Measuring and Analyzing Liquidity and Volatility Dynamics in the Euro-Area Government Bond Market

Conall O' Sullivan
University College Dublin
UCD Michael Smurfit Graduate Business School
conall.osullivan@ucd.ie

Vassilios G. Papavassiliou
University College Dublin
UCD Michael Smurfit Graduate Business School
vassilios.papavassiliou@ucd.ie

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Abstract

This chapter examines the impact the European sovereign debt market crisis had on liquidity and volatility dynamics and their interdependencies in the eurozone government bond market. In particular, we examine the impact across different countries and across different maturity buckets within individual countries. A comprehensive high-frequency dataset from MTS, Europe's premier electronic fixed-income trading market, is employed to construct a variety of microstructure liquidity and volatility measures. We analyze important trends in these measures over both tranquil and crisis periods. Additionally, we study time-varying correlations as well as the intertemporal interactions of liquidity proxies with volatility and returns. Our findings provide useful insights to regulators and policy makers on the relative strengths and weaknesses of domestic and global financial systems.

Keywords: Eurozone crisis; financial contagion; liquidity-volatility spillovers; bond markets

1 Introduction

There is a significant amount of interest in the empirical work on the microstructure of financial markets. Given the large market capitalization and trading volume in sovereign bond markets relative to equity markets, as well as the obvious importance of sovereign markets to their economies, these markets have received an increasing amount of attention from a microstructure perspective. The recent availability of high-frequency data on bond markets has significantly improved our understanding of bond market liquidity and trading. High-frequency data is the original form of market prices, also called tick-by-tick data, and not regularly spaced artifacts derived from the original market prices [Dacorogna et al., 2001]. Thus, high-frequency data provide a much clearer picture of variation in trading as well as access to constructing more efficient volatility and liquidity indicators.

In this chapter, we study high-frequency volatility and liquidity measures from the eurozone government bond market using a rich, comprehensive and unique dataset provided by MTS (Mercato dei Titoli di Stato), Europe's premier electronic fixed-income trading market for euro-denominated government bonds. The European sovereign debt crisis offers a unique opportunity to study the behavior of bond market volatility and liquidity as the market moves from the pre-crisis period to full blown crisis mode. Within each particular local market, we point out subsets of bonds that suffer the least as the crisis deteriorates. We also investigate whether the results for the PIIGS countries are more pronounced in terms of liquidity and volatility interdependence[1].

Our study contributes to the literature in a number of ways. First, we strive to analyze important trends in volatility and liquidity in the eurozone bond markets over both tranquil and crisis periods. Subsequently, we address the following questions: Has liquidity deteriorated across countries during the crisis? How does liquidity vary across countries and different maturity buckets? Has bond volatility intensified between calm and turbulent periods? Second, we analyze both static and time-varying correlations among various liquidity and volatility measures across countries. Whether or not liquidity and volatility shocks are significantly correlated with each other could be an indication of the systemic nature of those shocks and can also provide evidence on the existence of contagion effects across countries.

Third, the intertemporal interactions of liquidity proxies with returns and volatility across countries and asset classes have not been examined extensively, and we aim at filling this gap by drawing attention to the joint dynamics of liquidity, returns and volatility. Specifically, we study causality and volatility-liquidity spillovers across countries by employing VAR-type econometric techniques. Our findings are of great significance as they

[1]PIIGS is an acronym which refers to the economies of Portugal, Ireland, Greece, Italy and Spain that were unable to refinance their government debt or to rescue their problematic banking sector, and was popularized during the European sovereign debt crisis of the late 2000s.

offer useful insights on the workings of bond markets during periods of stress and on the future of the global economy where it seems inevitable for similar crises to happen again.

Finally, we employ the Forbes and Rigobon [2002] cross-market correlation coefficient, which adjusts the correlation estimate for heteroscedasticity, in order to test for financial contagion between (and within) PIIGS and non-PIIGS bond returns across different maturity segments. Our results document a deterioration of liquidity during the crisis period as transaction costs rise and quoted depth declines with the exception of the 30-year benchmark. Flight-to-liquidity effects are present in our sample period, as investors move into shorter-term and more liquid bonds. Additionally, flight-to-quality episodes are documented, as trading for benchmarks of higher credit ratings intensified during the crisis period.

Volatility intensified during the crisis for PIIGS countries, whereas it declined for non-PIIGS across all maturities. Shorter maturity bonds are more adversely affected than their longer-term counterparts by aggregate liquidity shortages and increases in volatility during the crisis period. Our VAR results suggest contemporaneous commonalities are driving daily volatility and returns, volatility and spreads, volatility and depth, as well as spread and depth liquidity measures, in both pre-crisis and crisis periods within and across PIIGS and non-PIIGS countries. We find strong evidence for a decoupling among European sovereign debt markets during the crisis, where shocks to PIIGS country volatility result in less PIIGS trading for benchmark securities but more non-PIIGS trading. We also provide strong evidence for a decoupling within the PIIGS countries whereas results are mixed within the non-PIIGS countries, as there are contagion effects among Germany, Netherlands and Finland and also between Finland and Austria.

The remainder of this chapter is organized as follows. Section 2 provides a selective literature review on the microstructure of the European bond markets. Section 3 discusses the MTS market structure, while Section 4 describes the data handling procedures and the construction of liquidity and volatility measures. Section 5 describes the econometric methodology. Section 6 presents the empirical results. Finally, Section 7 provides some concluding remarks.

2 A selective literature review

The existing literature on the microstructure of the European sovereign bond markets is fairly limited and mainly refers to periods prior to the financial crisis. Also, there are only a handful of papers that have employed high-frequency data from the MTS platform. Cheung et al. [2005] study the intraday price-order flow relation in the Euro bond market using data from the MTS platform. They found a larger impact of order flow during announcement days and a higher price impact of trading after a longer period of inactivity. Dunne et al. [2007] provide a formal theoretical argument on the meaning of benchmark bond and consider its role in pricing when there is concentration of liquidity and price discovery. Benchmarks in the European bond market are identified with the use of high-frequency transaction data from the EuroMTS platform.

Coluzzi et al. [2008] provide a description of the liquidity of the Italian wholesale secondary market using data from the corresponding MTS domestic platform. They found no sharp differences in terms of liquidity of the order book between on-the-run and off-the-run securities. They also show that modifications of issuance policies help securities in gaining their benchmark status. Girardi [2008] employs daily transaction prices from eleven European countries and finds that EuroMTS markets contribution to price discovery is about twenty percent and that price discovery turns out to be strongly related to trading activity and price volatility, even after controlling for institutional factors. Beber et al. [2009] use intraday European bond quotes and transactions from the MTS interdealer markets spanning the period from April 2003 to December 2004. Their evidence suggests that the bulk of sovereign yield spreads are explained by differences in credit quality, though liquidity plays a nontrivial role, especially for low credit risk markets and during times of heightened market uncertainty.

Favero et al. [2010] explore the determinants of observed yield differentials between eurozone sovereign bonds. Results indicate strong comovement in yield differentials of benchmark bonds, being explained by just the first principal component. Their econometric analysis reveals that the aggregate market risk factor is consistently priced and that the interaction of liquidity differentials with the risk factor is always negative when significant. Dufour and Nguyen [2012] analyze four years of transaction data for euro-area sovereign bonds traded on the MTS platform and find strong evidence of information asymmetry as well as evidence of demand for higher yields for bonds with larger permanent trading impacts.

Bai et al. [2012] investigate how variations in bond yields are affected by credit risk and liquidity risk in the euro area sovereign bond markets in order to shed light on the underlying causes of the European sovereign debt crisis. Using bond transaction data from MTS and CDS and interest rate swap spread data, they dispute the notion that the European sovereign bond crisis mainly propagates through the fundamental credit risk channel. Pelizzon et al. [2013] study market microstructure and liquidity in the Italian sovereign bond market using tick-by-tick data from MTS for the period June 2011 to November 2012. They conclude that credit risk resulted in unprecedented levels of illiquidity during the sovereign debt crisis. In particular, dealers reduced their liquidity position which led to a drop in prices and a spike in bond yields, causing deep losses in investors' portfolios. ECB's intervention has been successful as it improved market liquidity and substantially lowered credit risk, at least in the near term.

Darbha and Dufour [2013a,b] studied the relationship between bond illiquidity and bond characteristics before and after the onset of the liquidity crisis in August 2007 and showed that government bonds were not immune to the liquidity crisis. After controlling for standard risk factors, they conclude that liquidity does not provide a significant incremental explanatory contribution to yield dynamics before the crisis, but becomes an important explanatory factor during the crisis period.

3 The MTS market

The MTS market is the largest quote-driven interdealer electronic fixed-income market for euro-denominated government bonds. A smaller percentage of quasi-government and structured bonds (asset-backed securities and covered bonds) are also listed and traded on MTS platforms. It was launched in 1988 by the Italian Treasury and the Bank of Italy in an effort to enhance liquidity and transparency of the Italian secondary government bond market [Darbha and Dufour, 2013a]. The electronic platform was expanded in later years to include all major European countries and domestic MTS markets were subsequently developed[2]. According to Persaud [2006], excluding HDAT - the second largest electronic platform in Europe - the Bank of Greece's proprietary system for secondary trading in Greek government bonds (representing around 5 percent of outstanding Euro government bonds), the market share of MTS stands at 88.7 percent.

Apart from the domestic MTS markets for secondary trading, a platform for trading benchmark fixed-income securities, EuroMTS has also been established since 1999. Euro benchmark bonds are those bonds with an outstanding value of at least 5 billion. Bonds are allowed to trade on both domestic MTS and the EuroMTS platforms, therefore, liquidity is fragmented between the benchmark and the domestic markets. Despite the apparent fragmentation of trading between the two platforms, markets are closely connected in terms of liquidity as Cheung et al. [2005] demonstrate. The domestic MTS markets typically offer slightly better quoted and effective spreads, however, differences are infinitesimal if they exist. Dunne et al. [2006] argue that EuroMTS has been adopted by many of the smaller European issuers as their preferred location for the monitoring of the trading obligations of their primary dealers. As a consequence, the pre- and post-trade transparency in trading of the smaller issues has increased and has allowed smaller issuers to issue debt at more favourable rates.

Since October 2007, MTS is majority owned by the London Stock Exchange Group plc. In 2013, MTS expanded into US bond markets allowing for global coverage and increased harmonization and consistency in regulated electronic fixed-income trading. It currently facilitates fixed-income trading with over 500 global counterparties and average daily turnover exceeding 100 billion. MTS services are currently offered in more than 30

[2]Cheung et al. [2005] argue that the structure of the MTS trading platforms is similar to the EBS and D2002 electronic trading system for the foreign exchange market, but different from the quote screen-based US Treasury bond trading system.

communities with enhanced market-making on interdealer and B2C markets. Specifically, MTS trades bonds of the following countries: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Cyprus, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden, Turkey, Ukraine, United Kingdom, and United States.

MTS trading platforms support pre-trade, trade execution and post-trade capabilities across cash and repo markets and provide benchmark market data and comprehensive fixed-income indices. Participants are split into two categories, *primary dealers* and *dealers*. Primary dealers are obligated to continuously quote bid and ask proposals on a given number of bonds they have been assigned to, enhancing markets' liquidity (price makers-takers). On the other hand, dealers act as price takers and can only issue orders for proposals formulated by primary dealers [Dufour and Skinner, 2004].

