The Microstructure of the European Sovereign Bond Market: A Study of the Euro-zone Crisis *

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Abstract

We study market microstructure and liquidity in the Italian sovereign bond market, the largest in the Euro-zone, using a unique new dataset, recently obtained from the Mercato Telematico dei Titoli di Stato (MTS), which provides tick-by-tick trade and quote data from individual broker-dealers. Our data covers the sovereign bonds of most European Union countries, for the period June 1, 2011 to November 15, 2012, which includes the Euro-zone crisis period. This database is unique for any market, in that it allows us to track individual orders and their revisions during the trading day. We perform this analysis using a range of liquidity metrics, including some that capture intra-day changes, based on the orders placed by individual dealers and their quote revisions. Our cross-sectional analysis, across bonds, and time-series analysis, over the course of our sample period, allow us to examine how liquidity at the level of individual dealers, and in individual bonds, developed during the stressed period. We also examine how liquidity improved after intervention by the European Central Bank (ECB), through its Long Term Refinancing Operations (LTRO) and the Outright Monetary Transactions (OMT) programs, starting in December 2011. Thus, we are able to assess the efficacy of the intervention by studying the changing interaction between the liquidity measures and credit default swap (CDS) spreads, to examine whether the intervention was successful in ameliorating credit risk and illiquidity.

Keywords: Liquidity, Government bonds, financial crisis, MTS bond market

JEL Classification: G01, G12, G14.

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I Introduction

The European sovereign debt crisis has at its center the challenges facing the governments of the GIIPS countries (Greece, Ireland, Italy, Portugal and Spain) in refinancing their debt. After a series of credit rating downgrades of Euro-zone sovereigns, particularly those of Greece, Ireland and Portugal, in the spring of 2010, the crisis permeated throughout the Euro-zone, and even to other countries around the world. The widespread instability in the sovereign bond market reached new heights during the summer of 2011, when the credit ratings of two of the larger countries in the Euro-zone periphery, Italy and Spain, were downgraded. Thereafter, several Euro-zone countries faced serious hurdles in placing their new sovereign bond issues, and consequently, their bond yields spiked to unsustainable levels. The contagion soon spread into the European banking system due to the sovereign debt holdings of the major European banks, extending the sovereign debt crisis into a full-fledged banking crisis. It even threatened countries in the core of Euro-zone, such as France and Germany, due to the close linkages of their major banks with the sovereign debt of the periphery. The crisis has abated to some degree, thanks to fiscal measures by the European Union (EU) and intervention by the European Central Bank (ECB), with a series of policy actions, including the Long Term Refinancing Operations (LTRO) and the Outright Monetary Transactions (OMT) programs, starting in December 2011. Even so, the Euro-zone sovereign debt crisis remains on the front pages of newspapers around the world and represents a drag on the economic recovery of the global economy, leaving open the questions of whether the crisis will resurface at some point in the future and what actions, if any, the Euro-zone governments and the ECB will take to combat it.

Thus far, the discussion in the academic and policy-making literatures on the Euro-zone sovereign debt crisis has largely focused on market aggregates such as bond yields, relative spreads, and credit default swap spreads, at various points during the crisis, and the reaction of the market to intervention by the troika: the ECB, the European Union (EU) and the International Monetary Fund (IMF). While the analysis of yields and spreads is important, it is equally relevant for policy makers and market participants to understand the functioning of the European sovereign debt markets at a micro-level. In particular, the microstructure and liquidity effects, over time, and across individual bonds, are important to analyze in order for policy makers to assess the efficacy of their intervention intervene in these markets. We focus here on such an analysis in the Italian sovereign bond market, particularly since the inception of the Euro-zone crisis in July 2011. Italy has the largest sovereign bond market in the Euro-zone (and the third largest in the world after the US and Japan), and is also one that experienced substantial stress during the recent crisis. It also has a large number of bond issues with a wide variety of characteristics. Hence, the Italian sovereign bond market is best suited for an in-depth analysis of the liquidity effects of the crisis.

We address these issues by studying the microstructure of the Italian government bond market, based on an analysis of the MTS (Mercato Telematico dei Titoli di Stato) Global Market bond trading system, focusing on the crisis period since June 2011. The MTS market is the largest interdealer trading system for Euro-zone government bonds, largely based on electronic transactions, and hence, one of the most important financial markets in the world. Italy has the largest number of bonds and the largest trading volumes on the MTS trading platform. In our analysis, we use a unique new data set, recently made available to us by MTS, which provides tick-by-tick transaction and quote data from individual broker-dealers for the sovereign bonds of 16 European Union countries and Israel. Our data base is unique for any market, in that it allows us to track *individual* orders and their revisions over the course of the trading day.

Using a range of liquidity metrics, some of which can capture intra-day changes in liquidity, we analyze the liquidity of Italian sovereign bonds during the period June 1, 2011 to November 15, 2012, and examine how the characteristics of individual bonds influence their intra-day patterns of liquidity: for example, coupon-bearing vs. zero-coupon bonds, fixed coupon vs. floating coupon etc. We also provide evidence for some special days when macro-events caused the liquidity to suddenly dry up. We examine the interaction between credit risk and liquidity, by analyzing the time series of credit default swap (CDS) spreads and the liquidity measures. In particular, we study how the relationship between credit risk and liquidity changed due to intervention by the ECB, and whether it was successful in ameliorating credit risk and illiquidity. We combine cross-section and time-series data to confirm that our results hold even at the level of individual bonds, helping us to understand whether they differ in their respective reaction to the ECB intervention.

