a shock to one country, or group of countries (Forbes and Rigobon (2002).

135 I am grateful to the one of the examiners for this suggestion.

136 The theoretical link between asset volatility and correlation is analyzed in Section 2.5.
Therefore, the overall examination of cross-asset interaction in this Thesis, as well as that of cross-asset volatility linkages in Chapter III, could be extended towards this direction: to assess whether the financial and/or fiscal shocks during the recent European sovereign debt crisis have resulted in the transmission of contagion between the European sovereign bond and CDS markets. The issue of contagion is particular relevant, since contagion is a phenomenon in times of crisis. In addition, recent evidence from the EMU suggests that the diffusion of a fiscal shock may be different across the Eurozone (see Claeys and Vašíček, 2014; Broto and Pérez-Quirós, 2015). Countries with higher debt/deficits such as those of the EMU South are found to be immediately and negatively affected, whereas the direct impact on the EMU North is significantly less pronounced. In this respect, the analysis of sovereign bond-CDS contagion, could be further complemented with the examination of whether contagion is transmitted synchronously across different EMU member states.

Following the correlation concept of contagion - in the sense of Forbes and Rigobon (2002) - I can extend the empirical analysis in order to focus on whether changes in the conditional correlation between sovereign bond and CDSs after a negative shock, are of a significant size in order to justify the presence of contagion. In contrast to the traditional correlation analysis a measure of local Gaussian correlation could be instead be employed, e.g., the one introduced by Tjøstheim and Hufthammer (2013). This has a number of advantages relative to the traditional correlation analysis, since local Gaussian correlation does not suffer from the heteroscedasticity bias problem (Forbes and Rigobon, 2002). In addition, since linkages are not equally strong between all asset-markets (see Kaminsky and Reinhart, 2000) the effect that large fiscal shocks have on European markets could be different from the effect that is due to smaller shocks (asymmetric response). In this spirit, the local Gaussian correlation is able to detect more complex, nonlinear changes in the dependence structure, therefore providing a measure of both average and upper-lower tail dependence. This allows for a better understanding of asset interconnectedness in different segments of the distribution or under extreme market conditions (booming or crashing). Consequently, the implementation of a bootstrap

137 Studies following the traditional correlation approach include, inter alia, those of King and Wadhwani (1990), Baig and Goldfajn (1998), Calvo and Mendoza (2000).
procedure (see Stove et al., 2014) would enable the comparison of local correlations before and after different break points/periods, thereby providing information on the presence - or not - of contagion.\textsuperscript{138}

Hence, through the examination of contagion within the context of sovereign financial markets I can further extend my analysis of the primary forms of financial market interaction conducted in the present Thesis.

\textsuperscript{138} Exogenous break points could include the Lehman Brothers bankruptcy in September 2008, or Greece's upward budget deficit revision in October 2009.


Aït-Sahalia, Yacine, and Dacheng Xiu. "Increased correlation among asset classes: Are volatility or jumps to blame, or both?." *Journal of Econometrics* (2016).


Chen, Ren-Raw, Xiaolin Cheng, and Liuren Wu. "Dynamic interactions between interest rate, credit, and liquidity risks: Theory and evidence from the term structure of credit default swap


Delatte, Anne-Laure, Mathieu Gex, and Antonia López-Villavicencio. "Has the CDS market influenced the borrowing cost of European countries during the sovereign crisis?." *Journal of International Money and Finance* 31.3


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