The MTS system, effectively, works as a limit order book. Trading is anonymous and the identity of the counterparty is only revealed after a trade is executed. Market makers quotations are aggregated according to price and side of the market and order execution takes place based on the principle of price-time priority. The MTS system is highly transparent as quotes and trades data are instantly available to all market participants (at a cost) through data vendors such as Bloomberg and Reuters.

4 MTS data

4.1 Data handling procedures

Our dataset is by far the most complete representation of the eurozone sovereign bond market available and covers the period from January 2008 to December 2010, thereby it includes both tranquil and crisis periods. The euro sovereign debt crisis finds its origin in Greece. Toward the end of October 2009, bond yields rose significantly and benchmark bond prices fell, following the country's sovereign debt downgrade by Fitch [Papavassiliou, 2014]. A second development in November 2009 that disrupted the tranquility of European financial markets and led to increased risk aversion was when Dubai World conglomerate asked creditors for a six-month standstill on its debt obligations [Dellas and Tavlas, 2013]. A sharp increase in bond yields and a decline in prices intensified during November 2009, resulting in the yield curve to flatten considerably. Thus, we consider November 2009 as the period when the European debt crisis actually started.

Our high-frequency dataset consists of the following 11 countries: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain. It contains the three best bid and ask quotations (three levels of depth) throughout the trading day, time-stamped to the nearest second (Best Proposals file). We have selected to work with benchmark fixed coupon-bearing government bonds from both the EuroMTS and the domestic MTS markets. We consider bonds within four time-to-maturity groups: 2-, 5-, 10-, and 30-year. For each country and each maturity category we select the most heavily traded benchmark security. The dataset has been filtered as follows: (a) we only consider quotes recorded during the regular trading hours from 8:15 am until 5:30 pm CET. Thus, we exclude pre-sessional and end-of-day quotations in order to mitigate microstructure effects (b) we discard quotes with zero and negative bid-ask spreads (c) we exclude observations with relative quoted spread higher than 100 basis points.

4.2 Liquidity measures

Liquidity is an elusive concept and many different liquidity proxies have been proposed. Following the earlier literature [Bollen and Whaley, 1998; Hasbrouck and Seppi, 2001; Chordia et al., 2005; Coluzzi et al., 2008; Darbha and Dufour, 2013b; Pelizzon et al., 2013] we have estimated a wide variety of spread and depth liquidity measures, as well as measures combining a number of liquidity dimensions, as follows:

1. **Best bid-ask spread:** defined as the difference between the best ask quote and the best bid quote (best spread = best ask price - best bid price) $A_{it} - B_{it}$, where A_{it} is the posted best ask price for security i at time t, and B_{it} is the best posted bid price for security i at time t

2. **Quoted spread:** defined as the difference between the simple average of the three best ask prices and bid prices

3. **Relative or proportional spread:** defined as the best bid-ask spread divided by the midpoint of the bid and ask quotes, i.e. $100\left(A_{it} - B_{it}/M_{it}\right)$, where the midpoint is estimated as: $\left(A_{it} + B_{it}\right)/2$

4. **Best log spread:** defined as the logarithmic ratio of best ask over best bid - $log\left(A_{it}/B_{it}\right)$

5. **Quoted depth:** defined as best bid size + best ask size (quantity of securities bid or offered for sale at the posted bid and offer prices)

6. **Log quoted depth**: defined as log (best bid size) + log (best ask size)

7. **Quote slope**: defined as (best bid-ask spread / log quoted depth)

8. **Log Quote slope:** defined as (best log spread / log quoted depth)

9. **Euro depth:** defined as the sum of the euro value of the bonds bid and offered at the best quotes

10. **Market quality index:** defined as (1/2) Quoted depth / relative spread[3].

11. **Steepness:** defined as the absolute difference between the best and the worst quote, scaled on the mid-point between the two, i.e. steepness = (bid steepness + ask steepness)/2, where bid (ask) steepness equals: best bid (ask) price - worst bid (ask) price x 100 / best bid (ask) price + worst bid (ask) price / 2.

The corresponding daily average liquidity measures, derived from the aforementioned high-frequency liquidity measures, have also been constructed per country and maturity bucket.

4.3 Bond returns and volatility

We employ midpoints of bid-ask quotes as price measures which are generally less noisy measures of the efficient price than are transaction prices, as they do not suffer from bid-ask bounce effects [Bandi and Russell, 2006]. An intraday return has the same definition as a daily return defined as the change in the logarithm of the price during a time interval. When using quotation data, returns are calculated from midpoint prices as follows:

$$r_{it} = log\left(m_{it}/m_{i,t-1}\right) \tag{1}$$

where $m_{i,t}$ represents the midpoint of the bid-ask spread for security i prevailing at the end of interval t. Intraday prices (tick-by-tick) are generally only available at unevenly spaced time points, so the calculation of evenly spaced high-frequency returns inevitably relies on interpolation techniques applied around the endpoints of the desired sampling intervals. We artificially construct 5-minute returns from the linearly interpolated logarithmic midpoint of the continuously recorded bid and ask quotes. The selection of 5-minute returns as the optimal sampling frequency is probably the most popular choice and has been used extensively in the realized volatility literature [Andersen and Bollerslev, 1997; Andersen et al., 2001]. We also estimate daily bond returns as the summation of the 5-minute intraday returns for each security.

The emerging theory on volatility emphasizes the advantages of the realized volatility estimator. Andersen and Bollerslev [1998] show that realized volatility computed from high-frequency intraday returns is effectively an error-free volatility measure as the sampling frequency of the returns approaches infinity. Along these lines, we construct daily realized variance measures by the summation of squared 5-minute intraday returns, while daily realized volatility is obtained using the square-root of the variance series. Formally, for $N = 1, 2, 3, ...$ the realized variance for day t is defined as:

[3]The market quality index has been proposed by Bollen and Whaley [1998] in order to measure the effect on overall market liquidity following a regime change in financial markets. It is designed to capture the trade-off between quoted bid-ask spread and market depth.

$$\hat{\sigma}^2_{t,N} = \sum_{j=1}^{N} r^2_{t,j,N} \tag{2}$$

and the realized volatility is defined as $\hat{\sigma}_{t,N}$.

5 Econometric methodology

The extant literature has examined the dynamic interaction of liquidity and returns in stock markets [Hasbrouck, 1991], time-varying liquidity in Treasury bond markets [Krishnamurthy, 2002] and the joint dynamics of liquidity, trading activity, returns, and volatility in stock and US Treasury bond markets [Chordia et al., 2005]. However, the intertemporal interactions of liquidity proxies with returns and volatility across the euro-zone countries have not been examined extensively. We aim at filling this gap by drawing attention to the joint dynamics of liquidity, returns and volatility over both tranquil and crisis periods.

Univariate relationships between liquidity and returns have been discussed in Amihud and Mendelson [1986] among others, while volatility and liquidity univariate interactions have been addressed in Benston and Hagerman [1974] and Subrahmanyam [1994]. The main findings have demonstrated (a) a bidirectional causality between liquidity and returns, mainly exemplified through future trading behaviour and a premium for greater trading costs, (b) a bidirectional causality between liquidity and volatility, the idea being that increased volatility leads to higher bid-ask spreads as inventory risks increase, and decreased liquidity leads to increased price fluctuations. Given that cross-market effects and bidirectional causalities may be significant, especially during periods of stress, we follow Chordia et al. [2005] and adopt a pth order multivariate vector autoregression model VAR(p) of the following form:

$$X_t = \sum_{j=1}^{K} a_{1j} X_{t-j} + \sum_{j=1}^{K} b_{1j} Y_{t-j} + u_t \tag{3}$$

$$Y_t = \sum_{j=1}^{K} a_{2j} X_{t-j} + \sum_{j=1}^{K} b_{2j} Y_{t-j} + v_t \tag{4}$$

where X is the vector containing volatility, returns, relative spread and quoted depth measures in the (domestic MTS or EuroMTS) non-PIIGS market, and where Y is the vector containing the corresponding variables in the (domestic MTS or EuroMTS) PIIGS market.

The VAR(p) process is the basic multivariate model that is used to represent a set of dynamically dependent stationary time series. VAR models have several advantages compared with univariate time series models or simultaneous equations structural models, as (a) there is no need to specify which variables are endogenous or exogenous all are endogenous, and (b) VAR models allow the value of a variable to depend on more than just its own lags or combinations of white noise terms, thus they provide more flexibility than univariate AR models and are able to capture more features of the data [Brooks, 2014]. Our VAR methodology also deals with Granger-causality testing and impulse responses. Granger causality enables the proper identification of the direction of causality and the characterization of a set of variables either as exogenous or independent. Impulse responses trace out the responsiveness of the dependent variables in the VAR to shocks to each of the variables. For calculating impulse responses the ordering of the variables is important (based on the Cholesky factor), especially when there is strong contemporaneous correlation between the shocks [Lutkepohl, 1991].

In a second step, we strive to investigate for the presence of contagion by analyzing the correlation degree between PIIGS and non-PIIGS countries, across all four maturity buckets. As Claessens and Forbes [2001] note, contagion incorporates many different ideas and concepts. Not only contagion is a disease, but it also refers to the transmission of a disease among different markets and countries. The most popular definition of contagion is the one proposed by Forbes and Rigobon [2002]. They define contagion as a significant increase in cross-market linkages after a shock to one country. Even if two markets continue to be highly correlated after a shock to one market, this does not necessarily constitute contagion. Only if cross-market linkages increase significantly after a shock, this suggests that the transmission mechanism between the two markets strengthened after the shock and contagion occurred. Insignificant increases in cross-market relationships are characterized as *interdependence.*

Cross-market correlation coefficients are conditional on market volatility. The higher the volatility the more upward biased the estimates of correlation coefficients are. Forbes and Rigobon [2002] propose an adjusted unconditional correlation coefficient that adjusts for this bias and this is the approach we take in the following section. Specifically, assuming there are no omitted variables or endogeneity between markets, the conditional correlation is written as:

$$\rho^* = \rho\sqrt{\frac{1+\delta}{1+\delta\rho^2}} \tag{5}$$

where ρ^* is the conditional correlation coefficient, ρ is the unconditional correlation coefficient, and δ is the relative increase in the variance of market x:

$$\delta \equiv \frac{\sigma_{xx}^h}{\sigma_{xx}^l} - 1 \tag{6}$$

where l and h denote the tranquil period and the period of market turmoil, respectively. Manipulating equations (5) and (6) to solve for the unconditional correlation coefficient, adjusted for heteroskedasticity, yields

$$\rho = \frac{\rho^*}{\sqrt{1 + \delta \left[1 - (\rho^*)^2\right]}} \quad (7)$$

Our empirical analysis is complemented by a Dynamic Conditional Correlation (DCC) approach proposed by Engle [2002] which is a generalization of the Bollerslev [1990] constant conditional correlation (CCC) estimator. Define the variance-covariance matrix H_t, as:

$$H_t = D_t R_t D_t \quad (8)$$

where D_t is a diagonal matrix containing the conditional standard deviations on the leading diagonal and R_t is the conditional correlation matrix. Engle advocates a two-step estimation procedure where each variable in the system is first modeled separately as a univariate GARCH process. In the second stage, the conditional likelihood is maximized with respect to any unknown parameters in the correlation matrix. The log-likelihood function of the second stage takes the form:

$$l(\theta_2|\theta_1) = \sum_{t=1}^{T} \left(log\,|R_t| + u_t^{'} R_t^{-1} u_t \right) \quad (9)$$

where θ_1 denotes all the unknown parameters that were estimated in the first stage and θ_2 denotes all those to be estimated in the second stage. The DCC model allows for not only heteroskedasticity in time-series returns but also time-varying correlation processes.