For our empirical analysis, we examine several alternative liquidity measures grouped into three categories: (i) Bond Characteristics, (ii) Trade and Quote Activity Variables, and (iii) Liquidity Measures. Given the stressed period we consider, all the liquidity measures exhibit extreme values: for example, bid-ask spreads are orders of magnitude larger than those documented in previous research on government bond markets. As an illustration, in terms of bonds characteristics, we find that the relationship between liquidity measures and the time to maturity (or, conversely, age) of the bond is highly non-linear. In addition, our time series analysis shows that liquidity measures are clearly related to the dynamic evolution of credit risk. This relationship is largely convex, i.e., the impact of a large change in the CDS spread is proportionally larger than that of smaller changes.

We perform a Granger causality test using the liquidity measures and the CDS spreads to investigate whether illiquidity drives credit risk or vice versa. The results show that before the introduction of the LTRO by the ECB in December 2011, credit risk exacerbated the illiquidity of the Italian sovereign bond market. After the introduction of the LTRO, the causality reversed, in that the improvement in liquidity (or reduction in illiquidity) in the government bond market helped significantly in reducing the credit risk premium. Thus, the intervention not only vastly improved the liquidity of the market, but also substantially decreased credit risk, suggesting that the intervention was successful in meeting its objectives, at least in the near-term.

The results of our study have several policy implications. First, our findings would be of interest to Euro-zone national Treasuries to identify the maturities of the most liquid bonds for their planned issuance. Second, they could also be used by the ECB (and the national central banks) to identify the segments of the market in which to intervene so that the reduction in the bid-ask spread for a bond of given maturity would most benefit bonds of other maturities, so as to achieve the optimal impact of open market operations. Third, our analysis could be employed by market regulators the national central banks – to address issues relating to transparency in the organization of Treasury markets and the timely disclosure of information, as well as evaluating the performance of individual primary dealers.

In Section II of the paper, we survey the literature on sovereign bonds, particularly relating to liquidity issues. In the following section, Section III, we provide a description of the MTS market architecture, the features of our data base, and our data filtering procedures. We describe our liquidity measures in Section IV and present our descriptive statistics in Section V. Our analysis of the cross-sectional and time-series effects of the liquidity during the Euro-zone crisis is presented in Section VI. Section VII concludes.

II Literature Survey

The extant literature on liquidity effects in the global sovereign bond markets is sparse. There are a few papers on liquidity in the US Treasury bond market, although they largely cover the period *prior to* the global financial crisis, and mainly analyze liquidity at an aggregate level, using measures such as the bid-ask spread. Similarly, there is a handful of papers on the European sovereign bond markets, and again, these papers generally refer to a limited period, mostly prior to the financial crisis. However, there is hardly any detailed analysis of the micro-structure of the sovereign bond markets, in US or Europe, based on dealer-level orders and transactions. Hence, it is valid to conclude that the existing literature is fairly limited in depth and scope, in the context of what we study in this paper: the microstructure of the Euro-zone sovereign bond markets during the depths of the recent crisis. Nevertheless, we provide below a brief review of the existing literature to place our research in context.

We begin with a brief review of the papers on liquidity in the US Treasury bond market. Fleming and Remolona (1999) study the price and volume response of the US Treasury markets to unanticipated macro-economic news announcements. They hypothesize that there are two stages in the market response to announcement surprises, the first being a sharp, almost instantaneous, change in prices, with very little incremental trading activity, followed by a second stage with a further change in price accompanied by a surge in trading volume. They find corroborative evidence for this hypothesis in data from GovPX from the period 1993-1994. Chakravarty and Sarkar (1999) study the determinants of the bid-ask spread in the corporate, municipal and government bond markets in the US during 1995-1997, using data from the National Association of Insurance Commissioners. They estimate the realized bid-ask spread by analyzing the sell and buy trades on a given day, and relate it to the volume of trading, credit risk, age and other bond characteristics. Fleming (2003) studies the realized bid-ask spread using GovPX data from 1996-2000, and finds that it is a better measure of liquidity than the quote size, trade size, on-the-run-off-the-run spread and other competing metrics.

Pasquariello and Vega (2006) analyze the announcement effects of macro news using daily data from GovPX on the US Treasury bond market. They document that order flow surprises are linked to macro-economic news announcements. In a related paper, Pasquariello and Vega (2011) study the impact of outright (i.e., permanent) open market operations (POMOs) by the Federal Reserve Bank of New York (FRBNY) on the microstructure of the secondary U.S. Treasury market. They use a sample of intraday U.S. Treasury bond price quotes (from BrokerTec), and a proprietary dataset of all POMOs conducted by the FRBNY between 2001 and 2007, to conclude that the bid-ask spreads of on-the-run Treasury securities decline on days when POMOs are executed and POMOs' positive liquidity externalities are increasing in proxies for information heterogeneity.