6 Empirical results

6.1 Descriptive statistics

We present descriptive statistics on liquidity and volatility measures across the 2-, 5-, 10-, and 30-year maturity category in Table 1. The table shows the mean, standard deviation, as well as the minimum and maximum values of spread-based liquidity proxies which capture the tightness dimension of liquidity of the pan-European government bond market[4]. At a first glance best spreads, quoted spreads, and relative spreads widen for bonds with longer maturities. This observation holds for both the pre-crisis and the crisis period and is consistent with findings from earlier literature - bonds with lower maturities are more desirable and have greater liquidity [Pasquariello and Vega, 2009].

[4] Market liquidity has several dimensions. Tightness refers to the difference between buy and sell prices. Depth relates to the size of the transactions that can be absorbed without affecting prices. Immediacy denotes the speed with which orders can be executed, and resiliency denotes the ease with which prices return to normal after temporary order imbalances. A discussion is provided in Borio [2000].

Also, volatility as measured by the standard deviation, increases as we move from shorter to longer maturity buckets, and this result is more pronounced during the pre-crisis period.

Transitioning from the calm period to the turbulent, there is a sharp increase in all tightness measures for the 2-, 5-, and 10-year benchmark securities. This is an indication that liquidity has worsened during the crisis period as transaction costs have risen significantly. An interesting observation for the 30-year bonds is that their liquidity does not deteriorate during the crisis period, instead it is slightly improved. More specifically, the mean value of the best spread for the 30-year instrument declines from 0.6529 to 0.6010 after November 2009.

The same observation holds for the quoted and relative spreads whose mean values decline by approximately 8 and 6 percent, respectively. This result could indicate that, for bonds with very long maturities (so called buy-and-hold bonds), the selling pressure was not as high as for bonds with shorter maturities resulting in lower spreads. Friewald et al. [2012] found similar results using data from the US corporate bond market during the subprime crisis. Obviously, the shorter maturity benchmark bonds have been more vulnerable to liquidity disturbances during the crisis than the longer maturity bonds. Standard deviation values increase from the pre-crisis to the crisis period indicating higher volatility in liquidity across all maturity buckets.

Table 2 shows summary statistics for the depth liquidity measures. The average quoted depth of the 5-year bonds which amounts to 28.67 million euros turns out to be the largest across the four maturity segments. The 30-year bonds exhibit a much lower quoted depth than the medium and shorter term bonds. This finding reconfirms the inverse relationship between spreads and depth - lower quoted spreads are associated with larger depth. Furthermore, the variability of the 30-year bond quoted depth is very small, as shown by its standard deviation of around 3 million euros. In contrast, dispersion around the mean value of quoted depth for shorter maturities is much larger. The average quoted depth for the 2-year benchmark declines by 14 percent during the crisis period, indicating a deterioration in liquidity. Liquidity drops of similar magnitude are also observed for the 5- and 10-year benchmark between the tranquil and the crisis period. However, the decline in quoted depth for the 30-year instrument is less pronounced than the corresponding decline in shorter maturities depth - about only 4 percent.

Similar to the quoted depth, both the log quoted depth and the euro depth have declined during the crisis period. Shrinking liquidity exposes markets to crunches in response to shocks stemming from financial instabilities in global markets. Table 3 describes the features of breadth and multidimensional liquidity measures. In terms of steepness, the shorter maturity bonds exhibit lower values which indicates increased liquidity. For example, the average distance between the best and the worst quote of 2-year bonds amounts to 5.7 percent, followed by the 5- and 10-year benchmarks. The 30-year instrument has clearly the highest average steepness of all, exceeding 19 percent. Despite the fact that steepness is sometimes not consistent with other measures of liquidity, it behaves correctly in this case; that is, it is lower for more liquid securities. However, during the crisis period the picture is reversed, as the 2-year bond takes on the highest value of all. A rise in steepness between the two episodes implies that the government securities face less liquidity during the crisis period.

As a more transparent indicator of liquidity, quote slope (as well as log quote slope) confirms the higher liquidity for shorter maturities. Goyenko et al. [2011] provide evidence of a steeper liquidity term structure during periods of stress, indicating a flight to liquidity effect, as investors rebalance their portfolios by moving into shorter-term and more liquid bonds. Clearly, liquidity has deteriorated during the crisis period, as the mean value of quote slope has risen across all maturities, with the exception of the 30-year instrument. Standard deviation values are higher during the crisis period showing that the volatility of liquidity has intensified. The market quality index takes on higher values for shorter maturities. In agreement with other proxies, it shows that the longer a bond's maturity the more illiquid the bond is.

As shown in Table 3, the mean value of the market quality index declined between the pre-crisis and crisis period. This result suggests that the decrease in liquidity due to smaller depths and wider spreads leads to a deterioration in market quality. Table 4 describes the daily average bond returns, derived from the 5-minute returns set, along with the daily realized volatility estimator of the pan-European market. At a quick glance daily returns are higher for longer maturity bonds, which makes perfect sense as investors incur additional risks by holding longer-term instruments. The average daily return for the 30-year bond is 0.064 prior to the crisis and plummets to roughly one-half this level during the crisis period. What's more, the average daily returns for 2-, 5-, and 10-year maturity buckets become negative in the midst of the eurozone debt crisis. Similar to daily returns, daily realized volatility is higher for longer maturity benchmarks.

During the crisis volatility intensified as shown in the table for the 2-, 5-, and 10-year instrument. However, the 30-year benchmark follows an autonomous path, as its volatility and the dispersion around it dropped moderately. This is an indication of a decline in investors' appetite towards longer-term bonds, as they prefer to trade on their most liquid assets in search of liquidity. To sum up, with the exclusion of the 30-year instrument, shorter maturity bonds are more adversely affected than longer maturity bonds by liquidity dry ups and an intensification of volatility during the debt crisis period.

Figure 1 provides an interesting visual illustration of realized volatility and cumulative daily returns for both PIIGS and non-PIIGS countries, across the 5- and 10-year benchmarks. A significant decline in returns for the PIIGS countries during the crisis period is apparent in both graphs. Table 5 presents descriptive statistics of liquidity and volatility measures across the PIIGS and non-PIIGS countries. Overall, the sovereign bond markets of non-PIIGS countries are far more liquid than the PIIGS bond markets, as evidenced by lower transaction costs, higher depth and an enhanced market quality index. These results hold in both pre-crisis and crisis periods.

Obviously, the PIIGS countries are more adversely affected than their non-PIIGS counterparts during the crisis. Figures for the PIIGS countries rise up to eight times as much as that for non-PIIGS nations. Although volatility has strengthened for the PIIGS countries during the crisis, the opposite result has been observed for the non-PIIGS countries, as documented by smaller realized volatility indicators across all maturity buckets. This result is due to the fact that trading intensity for non-PIIGS government bonds lowered during the crisis, which is also evidenced by the smaller quoted depths for non-PIIGS bonds across all maturity buckets. It can also be partly attributed to the role played by hedge funds and derivatives markets that helped reduce volatility.

Results for the non-PIIGS countries are mixed between the tranquil and the crisis periods in terms of liquidity. With the exception of the 5-year instrument, realized spreads have narrowed during the crisis period. This result implies that trading for benchmarks of higher credit ratings has intensified during the crisis, as investors try to rebalance their portfolios by getting rid of lower quality instruments.

Mixed results are also documented for the quote slope and the market quality index. Although the market quality index declines from its pre-crisis levels across the 5- and 10-year maturity category, it increases for the shortest and longest maturity benchmarks. Figure 2 provides a visual illustration of PIIGS vs non-PIIGS 10-year relative spread and quoted depth and highlights the trends revealed by descriptive statistics. A noticeable variation in spreads and depth can be observed around September 2008 when Lehman Brothers collapsed. Lehman's demise which contributed to the erosion of roughly 10 trillion dollars in market capitalization from global equity markets, also affected the European government bond market.

Table 6 compares liquidity and volatility of the individual PIIGS members with the corresponding measures of the eurozone as a whole, during the crisis period. For brevity we provide comparisons across the 5- and 10-year benchmarks only. Clearly Greece experienced the most turbulent financial conditions, followed by Ireland and Portugal. The relative spreads in these markets are more than double of the European average. Similar patterns are detected in the slope and volatility measures. An interesting observation is that Italy and Spain, although severely affected by the crisis, are in a less dramatic situation than Greece, Ireland and Portugal. Their relative spreads and slopes are lower than the European average, especially for Italy, confirming Italy's position as the largest and most liquid bond market in Europe. Volatility levels in Italy are lower than the corresponding European volatility averages, whereas results are mixed for Spain, displaying higher sensitivity for the 5-year instrument.

Table 7 shows pair-wise static correlations across liquidity and volatility proxies. Not surprisingly, the best spread and relative spread are strongly correlated. Yet, the quoted spread exhibits a weaker correlation with the other two spread proxies. The positive correlation coefficient between spreads and volatility indicates that the increase in volatility coincides with wider spreads. On the contrary, quoted depth shows a weak and negative correlation with volatility. Similar results have been documented in Darbha and Dufour [2013a] where spreads are small for bonds with low volatility and large depth. Inferentially, when the variation in price changes increases, the size quoted by market makers shrinks.

Tightness and depth liquidity measures exhibit a negative correlation. It is evident that when the market becomes more liquid, depth proxies become larger and the spread dwindles. In terms of steepness, its correlation with the quoted spread is much stronger than its correlation with the best spread (a value of 0.7589 vs 0.2764). It is also worth noting that the co-movement produced by volatility and steepness is quite weak. The evidence from the correlation analysis confirms the expected behavior of the slope measure. A decrease in quote slope leads to tighter spreads and at the same time to increased market depth and volatility. As a hybrid liquidity measure, market quality index shows reasonable correlations with depth and tightness proxies - the two liquidity dimensions it is comprised of. Furthermore, market quality index and volatility exhibit an inverse relationship with each other.

Table 8 depicts a correlation analysis between volatility and all proxies of liquidity with respect to different periods and across various maturity segments. In brief, the degree of correlations is magnified during the crisis period regardless of the sign of the correlation[5]. The 30-year benchmark is the only exception in which the correlation between volatility and liquidity becomes weaker in the turbulent period. This implies that higher volatility will not necessarily cause liquidity to worsen.

6.2 Vector autoregression

The goal in this section is to study the cross-market intertemporal associations in volatility, returns, and liquidity between PIIGS and non-PIIGS bond markets in the pre-crisis period (1 January 2008 - 30 October 2009) and during the European sovereign bond market crisis period (1 November 2009 - 31 December 2010). To this, we use the daily volatility, returns, liquidity spread and liquidity depth measures, constructed for PIIGS and non-PIIGS countries using intraday data, as the VAR endogenous variables. For the shake of space we focus on the 10-year benchmarks that are the most liquid across all maturities. We denote the volatility measures as VOL-NP and VOL-P, the returns measures as RETS-NP and RETS-P, the spread measures as SPD-NP and SPD-P, and

[5]The link between liquidity and volatility is shared by the models of Stoll [1978] and Grossman and Miller [1988], among others.

the depth measures as DPT-NP and DPT-P, where NP denotes non-PIIGS measures and P denotes PIIGS measures.