Goyenko, Subrahmanyam and Ukhov (2011) use quoted bid and ask prices for Treasury bonds with standard maturities, obtained from the Center for Research in Security Prices (CRSP) data base, for the period November 1967 to December 2005, to study the determinants of liquidity in the US market. They compare the characteristics of on-the-run bonds with off-the-run bonds, as well as bonds of different maturities, to conclude that the illiquidity differences widen during recessions, hinting at a flight to liquidity, where investors move to more liquid instruments during tight economic conditions. They also document that macroeconomic variables forecast off-the-run liquidity better, suggesting that macro shocks are better reflected in this segment's liquidity premium.

There are a few papers in the literature analyzing data from the electronic trading platform known as BrokerTec, which was introduced in 2000. Fleming and Mizrach (2009) provide a detailed description of this market and an analysis of its liquidity. They show that the liquidity is much greater in this market than reported in prior studies using less detailed data from GovPX. They also analyze the price impact of trades and the effect of "iceberg" orders, which are partly hidden from the market. Engle, Fleming, Ghysels and Nguyen (2011) propose a new class of dynamic order book models based on prior work by Engle (2002). They study the interaction between liquidity and volatility and show that liquidity decreases with price volatility, but increases with liquidity volatility. They conjecture that liquidity suppliers curtail supply when faced with price volatility, but increase it when faced with liquidity volatility, which is more highly valued by the market.

There is a vast literature on liquidity effects in the US corporate bond market, examining data from the Trade Reporting and Compliance Engine (TRACE) database maintained by the Financial Industry Regulatory Authority (FINRA), using liquidity measures for different time periods, including the financial crisis. This literature is relevant to our research both because it analyzes a variety of liquidity measures and because it deals with a relatively illiquid market with a vast array of securities. For example, Friewald, Jankowitsch and Subrahmanyam (2012a) show that liquidity effects are more pronounced in periods of financial crises, especially for bonds with high credit risk, based on a sample of over 20,000 bonds and employing several measures including the Amihud measure, the price dispersion measure and the Roll measure, apart from bond characteristics and transactions measures such as the bid-ask spread.[1]

In the context of the European sovereign bond markets, Coluzzi, Gibri and Turco (2008) use various liquidity measures to analyze Italian Treasury bonds using data from the MTS market, during the period 2004-2006, to provide a comprehensive description of the market and a discussion of the liquidity in this market before the global financial and Euro-zone crises. Dufour and Nguyen (2011) analyze data from 2003-2007, in the Euro-zone sovereign bond market to estimate the permanent price response to trades. They show the relevance of information asymmetry in explaining the cross-sectional variation in bond yields across maturities and countries. They show that investors demand higher yields for bonds with a greater trading impact. Girardi (2008) uses the price series for a limited sample of bonds for a two-year period and shows that the MTS market's contribution to price discovery is about 20%, on average. He concludes that trades conveying information occur on the MTS platform, when the level of liquidity is high.

Beber, Brandt, and Kavajecz (2009) analyze ten Euro-zone sovereign markets using MTS data between April 2003 and December 2004. They examine the relative importance of credit quality versus liquidity, and conclude that both are demanded by investors, but in different periods. They show that most of the spread differences are accounted for by differences in credit quality, although liquidity plays a role for the bonds of higher rated countries. However, large portfolio flows are determined mainly by liquidity. Similar results has been found by Favero, Pagano and von Thadden (2010). More recently, Bai, Julliard and Yuan (2012) study how liquidity and credit risks evolve in the Euro-zone sovereign bond markets since 2006. They conclude that bond spread variations prior to the recent global financial crisis are mostly due to liquidity concerns, but after late 2009, are more attributable to credit risk concerns, exacerbated by contagion effects.

The paper whose analysis is closest to ours is by Darbha and Dufour (2012), who use a range of liquidity proxies to analyze the liquidity component of Euro area sovereign bond yield spreads prior

[1] Other recent papers quantifying liquidity in these markets provide related evidence. See, for example, Mahanti, Nashikkar, Subrahmanyam, Chacko, and Mallik (2008), Ronen and Zhou (2009), Jankowitsch Nashikkar and Subrahmanyam (2011), Bao, Pan, and Wang (2009), Nashikkar, Subrahmanyam, and Mahanti (2009), Lin, Wang, and Wu (2011), Feldhuetter (2012), and Dick-Nielsen, Feldhuetter and Lando (2012).

to the global financial crisis (2004-2007), and during the crisis period (2007-2010). They find that the liquidity of non-AAA bonds explains the dynamics of corresponding yield spreads more during the crisis than prior to the crisis. They also document the effects of maturity and conclude that the bid-ask spread is a good proxy for liquidity during the crisis period.