There is reason to expect that cross market effects across non-PIIGS and PIIGS markets may be significant and that these effects may change from the pre-crisis to the crisis period. In the pre-crisis period we expect non-PIIGS and PIIGS returns to be related with causation flowing from the larger non-PIIGS returns to the peripheral economy's PIIGS returns. However, in the European sovereign debt crisis the relationship may reverse in sign and causal flows from PIIGS returns to non-PIIGS returns may increase. Furthermore it will be interesting to discover the bidirectional causalities between volatility, returns and liquidity both within non-PIIGS and PIIGS measures and across markets e.g. how PIIGS liquidity affects non-PIIGS liquidity and vice versa. Finally, we will use the VAR results to describe how these bidirectional causalities change from the pre-crisis period to the European sovereign debt crisis period.

We adopt an eight equation variable autoregression that uses the following variables: VOL-NP, VOL-P, RETS-NP, RETS-P, SPD-NP, SPD-P, DPT-NP and DPT-P. These consist of four variables from each market (non-PIIGS and PIIGS) which are realized volatility, returns, and two dimensions of liquidity: relative spread and quoted depth. Hence we use a system of interlinked equations as shown in (3)-(4). Note that depth is multiplied by 1×10^{-8} so that it is comparable to the other measures in terms of scale.

We estimate these VAR equations in both the pre-crisis and crisis periods using domestic MTS data only and EuroMTS data only[6]. In the pre-crisis period we have 466 days of data whereas there are 297 days of data in the crisis period. We use the log likelihood ratio test with Sims [1980] correction to test K lags versus $K-1$ lags and find that the model does not deteriorate in a statistically significant manner if we choose K to be 5 lags. Specifically, the chi-squared distributed test statistic which has degrees of freedom equation to the number of restrictions imposed is:

$$LR = (T-c)\left(log\left|\sum r\right| - log\left|\sum u\right|\right) \tag{10}$$

where T is the number of observations, c is a degrees of freedom correction factor proposed by Sims [1980], and $|\sum r|$, $|\sum u|$ denote the determinant of the error covariance matrices from the restricted and unrestricted models respectively. The correction factor, c, recommended by Sims is the number of variables in each unrestricted equation of the VAR model.

Table 9 presents the LR test statistic and the corresponding p-values using data from the domestic MTS market during the crisis period. We elect to choose 5 lags in the interests of parsimony. The results on the EuroMTS market and in the pre-crisis period

[6]The domestic and Euro MTS market data are highly correlated so we elect not to group these data into a 16 equation VAR system to keep the model more parsimonious and the interpretations less complex.

are qualitatively very similar so we also choose to use 5 lags for the cases considered in the chapter (domestic MTS pre-crisis, domestic MTS crisis, EuroMTS pre-crisis and EuroMTS crisis).

6.2.1 Unfiltered correlations

Before presenting results from the VAR estimation we present correlations of the unfiltered variables in the pre-crisis period and in the crisis period using both domestic MTS and EuroMTS data. The pre-crisis correlation coefficients are reported in Table 10 for the domestic MTS market and Table 11 for the EuroMTS market. The correlation coefficients and their statistical significance are very similar across both markets so the following analysis applies to both the domestic and EuroMTS markets.

There are strong positive cross market correlations between non-PIIGS (NP) and PIIGS (P) volatility (0.86), NP and P returns (0.82), NP and P spreads (0.95) and NP and P depth measures (0.91)[7]. The correlation between returns and volatility is negative as expected across the two markets with the exception of RET-NP which is not statistically significantly negatively correlated with VOL-P. The correlation between relative spread and volatility is strongly positive both within NP/P markets and across NP to P (or P to NP) markets. The correlation between quoted depth and volatility is strongly negative both within and across markets. Finally the correlation between spread and depth is strongly negative both within and across markets.

The crisis period correlation coefficients are reported in Table 12 for the domestic MTS markets and Table 13 for the EuroMTS market. As with the pre-crisis period the correlation coefficients and their statistical significance are very similar across both markets so the following analysis applies to both the domestic and EuroMTS markets. There are still statistical significant positive cross market correlations but they drop considerably from their pre-crisis levels to 0.47 for NP and P volatility, 0.16 for NP and P returns, 0.64 for NP and P spreads and 0.57 for NP and P depth measures.

The negative correlations between returns and volatility within the NP and P markets are slightly more negative than their pre-crisis levels (-0.21 for crisis versus -0.11 for pre-crisis) but there are no longer negative cross market correlations between returns in one market and the volatility in the other market e.g. between RET-NP and VOL-P or between RET-P and VOL-NP. The correlation between relative spread (quoted depth) and volatility is strongly positive (negative) both within and across markets and similar to pre-crisis levels. The correlations, within and across markets, between spread and depth weaken slightly from pre-crisis levels of approximately -0.60 to crisis levels of approximately -0.44.

[7]The correlation coefficients reported in brackets are those estimated using domestic MTS market data in the pre-crisis period and are very similar to the correlations estimated using EuroMTS market data in the same period.

6.2.2 VAR estimation results

This section presents and interprets the VAR estimation results. Tables 14 and 15 report correlations of the VAR innovations using the domestic MTS data in the pre-crisis period and crisis period, respectively. We decide not to report the innovation correlations for the EuroMTS market in both the pre-crisis and crisis periods because results are qualitatively similar to the domestic market results as was shown to be the case in the unfiltered correlations.

Volatility is still negatively associated with returns within and across markets. However, volatility is positively (negatively) associated with spreads (depths) within and across markets. Furthermore, return innovations in both NP and P markets are negatively associated with spreads in the PIIGS markets but there is no association with spreads in the non-PIIGS markets. Similarly, return innovations in both NP and P markets are positively associated with depth in the PIIGS markets but the association with depth in the non-PIIGS markets is much weaker. As with the correlation results in the unfiltered data, innovations in spread and depth are negatively correlated both within and across markets.

Volatility innovations are still negatively associated with returns innovations within and across markets in the crisis period, and are positively (negatively) associated with spreads (depths) within and across markets. These results are comparable to the pre-crisis results. However, return innovations in non-PIIGS markets are not associated with spread innovations or depth innovations in non-PIIGS or PIIGS markets although there is a negative association between return and spread innovations in the PIIGS markets. Spread and depth innovations are still strongly negatively associated within and across markets in the crisis period at similar levels to the pre-crisis period levels. These results suggest contemporaneous commonalities are driving volatility and returns, volatility and spreads, volatility and depths, spreads and depths in both pre-crisis and crisis periods both within non-PIIGS and PIIGS markets and across non-PIIGS and PIIGS markets.

Furthermore in pre-crisis periods there are contemporaneous commonalities driving returns and liquidity measures (spread and depth) that weaken considerably in the crisis period. Tables 16 and 17 present pairwise Granger-causality tests between the endogenous variables in the VAR separately for pre-crisis and crisis periods. The results are only reported for domestic MTS data as they are qualitatively very similar if the domestic MTS data is replaced by EuroMTS data. Table 16 illustrates that causation in volatility does not operate across markets but only within markets in the pre-crisis period i.e. VOL-NP(P) causes VOL-NP(P) but there is no causality from NP(P) to P(NP).

There is bidirectional causality in returns across markets although the causality from NP to P returns is significant at the 1 percent level whereas the reverse causality is only significant at the 10 percent level. This is to be expected given the NP market is the more important market. There is also bidirectional causality in spreads (and in depths) across markets. There is strong bidirectional causality between returns and spreads both within and across markets but not between returns and depth.

Table 17 illustrates that the causal directions in the volatility variables do not change from their pre-crisis directions. There is no cross market causation for volatility and only causation within markets for volatility i.e. VOL-NP(P) causes VOL-NP(P) but there is no causality from VOL-NP(P) to VOL-P(NP). Unlike for the pre-crisis case there is no longer bidirectional causality in returns across markets with causality in returns only running from P to P itself in the crisis period. Furthermore in the crisis period the cross market bidirectional causality in spreads (and in depths) breaks down with causality only running within markets i.e. SPD-NP(P) causes SPD-NP(P) but there is no causality from SPD-NP(P) to SPD-P(NP).

Returns in PIIGS cause spreads in both PIIGS and non-PIIGS markets in the crisis period but this is not the case for the returns in non-PIIGS. This is a direct result of the increasing importance of the PIIGS returns during the crisis. Before the crisis there was bidirectional causality with the non-PIIGS returns being the more important variable. There are strong causal links between PIIGS liquidity measures (SPD and DPT) and non-PIIGS volatility that were not present in the pre-crisis period. This demonstrates that liquidity effects are more important during the crisis with PIIGS liquidity impacting non-PIIGS volatility. Furthermore there are feedback effects in PIIGS liquidity measures during the crisis period that were not present in the pre-crisis period. This is demonstrated by the bidirectional causality between SPD-P causing DPT-P.

6.2.3 VAR impulse response functions

To investigate these findings further we present impulse response functions from the VAR estimated using pre-crisis data in Figure 3 and crisis data in Figure 4. Impulse responses use the orthogonalised VAR residual covariance matrix to estimate the effect a one-unit standard deviation shock to one of the variables has on current and future values of the shocked variable and the other variables.

For example the top left panel of Figure 3 depicts the response of all eight variables to a one standard deviation shock to the first variable VOL-NP. VOL-NP is the variable most affected by a shock to itself with the shock decaying to halve its magnitude within two days but displaying strong persistence with the initial shock of 2.75×10^{-4} taking 20 days to decay to just under 0.5×10^{-4}. The VOL-NP shock strongly affects the returns (RET-P) and liquidity (SPD-P) of the peripheral economies demonstrating strong cross market dynamics from non-peripheral volatility to peripheral returns and liquidity in the pre-crisis period. Similar cross market dynamics can be observed in the top right panel in Figure 3. A one standard deviation shock to VOL-P has an even larger effect on

VOL-NP although this cross market effect decays much faster than the effect VOL-P has on itself. The shock to VOL-P also increases the spreads in the non-peripheral countries (SPD-NP).

The shocks to both RET-NP and RET-P also display cross market dynamics but these effects decay much faster than volatility shocks. Shocks to spreads in one market increase spread in the other market, and increase volatility and decrease depth in both markets (both NP and P). Furthermore shocks to spreads in both markets decrease returns in the peripheral market. Finally shocks to depth in either markets increase depth and reduce spreads in both markets.

Figure 4 presents impulse responses from the VAR estimated during the crisis period. The top left panel of Figure 4 depicts the response of all eight variables to a one standard deviation shock to the first variable VOL-NP. As with the tranquil period VOL-NP is the variable most strongly affected by a shock to itself. The shock decays to halve its magnitude within two days but displays strong persistence with a slow decay thereafter. Shocks to VOL-NP barely affect VOL-P which is a change from the tranquil period however, VOL-NP shocks do strongly increase SPD-P and reduce RET-P. Shocks to VOL-P increase VOL-NP by approximately half the magnitude of the shock. In the crisis period shocks to VOL-P strongly reduce RET-P. Interestingly shocks to VOL-P increase SPD-P but decrease SPD-NP in an almost mirror image indicating that shocks to PIIGS volatility decrease PIIGS liquidity but increase non-PIIGS liquidity. This is evidence of a market decoupling where shocks to PIIGS country volatility result in less PIIGS trading but more non-PIIGS trading.

The returns impulse responses in Figure 4 also demonstrate this market decoupling. Shocks to RET-NP are associated with decreases in VOL-NP as expected but large increases in VOL-P. Shocks to RET-P are associated with decreases in RET-NP. Shocks to liquidity (measured either by SPD or DPT) are more persistent than shocks to returns or even volatility. The crisis period liquidity impulse responses in PIIGS countries generally remain within the PIIGS countries with a lower degree of cross market dynamics when compared to the pre-crisis period liquidity impulse response functions.

6.3 Forbes and Rigobon test for contagion

As described in the methodology section we test for changes in equivalent maturity correlations for non-PIIGS and PIIGS bond returns between the tranquil and crisis period using the Forbes and Rigobon unconditional correlation measure adjusted for heteroskedasticity. We do this using both unfiltered raw returns series (RET-UF) and filtered return residuals (RET-F) from the previous VAR estimation for all four benchmark maturities but where the VAR is estimated over the full period. The use of the filtered returns allows us to strip out the within and cross market effects that volatility and liquidity have on returns thereby isolating filtered returns that are orthogonalized to these volatility and liquidity effects. Results are presented in Table 18 below for both unfiltered and VAR filtered return residuals.

The results reported in Table 18 clearly illustrate large and statistical significant drops in correlations between non-PIIGS and PIIGS bond returns of the same maturity. The largest drop is the correlation between 2 year bonds which drops from 0.90 in the tranquil period to 0.04 in the crisis period. Furthermore as the maturity of the bonds rises, the drop in correlations from tranquil to crisis period reduces, although still remains statistically significant. These results are in agreement with Jotikasthira et al. [2015] who show that whilst the monetary policy channel often cause short term international yields to diverge, the risk compensation channel results in longer term international bond yields diverging by much less than their shorter term counterparts.

These results show that there is no evidence of contagion between non-PIIGS and PIIGS bond returns of the same maturity. In fact, we find strong evidence for a decoupling between non-PIIGS and PIIGS sovereign debt markets during the crisis, with changes in a country's debt being transmitted to neighboring countries much less intensively during the debt crisis period than the pre-crisis period[8]. These results are in line with those of Beirne and Fratzscher [2013] who analyse the drivers of sovereign risk for 31 advanced and emerging economies during the European sovereign debt crisis.

Figure 5 depicts the DCC time-varying correlation coefficients between non-PIIGS and PIIGS countries using both unfiltered and filtered 10-year and 30-year bond returns. The drop in correlations during the crisis period for the 30-year benchmark, although statistically significant, is not as dramatic as the corresponding drop in correlations for the 10-year benchmark security. It is apparent from Figure 5 that the relation between non-PIIGS and PIIGS returns has been rather unstable over time. The estimates of the correlations illustrate a significant fluctuation from high positive levels in the pre-crisis period, to large negative levels in the crisis period. The correlation levels of the 30-year benchmark reach their minimum in May 2010 with negative values for both filtered and unfiltered returns and their maximum level in June 2008. Results for the 10-year benchmark show that correlation levels reach their minimum in April 2010 for unfiltered returns and in November 2010 for filtered returns, whereas their maximum values are reached in September 2008 and July 2008, respectively.

Table 19 depicts the adjusted for heteroskedasticity correlation values for tranquil, crisis and the full data periods calculated using 10-year returns within non-PIIGS and PIIGS countries. The results shown in the lower panel of the table are striking and provide strong evidence for a decoupling among all PIIGS countries, as correlation coefficients take on much lower and statistically significant values during the crisis period. The

[8]Decoupling implies a break in a relationship that was previously more coupled and closely linked. For a discussion see Pesce [2015].

results for non-PIIGS countries, however, are mixed as shown in the upper panel of Table 19. There is evidence of contagion among Germany, Netherlands and Finland as well as between Finland and Austria. This contagion effect can be possibly explained by income shocks that are transferred from one country to the other due to trade and economic linkages. There is also evidence of decoupling among Germany, France and Belgium and between Belgium and Netherlands - Austria - Finland.

7 Conclusions

This study measures and analyses liquidity and volatility dynamics in the eurozone government bond market from a microstructure perspective, during both the pre-crisis and crisis periods. It employs a unique and comprehensive high-frequency dataset obtained from MTS, the worlds largest trading platform for euro denominated government bonds. Our dataset is comprised of benchmark fixed coupon-bearing government bonds of various maturities from both the EuroMTS and the domestic MTS markets.

We document wider spreads for benchmarks with longer maturities during both pre-crisis and crisis periods, as well as heightened volatility and returns for longer maturity benchmarks, especially amidst the crisis. Liquidity deteriorates and volatility intensifies during the crisis period as spreads rise and quoted depth declines, with the exception of the 30-year instrument. Evidence of a flight-to-liquidity effect is provided, as investors rebalance their portfolios by moving into shorter-term and more liquid government securities. However, shorter maturity bonds are more vulnerable than their longer-term counterparts to liquidity episodes in which market liquidity disappears rapidly.

Volatility strengthened for PIIGS whereas it declined for non-PIIGS countries during the crisis across all maturities. Trading for benchmarks of a higher credit quality increased during the crisis period, providing evidence of flight-to-quality episodes that have taken place, as investors move their capital away from riskier investments to the safest possible investment vehicles.

We provide a more thorough understanding of liquidity and volatility dynamics by analyzing the intertemporal interactions of liquidity proxies with returns and volatility across countries and maturity segments. Volatility shocks are found to be negatively associated with returns within and across markets and positively and significantly associated with spreads (negatively associated with depth) across the PIIGS and non-PIIGS countries, indicating that liquidity and volatility shocks can be systemic in nature and can cause market-wide effects.

Interestingly, our results find no evidence of contagion between non-PIIGS and PIIGS returns, as the correlation coefficients drop significantly during the crisis period. Instead, we show that returns between non-PIIGS and PIIGS markets actually decouple and many of the bidirectional causalities from one market to the other break down, as we move from pre-crisis to crisis mode. From an investor's perspective, a lower level of correlation implies that the benefits from portfolio diversification are amplified during the crisis relative to the pre-crisis period. Strong evidence of decoupling within the PIIGS countries is also documented whereas we provide mixed results within the non-PIIGS countries, where contagion effects are exhibited among Germany, Netherlands, Finland and Austria.

We hope that our study has undertaken a systematic rethink of the functioning of eurozone's sovereign bond markets and will provide useful insights to policy makers and regulators. Knowing the mechanisms via which financial shocks are transmitted, would be beneficial to those who design fiscal and monetary policies and would enable them to establish policy measures that could mitigate the adverse effects of financial crises.

8 References

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Table 1: Summary statistics of tightness liquidity measures over the pre-crisis and crisis periods. The Mean, Standard Deviation, Minimum and Maximum values are shown for Best, Quoted and Relative spreads across the 2, 5, 10 and 30 year maturity segments

LM	Maturity	Mean		SD		Min.		Max.	
		Pre-crisis	Crisis	Pre-crisis	Crisis	Pre-crisis	Crisis	Pre-crisis	Crisis
Best spread	02-year	0.1221	0.2972	0.1107	0.3700	0.0089	0.0085	1.3969	2.0000
	05-year	0.1943	0.3467	0.1835	0.3614	0.0126	0.0073	1.6000	1.9083
	10-year	0.3148	0.4316	0.3081	0.4061	0.0119	0.0087	1.9948	1.9908
	30-year	0.6529	0.6010	0.3976	0.3194	0.1000	0.1728	2.2904	1.9900
Quoted spread	02-year	0.1706	0.4531	0.2143	0.6653	0.0116	0.0113	3.8374	6.7428
	05-year	0.2506	0.4762	0.2720	0.6928	0.0165	0.0102	6.9857	22.1599
	10-year	0.3964	0.5523	0.4212	0.6416	0.0163	0.0122	8.9447	15.3984
	30-year	0.8088	0.7461	0.5402	0.5848	0.1000	0.1988	7.6783	15.9233
Relative spread (bps)	02-year	11.96	29.29	10.83	36.65	0.84	0.82	136.16	198.88
	05-year	18.91	34.67	18.16	37.81	1.22	0.70	166.08	199.69
	10-year	30.79	43.32	30.29	43.73	1.13	0.83	194.19	199.99
	30-year	64.77	61.09	38.83	42.51	9.26	13.99	197.39	199.96

Table 2: Summary statistics of depth liquidity measures over the pre-crisis and crisis periods. The Mean, Standard Deviation, Minimum and Maximum values are shown for Quoted, Log Quoted and Euro depth across the 2, 5, 10 and 30 year maturity segments

LM	Maturity	Mean		SD		Min.		Max.	
		Pre-crisis	Crisis	Pre-crisis	Crisis	Pre-crisis	Crisis	Pre-crisis	Crisis
Quoted depth (in millions)	02-year	25.11	21.67	10.42	8.48	5.00	2.00	82.53	57.22
	05-year	28.67	23.20	14.99	8.78	5.00	2.06	148.11	70.26
	10-year	27.16	22.58	12.25	8.14	5.39	2.02	108.78	60.34
	30-year	10.85	10.35	2.56	2.96	5.00	1.70	25.79	29.64
Log quoted depth	02-year	32.34	31.97	0.73	1.19	29.46	27.63	34.49	34.04
	05-year	32.53	32.12	0.77	1.07	29.46	28.04	35.61	34.31
	10-year	32.44	32.05	0.73	1.06	29.57	28.01	34.96	34.01
	30-year	30.82	30.65	0.47	0.68	29.46	27.13	32.48	32.15
Euro depth (in billions)	02-year	2.53	2.20	1.04	0.87	0.50	0.18	8.36	5.88
	05-year	2.89	2.39	1.48	0.92	0.49	0.15	15.13	7.28
	10-year	2.75	2.36	1.24	0.89	0.48	0.13	11.43	6.33
	30-year	1.08	1.11	0.27	0.36	0.40	0.11	2.63	3.73

Table 3: Summary statistics of breadth and other multidimensional liquidity measures over the pre-crisis and crisis periods. The Mean, Standard Deviation, Minimum and Maximum values are shown for Steepness, Quote slope, Log quote slope and Market Quality Index measures across the 2, 5, 10 and 30 year maturity segments

LM	Maturity	Mean		SD		Min.		Max.	
		Pre-crisis	Crisis	Pre-crisis	Crisis	Pre-crisis	Crisis	Pre-crisis	Crisis
Steepness	02-year	0.0570	0.2056	0.2152	0.5979	0.0026	0.0023	5.0546	8.1022
	05-year	0.0646	0.1528	0.1678	0.5839	0.0029	0.0027	7.1863	22.4294
	10-year	0.0941	0.1425	0.2420	0.4701	0.0031	0.0028	8.7858	15.9938
	30-year	0.1912	0.1966	0.8487	0.7129	0.0210	0.0195	50.0730	27.2430
Quote slope	02-year	0.0038	0.0093	0.0035	0.0116	0.0003	0.0003	0.0434	0.0648
	05-year	0.0059	0.0109	0.0057	0.0116	0.0004	0.0002	0.0519	0.0596
	10-year	0.0096	0.0135	0.0095	0.0130	0.0004	0.0003	0.0617	0.0637
	30-year	0.0210	0.0195	0.0129	0.0106	0.0036	0.0054	0.0765	0.0675
Log quote slope	02-year	3.73	9.42	3.43	12.00	0.26	0.25	42.28	68.31
	05-year	5.85	11.03	5.69	12.34	0.38	0.21	53.84	64.73
	10-year	9.53	13.77	9.42	14.29	0.35	0.26	60.88	68.82
	30-year	21.06	20.10	12.71	14.38	3.89	4.53	64.99	71.48
Market Quality Index (in billions)	02-year	26.04	19.57	28.02	24.43	0.73	0.08	210.30	225.78
	05-year	22.21	13.61	29.91	18.69	0.25	0.06	218.40	219.99
	10-year	14.41	7.34	20.41	8.56	0.17	0.05	135.84	195.10
	30-year	1.37	1.35	1.13	0.88	0.16	0.05	7.05	5.12