There are several important differences between the prior literature and the evidence we present in this paper. First, while most of the previous literature spans past, more normal time periods in the US and Euro-zone markets, the sample period we consider includes the most relevant period of the Euro-zone sovereign crisis that we have observed in the last 18 months, i.e., after both Italy and Spain experienced a series of rating downgrades that spread instability both to other European countries (including France, and later on, even Germany) and to many European banks. Second, the datasets used by previous researchers, both from MTS in Europe and BrokerTec in the US, including the recent paper by Darbha and Dufour (2012), are based on quote and trade data, and typically record changes to the best three bids and ask quotes of the day, rather than tick-by-tick data, or detailed quote data from individual dealers. Moreover, the less recent data used by other researchers included only the executions of the orders, while the database we analyze includes both executions and the orders that generated them. In particular, our analysis includes intra-day order proposals, quote revisions and trader identity to draw conclusions about the microstructure determinants of liquidity in the Euro-zone sovereign bond market, especially under conditions of stress. This enhanced level of detail will allow us to shed light on the submission strategies of the traders and sharpen our understanding of demand for and the realization of liquidity. It also casts a spot light on the intra-day evolution of the liquidity effects, in particular on days of important macro-announcements.

III MTS Market Structure and Data Description

The data we use in this analysis relate to the transactions, quotes, and orders for European government bonds from the MTS Group. The MTS data include trade and quote data of fixed-income securities, mostly those issued by the national Treasuries and local governments of twelve countries: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Slovenia and Spain. The MTS system is the largest interdealer market for Euro-denominated government bonds. The time-series data are based on all MTS inter-dealer markets making up the MTS system, including EuroMTS, EuroCredit MTS and various domestic MTS markets. The structure of the MTS trading platform is very similar to the EBS and D2002 electronic trading systems for the foreign exchange market, but is different from the quote screen-based US Treasury bond trading system. The MTS inter-dealer trading system is fully automated and works as a quote-based electronic limit order market. According to the MTS data manual, "EuroMTS is the reference electronic market for Euro benchmark bonds, or bonds with an outstanding value of at least 5 billion Euro."[2]

The sample period for our study is from June 1, 2011 to November 15, 2012. This time period provides a good window to study the behavior of European government bond markets during the most recent part of the Euro-zone sovereign debt crisis and the period leading up to it. Specifically, the earlier part of our sample covers a number of significant sovereign events that directly affected the liquidity in Euro-zone government bonds, and, in general, the wider loss of confidence in European efforts to manage the sovereign debt crisis. In this period, dealers also witnessed the substantial increase in the Italian bond-yield spread (over German Treasury bonds or "bunds") and Italian sovereign CDS

[2] See also Dufour and Skinner (2004).

spread. After a few months of great uncertainty, it culminated in the restoration of market confidence thanks to the LTRO program with a three-year maturity introduced by the ECB in December 2011 and, at the end of July 2012, the speech by Mario Draghi, the ECB President, who unveiled the potential for new tools to ease the European sovereign debt crisis.[3] Since Italy has the largest number of bonds traded in the Euro-zone throughout the sample with the largest volume and was the bellwether country during the European sovereign crisis, we initially focus our analysis on Italian government bonds, based on the most detailed historical data set that MTS makes available to the public.[4]

There are four data bases currently offered by MTS. At the highest level, "daily summaries," including aggregate price and volume information regarding the trading of European bonds, are published. At the second level, the "trade-by-trade" data including all transactions, stamped at the millisecond level, are available. However, neither of the two aggregate data bases has any information on the price quotations of the instruments, at the dealer, or even the market-wide level. The best publicly available data set at the third level includes the best three bid and ask prices and the aggregate quantities offered at those levels. Studies that use this prior data set are unable to describe the market in its entirety, as the two dimensions indicating willingness to trade, quotes and orders, respectively, for primary dealers and dealers, were not provided in the data set. Only *actual trading* events are observable and *trading intent* as a pre-trade measure cannot be measured with this data set. Thus, it is not possible to study liquidity provision as measured by the dealers' willingness to trade, as evidenced by their bid and offer quotations, based on this data.

In contrast, the data set we analyze in the present study is at the fourth level, and is, by far, the most complete representation of the market available, and has been released only recently. It covers *all* trades, quotes, and orders that took place on the MTS market between June 1, 2011 and November 15, 2012. Every event is stamped at the millisecond level, and the order IDs permit us to link each order to the trade that was eventually consummated from it. Every quote - in this market, and henceforth called a "proposal," - can be followed in the data base in terms of its "revisions" over time, thanks to a "single proposal" identifier.

There are two kinds of traders in the sovereign bond markets, primary dealers and other dealers . Primary dealers are authorized market-making members of the market, i.e., they issue standing quotes, which can be either single sided or double sided, on the bonds they have been assigned. They indicate the quantity they are willing to trade and the non-negative fraction of that quantity they are willing to "show" to the market. Primary dealers can be both on the passive side, when their proposals are hit, and on the active side of the market, when they submit orders aimed at hitting another primary dealer's standing quote. Primary dealers have market-making obligations that, in spite of some relaxation after 2007, still require each primary dealer not to diverge from the average quoting times and spread, calculated among all market-makers. In this market, the event of crossed quotes is ensured not to occur, except by chance, since when the opposite sides of two proposals cross, a trade takes place for the smaller of the two quoted quantities[5]. Other dealers with no market-making responsibilities can originate a trade only by "hitting" or "lifting" primary dealers' standing quotes with market orders. However, it should be noted that primary dealers are also on the active side of 96% of the trades present in our database.

"Proposals" are a peculiarity of this market. While we cannot observe individual primary dealers'

[3]In his speech on July 26, 2012, at the Global Investment Conference in London, Mario Draghi stated: "The ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough."