Table 4: Summary statistics of 5-minute returns and Realized Volatility. The Mean and Standard Deviation values are shown over the pre-crisis and crisis periods across the 2, 5, 10 and 30 year maturity segments

Measures	Maturity	Mean		SD	
		Pre-crisis	Crisis	Pre-crisis	Crisis
5-minute returns	02-year	0.0119	-0.0107	0.1278	0.2663
	05-year	0.0196	-0.0144	0.2139	0.3154
	10-year	0.0289	-0.0196	0.3659	0.4757
	30-year	0.0640	0.0327	0.8388	0.6429
Realized Volatility (%)	02-year	0.1240	0.1846	0.0938	0.2320
	05-year	0.2121	0.2416	0.1395	0.2193
	10-year	0.3625	0.3750	0.1768	0.2463
	30-year	0.7672	0.6232	0.2962	0.2266

Table 5: Comparisons between PIIGS Non-PIIGS countries over the pre-crisis and crisis periods. The Mean and Standard Deviation values are shown for the Relative spread, Quoted depth, Quote slope, Market Quality Index and Realized Volatility measures across the 2, 5, 10 and 30 year maturity segments

Measures	Maturity	Mean				SD			
		Pre-crisis		Crisis		Pre-crisis		Crisis	
		Non-PIIGS	PIIGS	Non-PIIGS	PIIGS	Non-PIIGS	PIIGS	Non-PIIGS	PIIGS
Relative spread (bps)	02-year	9.17	14.49	7.81	46.05	5.80	8.56	4.30	25.25
	05-year	14.91	23.18	17.39	57.17	9.32	16.60	6.64	28.44
	10-year	27.76	34.63	22.42	69.72	20.26	25.32	9.07	31.23
	30-year	61.71	68.71	44.68	87.05	29.77	35.13	13.29	25.38
Quote depth (in millions)	02-year	27.31	23.16	25.97	18.39	5.66	6.95	3.14	3.50
	05-year	29.98	27.34	26.52	18.98	10.73	11.13	3.12	3.45
	10-year	28.64	25.36	25.70	18.67	10.32	8.29	3.01	3.39
	30-year	11.09	10.52	10.73	9.70	1.67	1.64	1.05	1.81
Quote slope	02-year	0.0029	0.0046	0.0024	0.0146	0.0018	0.0028	0.0014	0.0079
	05-year	0.0047	0.0073	0.0056	0.0177	0.0029	0.0052	0.0022	0.0087
	10-year	0.0087	0.0108	0.0074	0.0212	0.0064	0.0079	0.0030	0.0093
	30-year	0.0211	0.0210	0.0166	0.0243	0.0108	0.0109	0.0052	0.0068
Market Quality Index (in billions)	02-year	28.17	24.01	31.40	10.52	19.85	22.69	12.60	12.46
	05-year	23.87	20.53	17.41	8.68	25.81	25.24	5.78	12.59
	10-year	16.91	11.37	10.07	3.92	19.75	14.80	4.03	4.85
	30-year	1.45	1.26	1.61	0.93	1.10	0.98	0.51	0.40
Realized Volatility (%)	02-year	0.1117	0.1354	0.0704	0.2749	0.0591	0.0584	0.0512	0.1642
	05-year	0.2033	0.2214	0.1570	0.3497	0.0870	0.0896	0.0511	0.1468
	10-year	0.3594	0.3658	0.3015	0.4675	0.1328	0.1384	0.0964	0.1628
	30-year	0.7474	0.7891	0.6281	0.6272	0.2595	0.2790	0.1688	0.1729

Table 6: Comparisons between PIIGS countries vs the pan-European bond market. Mean values are shown for the Relative spread, Slope and Realized Volatility measures across the 5 and 10 year maturity segments

Countries	Maturity	Relative spread (bps)		Slope		Realized Volatility	
		Domestic	EU	Domestic	EU	Domestic	EU
Greece	05-year	86.74	34.67	0.0264	0.0116	0.5722	0.2416
	10-year	99.55	43.32	0.0282	0.0130	0.7165	0.3750
Ireland	05-year	74.77	34.67	0.0234	0.0116	0.3583	0.2416
	10-year	94.08	43.32	0.0294	0.0130	0.4370	0.3750
Italy	05-year	19.56	34.67	0.0063	0.0116	0.2089	0.2416
	10-year	25.30	43.32	0.0082	0.0130	0.3345	0.3750
Portugal	05-year	68.63	34.67	0.0212	0.0116	0.3415	0.2416
	10-year	88.64	43.32	0.0272	0.0130	0.4731	0.3750
Spain	05-year	34.35	34.67	0.0107	0.0116	0.2732	0.2416
	10-year	40.50	43.32	0.0126	0.0130	0.3723	0.3750

Table 7: Pair-wise correlations across liquidity and volatility measures. The measures considered are the Best spread, Quoted spread, Relative spread, Quoted depth, Quote slope, Euro depth, Market Quality Index (MQI), Steepness and Realized Volatility

	Best spread	Quoted spread	Relative spread	Quoted depth	Quote slope	Euro depth	MQI	Steepness	RV
Best spread	1								
Quoted spread	0.825	1							
Relative spread	0.989	0.831	1						
Quoted depth	-0.397	-0.368	-0.409	1					
Quote slope	0.997	0.829	0.995	-0.409	1				
Euro depth	-0.410	-0.382	-0.427	0.994	-0.422	1			
MQI	-0.452	-0.374	-0.440	0.761	-0.448	0.761	1		
Steepness	0.276	0.759	0.305	-0.195	0.287	-0.206	-0.126	1	
RV	0.497	0.472	0.512	-0.293	0.499	-0.320	-0.302	0.264	1

Table 8: Pair-wise correlations between liquidity and volatility over the pre-crisis and crisis periods. The measures considered are the Best spread, Quoted depth, Quote slope, Euro depth, Market Quality Index (MQI) and Steepness across the 2, 5, 10 and 30 year maturity segments

	2-year		5-year		10-year		30-year	
	Pre-crisis	Crisis	Pre-crisis	Crisis	Pre-crisis	Crisis	Pre-crisis	Crisis
Best spread	0.505	0.610	0.481	0.582	0.524	0.451	0.420	0.215
Quoted depth	-0.016	-0.421	-0.124	-0.371	-0.287	-0.349	-0.214	-0.100
Quote slope	0.496	0.615	0.484	0.588	0.539	0.455	0.416	0.205
Euro depth	-0.021	-0.431	-0.124	-0.396	-0.305	-0.379	-0.235	-0.104
MQI	-0.240	-0.395	-0.264	-0.420	-0.346	-0.353	-0.375	-0.265
Steepness	0.036	0.450	0.229	0.271	0.289	0.252	0.056	-0.024

Table 9: Log likelihood test ratios and p-values used to choose the lag length in the VARs. nlag-u and nlag-r denote the lag length from the unrestricted and restricted models, respectively

nlag-u	nlag-r	LR stat	p-value
12	11	67.34	0.363
11	10	84.98**	0.041
10	9	72.80	0.211
9	8	65.42	0.427
8	7	75.78	0.149
7	6	91.40	0.014
6	5	55.95	0.753
5	4	82.80*	0.057
4	3	80.49*	0.080
3	2	97.59***	0.004
2	1	107.34***	0.001

Table 10: Pre-crisis correlations of unfiltered domestic MTS variables. VOL (volatility), RET (returns), SPD (spread), DPT (depth), P (PIIGS), NP (non-PIIGS)

	VOL-NP	VOL-P	RET-NP	RET-P	SPD-NP	SPD-P	DPT-NP	DPT-P
VOL-NP	1							
VOL-P	0.86***	1						
RET-NP	-0.13***	-0.07	1					
RET-P	-0.10**	-0.09*	0.82***	1				
SPD-NP	0.64***	0.69***	-0.02	-0.03	1			
SPD-P	0.64***	0.72***	-0.05	-0.06	0.95***	1		
DPT-NP	-0.37***	-0.44***	0.02	0.01	-0.61***	-0.59***	1	
DPT-P	-0.41***	-0.47***	0.03	0.04	-0.63***	-0.61***	0.91***	1

Table 11: Pre-crisis correlations of unfiltered EuroMTS variables. VOL (volatility), RET (returns), SPD (spread), DPT (depth), P (PIIGS), NP (non-PIIGS)

	VOL-NP	VOL-P	RET-NP	RET-P	SPD-NP	SPD-P	DPT-NP	DPT-P
VOL-NP	1							
VOL-P	0.81***	1						
RET-NP	-0.15***	-0.07	1					
RET-P	-0.11**	-0.12**	0.83***	1				
SPD-NP	0.62***	0.68***	-0.03	-0.06	1			
SPD-P	0.62***	0.71***	-0.05	-0.07	0.94***	1		
DPT-NP	-0.37***	-0.47***	0.02	0.03	-0.62***	-0.60***	1	
DPT-P	-0.38***	-0.49***	0.02	0.04	-0.62***	-0.61***	0.92***	1

Table 12: Crisis correlations of unfiltered domestic MTS variables. VOL (volatility), RET (returns), SPD (spread), DPT (depth), P (PIIGS), NP (non-PIIGS)

	VOL-NP	VOL-P	RET-NP	RET-P	SPD-NP	SPD-P	DPT-NP	DPT-P
VOL-NP	1							
VOL-P	0.47***	1						
RET-NP	-0.21***	-0.09	1					
RET-P	-0.04	-0.20***	0.16***	1				
SPD-NP	0.59***	0.34***	-0.04	0.04	1			
SPD-P	0.53***	0.40***	-0.03	-0.08	0.64***	1		
DPT-NP	-0.28***	-0.19***	0.04	-0.06	-0.44***	-0.44***	1	
DPT-P	-0.44***	-0.41***	0.05	0.08	-0.55***	-0.77***	0.57***	1

Table 13: Crisis correlations of unfiltered EuroMTS variables. VOL (volatility), RET (returns), SPD (spread), DPT (depth), P (PIIGS), NP (non-PIIGS)

	VOL-NP	VOL-P	RET-NP	RET-P	SPD-NP	SPD-P	DPT-NP	DPT-P
VOL-NP	1							
VOL-P	0.48***	1						
RET-NP	-0.21***	-0.04	1					
RET-P	-0.08	-0.21***	0.18***	1				
SPD-NP	0.59***	0.32***	-0.04	0.02	1			
SPD-P	0.54***	0.38***	-0.03	-0.10*	0.64***	1		
DPT-NP	-0.35***	-0.26***	0.05	-0.01	-0.49***	-0.53***	1	
DPT-P	-0.43***	-0.36***	0.06	0.07	-0.57***	-0.76***	0.59***	1