[4]In later analysis, we will also examine the bonds of other Euro-zone countries.

[5]While this is one way for the primary dealers to trade, it seldom happens. Hence, we do not include trades originated in this manner in our sample

IDs, conversations with the MTS officials revealed that, most of the time, a primary dealer issues a single proposal per bond per day, and updates it throughout the day, thereby conserving the proposal ID.[6] While some proposals, often one-sided, are made to build a position, the vast majority are quotes with both a bid- and an ask-price, together with quantities that the primary dealer is willing to sell and buy, respectively. Proposal IDs are bond-date specific; hence, it is not possible to track the same proposal through different days. Nonetheless, they constitute a proxy for the number of dealers interested in actively trading the bond at any point in time, and they allow us to follow the dynamics of market making activities throughout the day.

In this market, primary dealers have the right to quote different quantities (at the same bid- and ask-prices) for the European and domestic markets. However, both quantities are merely "drip quantities", which in order-driven markets would be called the visible part of the "iceberg," or partially hidden, orders. The primary dealers communicate only to the trading platform engine the overall quantity they are willing to trade, but this information is never disclosed to other market participants. Unless otherwise noted, in this paper, we will always consider the total quantities dealers are willing to trade, regardless of how much they disclose to the different markets participants, since we believe such a connotation best fits the current academic understanding of liquidity.

Whenever a bid proposal is hit by an order submitted by a dealer or another primary dealer, the proposal is suspended in order to allow the primary dealer to trade a larger quantity than she was initially willing to, as indicated in the initial proposal. Contrary to other markets systems, such as NASDAQ's ITCH, there is no way to know exactly which proposal was hit by an order, or whether the proposal was actively suspended by the primary dealer, or by the matching engine, to ensure the exchanged quantity would not exceed the bid or ask quantity. However, MTS officials suggest that if an order hits one or more proposals, the latter would be suspended one millisecond before the recorded time of arrival of the order. Matching orders, the trades they result in, and proposals that were in place up to a millisecond before the order's arrival, permit us to match the first price at which the order trades with the best bid- or ask-price 99% of the time.[7]

While the data set does not suffer from misreporting issues that other data bases such as the TRACE data suffer from, a few words on our data-cleaning procedures in the context of the MTS data-base are nevertheless in order.[8] First, the same bond-day specific proposal ID can be tracked throughout the day, which means that, at any point in time, only one "message will be left standing per bond per proposal ID. This is not always the case and when two messages belong to the same proposal ID and overlap in time, they are both deleted. Often, two messages occur regarding the same proposal ID differ in key variables indicating whether or not the quote is suspended or whether or not the dealer is on-line. Keeping both records would, however, cause a stale, unrealistic quote to be considered in the calculations, resulting in flawed effective bid-ask spread calculations, even resulting in negative effective spreads. For this reason, we delete both records. Second, orders that result in trading indicate how many contracts (trades) they originate. Being able to match orders and trades, we check whether the indicated amount of originated contracts coincide with our corresponding

[6]It is, however, possible that the same financial institution has two different desks trading the same bond, e.g. a market making desk and a proprietary trading desk. It is unclear if the two desks would interact and co-ordinate, or if they would compete. Even so, MTS officials believe that only a small minority of traders would have more than a single contemporaneous proposal per-bond.

[7]The remaining 1% of the time, it is impossible to match the best price the order traded at with the best bid- or ask-price, as the matching engine seems to skip the best standing bid- or ask-price.

[8]See Dick-Nielsen (2009) and Friewald, Jankowitsch and Subrahmanyam (2012a) for details of data cleaning and filtering procedures for the TRACE data set.

calculation. When the two numbers are different, we do not include the orders in our statistics.

Last, in the bond descriptions files, coupon-bearing bonds are sometimes identified with a nil coupon rate. If a coupon-bearing bond indicates a non-zero coupon rate on at least one date in the sample, we assume that is the correct coupon-rate. If a supposedly coupon-bearing bond is never indicated as having a non-null coupon rate, we exclude it from the sample, since it may have erroneous data.

Our data set consists of 148 Italian government bonds. Table 1 presents the distribution of these bonds in terms of maturity and coupon rate, between maturity groups as well as bond types. Maturity groups were determined by looking at the time distance between bond maturities and the closest round year. As Table 1 shows, the large majority (in numbers) of the bonds considered have a short maturity (from 0 to 5 years). All bonds considered in this analysis belong to one of the following types: Buoni Ordinari del Tesoro (BOT) or Treasury Bills or Certificato del Tesoro Zero-coupon (CTZ) or Zero coupon bonds, Certificati di Credito del Tesoro (CCT) or Floating notes, and Buoni del Tesoro Poliennali (BTP) or Fixed-income Treasury Bonds. The vast majority of the bonds we consider here belongs to the BOT and BTP types. We excluded from our analysis inflation or index-linked securities, as mentioned earlier.

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IV Liquidity Proxies and Methodology

In the context of the Italian sovereign bond market, we first analyze the relationship between various liquidity proxies proposed in the literature, which are defined below. The liquidity proxies we use span the entire range of metrics that have been computed in the literature, with some additions, that can be used in the context of the detailed dealer-level data available to us. The relationships we investigate allow us to compare the effectiveness of different proxies in the estimation of liquidity in the MTS market. The proxies we use can be divided into three main categories: (i) Bond Characteristics, (ii) Trade and Quote Activity Variables, and (iii) Liquidity Measures.

The bond characteristics we use as liquidity proxies include: *Amount Issued*, *Coupon*, *Maturity*, *Age* and *Time to maturity*. In line with the vast literature on the liquidity of corporate bonds, we expect larger issues to be more liquid.[9] Similarly, after adjusting for risk, bonds with a lower coupon have a propensity to be more liquid, in part because the lower coupon may proxy for lower credit risk. Bonds with longer maturities are likely to be less liquid, since they are often bought to be held to maturity. Older bonds tend to be less liquid, since on-the-run bonds are typically more liquid than their off-the-run counterparts.

We study several trade and quote activity variables, some of which we are able to compute given the detailed dealer-level order information available in our data set. We investigate the daily average of the *Number of Trades*, *Traded Volume*, *Quote Revisions* (number of total proposals over number of single proposals), *Single Proposals* (as a proxy for the presence of primary dealers), *Quoted Quantity at the Best Bid or Offer*, and *Total Quoted Quantity*. It should be emphasized that only the first two measures are commonly used in prior studies of liquidity in most markets. We are able to augment these with more detailed metrics obtained from the levels of quantities and prices of bids and offers.

[9]See, for example, Friewald, Jankowitsch and Subrahmanyam. (2012a) and Dick-Nielsen, Feldhuetter and Lando (2012).

In general, the greater the value of each of these metrics the more liquid the bond. For instance, the greater the *Number of Trades*, the greater is the liquidity.

In addition, we investigate the following more specific liquidity measures, which have all been used in the prior literature: the *Quoted Bid-Ask Spread*, *Effective Bid-Ask Spread*, *(Log) Return Variance*, *Amihud Measure*, and *Roll Measure.* The lower the value of each of these measures, the greater the liquidity. For example, the lower the *Quoted Bid-Ask Spread*, the greater is the liquidity.

After cleaning the data as described in Section III, our statistics are computed as follows: We first match the orders to the trades they translate into, if there are any. We then match the order-trade groups with the proposals that were in force up to a millisecond before the arrival of the order. We calculate the best bid- and ask-prices and the volume-weighted effective spreads. We then group the statistics per bond per day, before proceeding to the cross-sectional and time-series analysis. With regards to the proposals, we calculate daily measures for the whole dataset. Other measures are calculated at a five-minute frequency, and then aggregated throughout the day, in order to create various per bond, per day, measures.

Bond characteristics, trade and quote activity measures, and liquidity measures are defined as follows. *Maturity*, *Time-to-maturity*, *Coupon Type*, *Amount Issued* and *Coupon Rate* are the specific bond characteristics we take into consideration. *Maturity* is defined as the time, in years, between the issue date and the maturity date. *Time-to-maturity* is the time in years between the settlement date of the bond and its maturity date. *Coupon Type* refers to whether a bond is a coupon-bearing, zero coupon, or floating rate bond.[10] *Amount Issued* is the amount issued of the bond in euro. In case the bond was re-opened for additional issues, this variable would include such further issuance. *Coupon rate* is the annual coupon rate, as indicated in the bond description files.

The trade activity measures are defined as follows. In the cross-section, *Traded Quantity* is the overall quantity traded for a single bond in the sample, while, in the time-series, it is the overall quantity traded on all bonds on that day. In the cross-section, *Trades* and (*Orders*) represent the overall number of trades (orders) relating to a particular bond, while in the time-series, they indicate the overall number of trades (orders) taking place on all bonds on a given date. *Fill Ratio* is the percentage of all orders for a bond that were executed, at least partially, in the sample. *Trading Days* is the number of days a bond was traded in our sample, *Sample Days* is the number of days the bond is present in the sample, which can be shorter than the overall sample because of early maturity, late issuance, or short duration. *Daily Trades/Orders/Quantity* is a per-bond measure, and equals the total number of trades/orders/quantity divided by the number of days the bond is in the sample. *Traded Bonds* is a time-series measure indicating the euro amount of bonds that were actually traded on a given day.

In addition to the trading measures also defined above, we have detailed information about individual dealer quotes, permitting us to compute quote measures. The quote measures are as follow. *Daily Revisions* is the number of quote revisions for a bond on a given day, *Total Single Proposals* is the number of single proposals that were quoted for a bond on a day. *Contemporaneous Single Proposals* is a measure of how many of the single proposals are, in fact, contemporaneously in place and is calculated on a five-minute basis. *Revisions per Single Proposal* is the average of revisions per single proposal; it is the ratio of the *Daily Revisions* to the *Total Single Proposals. Total Quoted Quantity* is the average of the total quantity offered at any level of the bid price and the total quantity offered at any level of the ask price. *Best Bid (Ask) Proposals* is the number of single proposals

[10] We discard bonds that are linked to indexes, such as inflation, to limit the influence of macro-economic variables and events that are not explicitly controlled for.

contemporaneously at the best bid- (ask-) price. *Best Quantity* is the average quantity quoted at the best bid- and best ask-price. The latter three measures are also sampled at a five-minute frequency.