Table 14: Pre-crisis period correlations of VAR innovations in the domestic MTS variables. VOL (volatility), RET (returns), SPD (spread), DPT (depth), P (PIIGS), NP (non-PIIGS)

	VOL-NP	VOL-P	RET-NP	RET-P	SPD-NP	SPD-P	DPT-NP	DPT-P
VOL-NP	1							
VOL-P	0.72***	1						
RET-NP	-0.15***	-0.08*	1					
RET-P	-0.10**	-0.11**	0.83***	1				
SPD-NP	0.20***	0.20***	0.01	-0.06	1			
SPD-P	0.19***	0.34***	-0.09*	-0.19***	0.42***	1		
DPT-NP	-0.15***	-0.17***	0.08*	0.07	-0.12***	-0.19***	1	
DPT-P	-0.19***	-0.21***	0.08*	0.13***	-0.19***	-0.21***	0.50***	1

Table 15: Crisis period correlations of VAR innovations in the domestic MTS variables. VOL (volatility), RET (returns), SPD (spread), DPT (depth), P (PIIGS), NP (non-PIIGS)

	VOL-NP	VOL-P	RET-NP	RET-P	SPD-NP	SPD-P	DPT-NP	DPT-P
VOL-NP	1							
VOL-P	0.40***	1						
RET-NP	-0.14**	-0.13**	1					
RET-P	-0.10*	-0.21***	0.22***	1				
SPD-NP	0.47***	0.29***	-0.06	-0.08	1			
SPD-P	0.15***	0.19***	0.06	-0.12**	0.16***	1		
DPT-NP	-0.13**	-0.14**	0.03	-0.04	-0.28***	-0.16***	1	
DPT-P	-0.21***	-0.24***	0.04	0.07	-0.24***	-0.14**	0.31***	1

Table 16: Pre-crisis period Granger causality p-values where the variable along the row does (or not) cause the variable along the column. Tests were run using the domestic MTS data. VOL (volatility), RET (returns), SPD (spread), DPT (depth), P (PIIGS), NP (non-PIIGS)

	VOL-NP	VOL-P	RET-NP	RET-P	SPD-NP	SPD-P	DPT-NP	DPT-P
VOL-NP	0.03**	0.53	0.37	0.64	0.55	0.10	0.55	0.62
VOL-P	0.31	0.04**	0.54	0.84	0.13	0.04	0.24	0.88
RET-NP	0.43	0.45	0.02**	0.09*	0.96	0.97	0.27	0.88
RET-P	0.79	0.67	0.00***	0.00***	0.61	0.39	0.90	0.70
SPD-NP	0.47	0.11	0.00***	0.05**	0.00***	0.00***	0.32	0.89
SPD-P	0.25	0.23	0.00***	0.00***	0.03**	0.00***	0.97	0.33
DPT-NP	1.00	0.74	0.94	0.95	0.93	0.72	0.00***	0.07*
DPT-P	0.37	0.94	1.00	0.58	0.30	0.70	0.00***	0.00***

Table 17: Crisis period Granger causality p-values where the variable along the row does (or not) cause the variable along the column. Tests were run using the domestic MTS data. VOL (volatility), RET (returns), SPD (spread), DPT (depth), P (PIIGS), NP (non-PIIGS)

	VOL-NP	VOL-P	RET-NP	RET-P	SPD-NP	SPD-P	DPT-NP	DPT-P
VOL-NP	0.00***	0.82	0.22	0.11	0.02**	0.01***	0.71	0.03**
VOL-P	0.11	0.00***	0.24	0.02**	0.36	0.18	0.22	0.04**
RET-NP	0.01***	0.59	0.67	0.59	0.58	0.48	0.88	0.56
RET-P	0.83	0.42	0.12	0.00***	0.01***	0.90	0.28	0.13
SPD-NP	0.92	0.89	0.28	0.01***	0.00***	0.22	0.46	0.16
SPD-P	0.29	0.46	0.85	0.00***	0.36	0.00***	0.81	0.04**
DPT-NP	0.39	0.13	0.58	0.34	0.56	0.45	0.00***	0.45
DPT-P	0.59	0.77	0.94	0.36	0.20	0.00***	0.11	0.00***

Table 18: Heteroskedasticity adjusted correlation values for tranquil, crisis and the full data periods run on both unfiltered returns (RET-UF) and VAR filtered return residuals (RET-F) between non-PIIGS and PIIGS and across the 2, 5, 10 and 30 year maturity segments. Also reported are t-statistics computing statistical differences and whether or not we detect a significant drop in correlation (decoupling)

Heteroskedasticity adjusted correlation values					
	Tranquil	Crisis	Full	t-stat	Decoupling
2Y RET-UF	0.90	0.04	0.49	19.52	Y
2Y RET-F	0.90	0.05	0.49	20.01	Y
5Y RET-UF	0.89	0.13	0.59	17.38	Y
5Y RET-F	0.89	0.14	0.59	16.82	Y
10Y RET-UF	0.84	0.24	0.58	12.94	Y
10Y RET-F	0.85	0.18	0.58	14.12	Y
30Y RET-UF	0.91	0.39	0.81	15.03	Y
30Y RET-F	0.92	0.41	0.81	15.41	Y

Table 19: Heteroskedasticity adjusted correlation values for tranquil, crisis and the full data periods calculated using 10-year returns within non-PIIGS and PIIGS countries. Also reported are t-statistics computing statistical differences and whether or not we detect a significant increase (contagion: C), drop (decoupling: D) or no change (N) in correlation

Heteroskedasticity adjusted correlation values					
	Tranquil	Crisis	Full Period	t-stat	C/D/N
GER-AUS	0.67	0.70	0.68	-0.76	N
GER-BEL	0.78	0.54	0.70	6.08	D
GER-FIN	0.84	0.92	0.86	-4.69	C
GER-FRA	0.89	0.84	0.88	2.83	D
GER-NLD	0.85	0.92	0.87	-4.48	C
FRA-AUS	0.75	0.77	0.75	-0.84	N
FRA-BEL	0.85	0.73	0.81	4.19	D
FRA-FIN	0.87	0.90	0.87	-1.75	N
FRA-NDL	0.90	0.89	0.89	0.29	N
NDL-AUS	0.67	0.70	0.68	-0.76	N
NDL-BEL	0.78	0.54	0.70	6.08	D
NDL-FIN	0.84	0.92	0.86	-4.69	C
FIN-AUS	0.67	0.79	0.70	-3.59	C
FIN-BEL	0.79	0.68	0.75	3.20	D
AUS-BEL	0.88	0.75	0.84	5.51	D
GRE-SPN	0.46	0.14	0.23	4.76	D
GRE-IRE	0.45	0.25	0.30	3.00	D
GRE-ITY	0.58	0.14	0.26	7.08	D
GRE-PTG	0.55	0.24	0.32	5.00	D
IRE-SPN	0.62	0.34	0.48	5.00	D
IRE-ITY	0.60	0.31	0.47	4.93	D
IRE-PTG	0.63	0.51	0.55	2.47	D
PTG-SPN	0.70	0.32	0.46	7.11	D
PTG-ITY	0.73	0.29	0.46	8.60	D
SPN-ITY	0.73	0.66	0.69	2.04	D

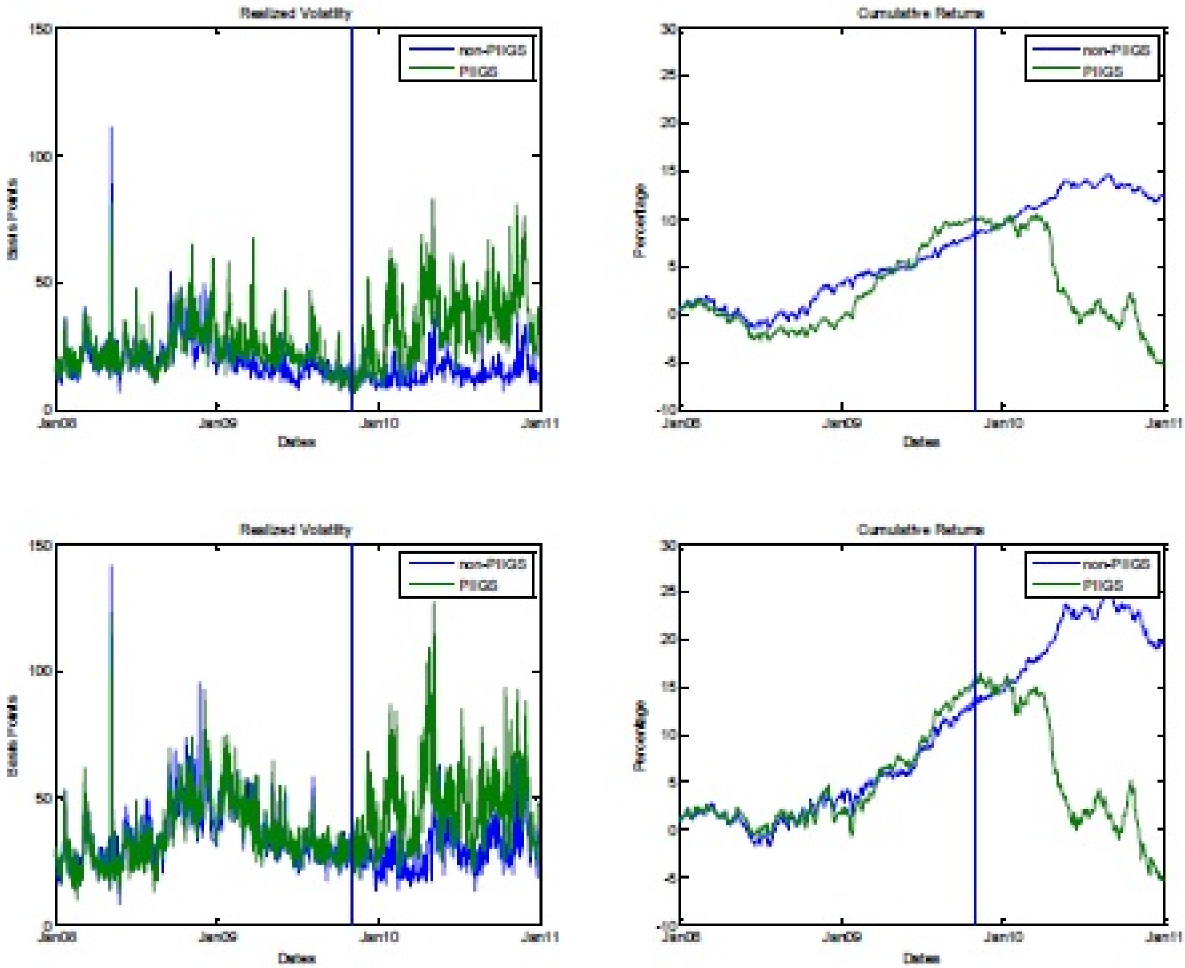

Figure 1: Top panel refers to realized volatility and cumulative returns for 5-year bonds and bottom panel refers to the corresponding measures for the 10-year benchmark for both PIIGS and non-PIIGS countries