As for the standard liquidity measures, we calculate the *Quoted Bid-Ask Spread (9 to17)*, the *Effective Spread*, the *Return Variance*, the *Log-Variance*, the *Amihud Measure*, and the *Roll Measure.* The *Quoted Bid-Ask Spread* is calculated after taking into account firm proposals of the "logged-on" dealers, after the aforementioned data-cleaning, at a five-minute sampling frequency. The bid-ask spread is an absolute value in euro (per 100 euro of face value). Given the U-shaped nature of the bid ask spread over the trading day, we also calculate the *Quoted Bid-Ask Spread 9 to 17*, where we exclude the first hour and the last half-hour of trading. For this reason, we conduct our analysis with the *Quoted Bid-Ask Spread*, and use the truncated version as a robustness check. *Effective Spread* is calculated as $Q \cdot (AP - M) \cdot 2$, where $Q = 1$, if it is a buy order, and $Q = -1$, if it is a sell order, AP is the face value-weighted trade price, and M is the mid-quote in place at the arrival of the order. Since orders might "walk" the book, once the quantity offered at the best bid- and ask-price is depleted, given the endogenous relationship between quoted spread and the trading decision regarding quantities bid or offered, effective and quoted spreads are bound to differ. *Return Variance* is calculated as the variance of mid-quote-returns, sampled at a five-minute frequency. *Log Var* is the log of *Return Variance.* The *Amihud Measure* is calculated in its daily formulation as $\frac{\|r_{it}\|}{V_{it}}$ where $\|r_{it}\|$ is the mid-quote return between 9 and 17 for bond i on day t and V_{it} is the bond i day t exchanged quantity. The *Roll Measure* is calculated as $Roll_{it} = 2\sqrt{Corr(\Delta p_k, \Delta p_{k-1})}$, where Δp_k is the price change between transaction k and transaction $k-1$. Following the literature, we calculate the correlations during a 21 day window; we require at least three entries, which means three days with three trades a day or a day with seven trades in the 21 days preceding the days for which the measure is calculated.[11]

In section V, we present the cross-sectional and time-series descriptive statistics of our data. In the cross-section, each bond participates with only one observation. For measures like *Maturity*, *Age*, *Coupon Type*, *Amount Issued*, *Coupon Rate*, *Traded Quantity*, *Trades*, *Orders*, *Fill Ratio*, *Sample Days*, and *Daily Trades/Orders/Quantity* only one observation is available, per bond. The other measures are daily measures and every bond is included in the time-series average of each of the liquidity measures, e.g., *Contemporaneous Single Proposals* is calculated as follows: For every bond-day-five-minute interval, the number of standing single proposals is calculated. The several bond-day specific observations are averaged to create a bond-day measure. In the cross-section, the 377 bond-day measures are averaged to create the bond-specific measure. In the time-series, bond-date measures are aggregated across bonds to create an observation per day, unless the measure are already defined on a daily basis, as in the case of *Traded Bonds* or *Traded Quantity.*

V Descriptive Statistics and Stylized Facts

V.I Bond characteristics and liquidity

Table 2 presents the summary statistics for 148 Italian sovereign bonds quoted on the MTS trading platform between June 2011 and November 2012, spanning the period when the sovereign crisis deepened in Italy and other Euro-zone countries. The average issue size of these bonds is 14 billion euro, with a maximum of 30 billion euro and a minimum of 3 billion euro. The average maturity (*Maturity*)

[11]This is common practice in the prior literature, e.g., Friewald et al.(2012a).

of the bonds in our sample is 5.87 years and their average age (*Age*) is 2.38 years. The maturity of individual bonds ranges from 2.5 months to 30 years. Given that we observe ages from 0 to 18 years, it is evident that some bonds are issued, and others mature within our sample period: in particular, bonds with a maturity of less than 10 years. Thus, we do not observe any 30-year bonds maturing during our sample period.

Among trading activity variables, over the 377 days of our sample, the mean (median) bond trading volume is 5.37 (4.58) billion euros. Therefore, on average, the daily trading volume during our sample periods is 34 (26) million euros. The trading volume as a whole, for all 148 bonds, trades on average around 1.8(1.5) billion euros a day (Cf. Table 4).

The daily trading volume in the Italian MTS market is much smaller than the US Treasury market by a couple of orders of magnitude - the average traded quantity is around \$500 billion per day.[12] The average daily trading volume in the MTS Italian bonds market is more comparable to the US municipal market (\$15 billion), the US corporate bond market (\$15 billion), and the spot US securitized fixed income market (\$2.7 billion (asset-backed securities), \$9.1 billion (collateralized mortgage obligations), and \$13.4 billion (mortgage-backed securities)).[13]

Our statistics are in line with the stylized facts documented in previous literature, along with the consistent shrinkage of market volume since the Euro-zone crisis. Dufour and Nguyen (2011) report that the Italian segment of the MTS market volume as a whole, over their 1641 days sample, was 4,474 billion euros.[14] This translates into an average of 3.8 billion euro daily volume.[15] Darbha and Dufour report that the daily volume per bond shrank from 12 million in 2004 to 7 million in 2007. Their sample only includes coupon-bearing bonds; thus, their figures for overall market volume are not directly comparable with ours.