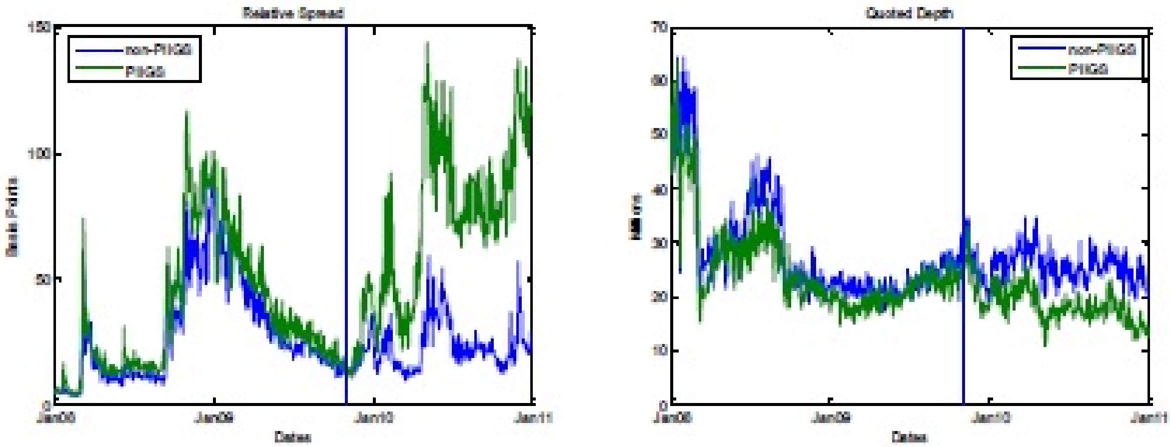

Figure 2: Relative spread and quoted depth for PIIGS and non-PIIGS 10-year benchmark bonds

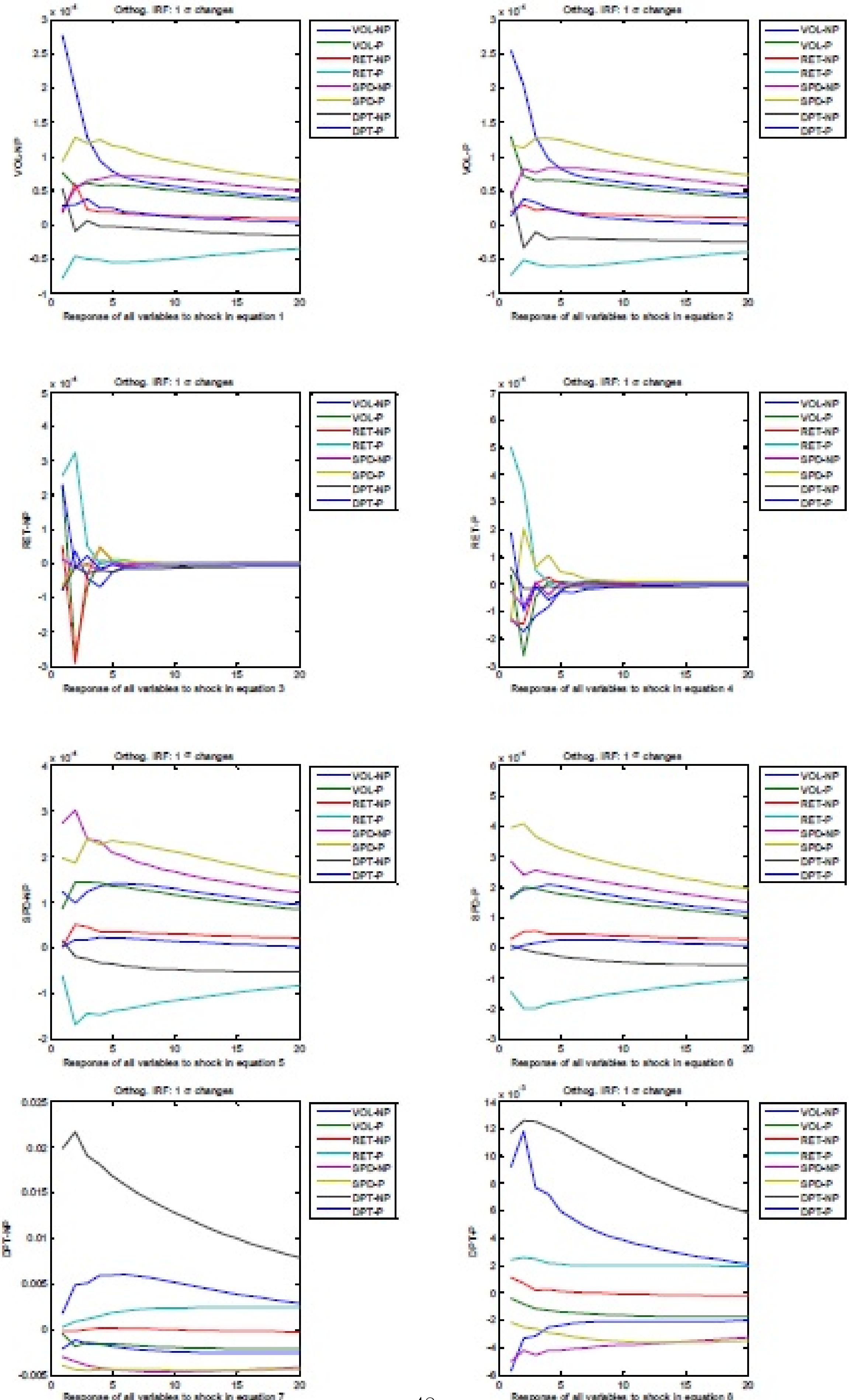

Figure 3: Pre-crisis Impulse Response Functions

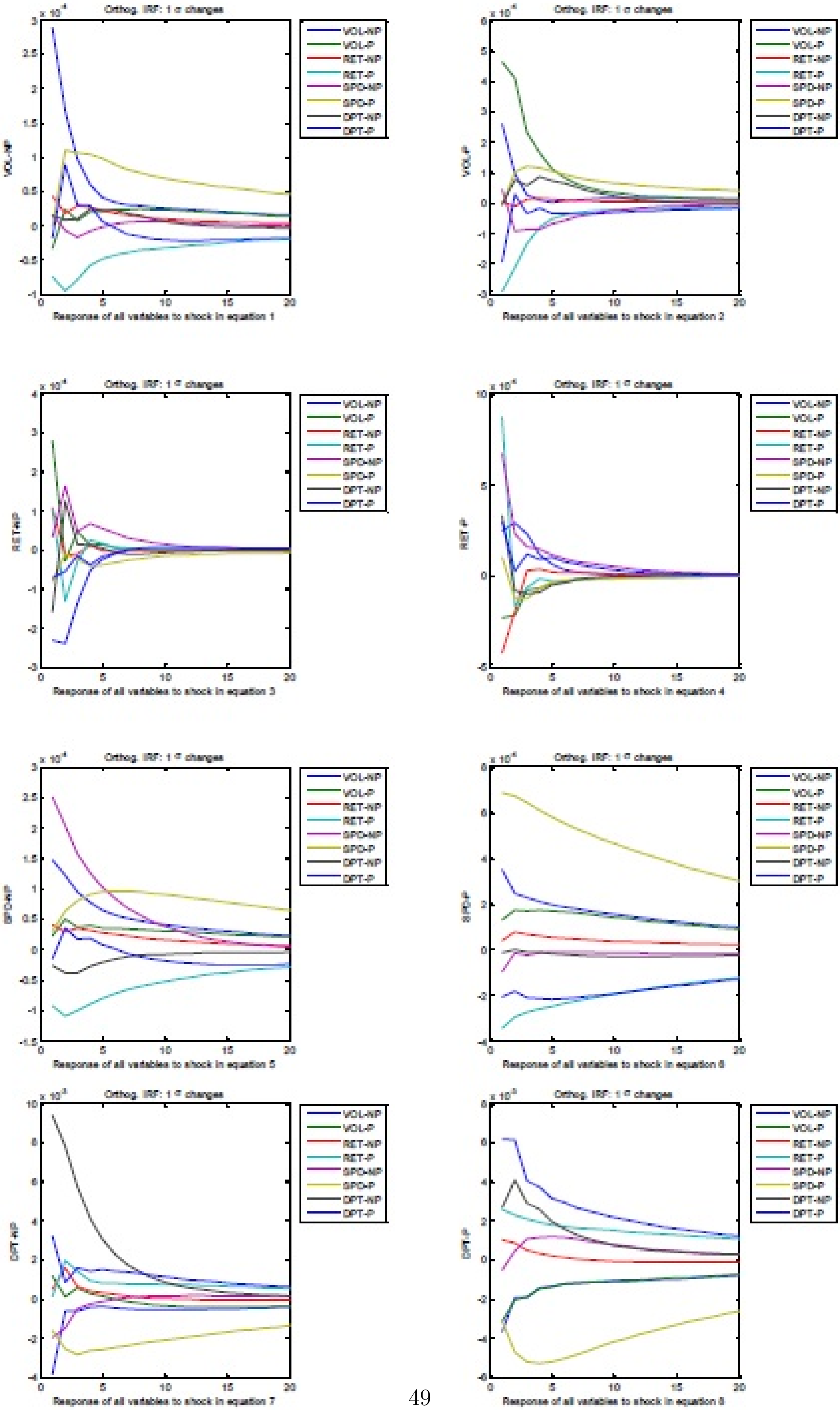

Figure 4: Crisis Impulse Response Functions

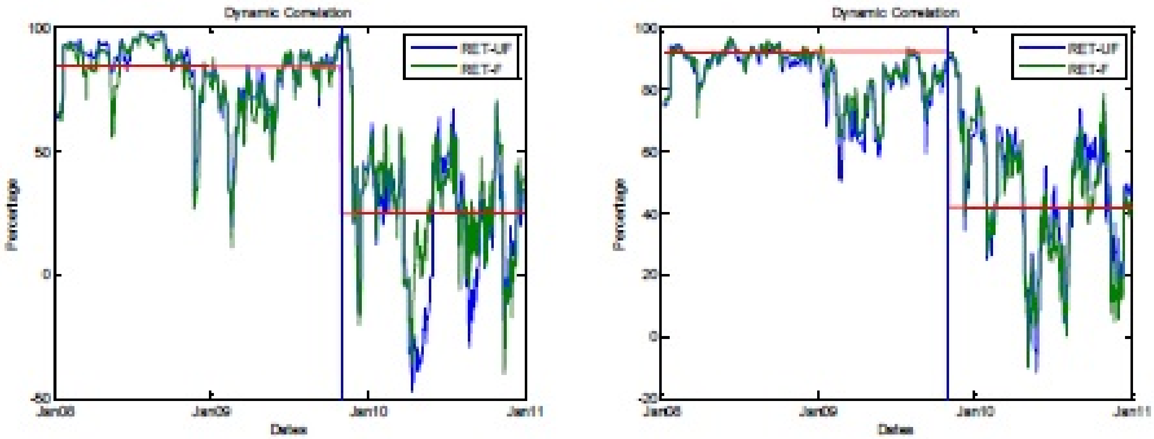

Figure 5: LHS panel refers to 10-year bond DCC dynamic correlations and the RHS panel refers to 30-year bond DCC dynamic correlations between non-PIIGS and PIIGS countries. RET-UF (unfiltered returns), RET-F (filtered returns)