INSERT TABLE 2 HERE

The number of trades per day per bond in the MTS Italian sovereign bond market is 4.05, which is similar to the 3.47 trades a day per corporate bond on TRACE, as reported in Friewald, Jankowitsch and Subrahmanyam (2012a). Dufour and Nguyen (2011) report an average of 10 trades per day per Italian bond in the prior period between 2003 and 2007. Table 3 shows the cross-sectional distribution of the various liquidity measures for the Italian sovereign bond market in our sample period. For these metrics, only one observation is used per bond, namely the time-series average of the trading or liquidity measure.[16]

While section V.III presents our detailed analysis of the time-series evolution of the liquidity measures, we can infer from Table 3 that even at an aggregate level, liquidity measures vary substantially across bonds. The bid-ask spread goes from a minimum of 0.001 euro to an maximum of 1.47 euro per 100 euro face value, with an average of 0.37 euro per 100 of face value. Darbha and Dufour (2012) report the bid-ask spread for short and long maturity bonds of countries with lower credit ratings to be 0.38 and 0.61 respectively from the period 2004-2010; our figures are in line with their findings indicating that, on average, even during the Eurozone sovereign crisis of 2011-2012, the spread does not change so much.

[12] See e.g., Bessembinder and Maxwell (2008).

[13] Details for the corporate bond, municipal securities and securitized fixed income markets are provided in Friewald, Jankowitsch and Subrahmanyam (2012a), Vickery and Wright (2010) and Friewald, Jankowitsch and Subrahmanyam (2012b) respectively.

[14] The sample spans the period of April 2003 through September 2007.

[15] Assuming 250 business days Cf. Table 1 page 34 of their paper.

[16] The definitions of the metrics were presented in Section III.

INSERT TABLE 3 HERE

Due to the endogeneity of the trading decision of dealers, given the quoted spread, the effective spread is typically much lower than the quoted spread, and varies from 0.001 euro to 0.63 euro per 100 of face value. This is in line with the 0.70 euro value of the 99th percentile for the quoted spread, at time of trade execution, which appears in Darbha and Dufour (2012).

Since the previous literature did not have access to the detailed quote data we are using, we cannot compare the following measures with prior research. The total quoted amount per bond (Total Quoted Quantity), on each side of the market, sampled at a five-minute frequency and averaged through our sample, varies from a minimum of 69 to a maximum of 524 million euro, with a mean (median) of 127 (123). Of this quantity, 6 to 124 million euro are quoted at the best bid- or ask-price, with a mean (median) of 14 (12) million euro. This means that about 10% of the Total Quoted Quantity is, on average, at the best bid- or ask-price.

As for the presence of competition between market-makers, the number of standing single proposals varies between 13 and 22 across the different bonds, with an average of 17. Each single proposal, which is bond specific, is updated on average 1,248 times a day. This translates into a revision every 2.2 minutes, over a 9.5 hour (=570 minute) long business day. There is a high degree of heterogeneity in the number or revisions, since some bonds have proposals changing every five-minutes, and other bonds have single proposals updating as often as every 10 seconds. Combining the number of single proposals and the amount of revisions per single proposal indicates that the quotes are updated from 3,000 to 108,000 times a day; hence, on average, the book for a specific bond changes every second.[17]

While the previous measures could provide us with an idea of the overall market, focusing only on the best bid- and ask-price, we find that there are, on average, 1.5 single proposals at the best bid- and ask-price: Half the time, a single market maker is at the best bid- or ask-price, and the remaining half of the time she is competing with another market maker. The minimum Amihud measure is 0.001 while its maximum is 18.37; therefore, on average, a million euro transaction moves the price about 0.0271%. For the most liquid bonds, the price will stay substantially the same, while for the least liquid bonds a million dollar trade will move the price about 0.18%.

V.II Intraday characterization of liquidity

Our measures show clear intraday patterns, as Figure 1 and Figure 2 show. The quantities plotted in these graphs have been averaged through the 377 days and 148 bonds in our sample, for every five-minute interval. Figure 1a shows the patterns of two very similar trading activity variables, namely *Number of Orders* and *Traded Quantity*. Although the MTS market opens at 8:00 am [Central European Time (CET)], trading activity remains muted until 9:00 and reaches the daily average at around 10:00. Traded volume peaks around 10:30 with a trade quantity of 58 million euro per five-minute interval. After 11:00, trade quantity drops to its daily average of about 25 million euro exchanged per five-minute interval, and remains reasonably constant until the market-close at 17:30.

The quoted (effective) bid-ask spread, shown in Figure 1b, is as high as 3.5 (1.8) euro per 100 euro of face value, following the market-open, and steadily declines until 9:30, when it approaches its time-series median of 0.43 (0.12) euro per 100 euro of face value.[18] The bid-ask spread stays constant throughout the remaining trading hours, until the market-close at 17:30, when it spikes in the last five-minutes of trading, confirming the usual U-shape documented extensively in other markets.

[17] 34000 quote revisions/9.5 trading hours/3600second per hour = 0.99 quote update per second.

[18] See next Section for the time-series descriptive statistics

INSERT FIGURES 1 AND 2 HERE

The intraday behavior of the quote measures is graphed in Figure 2. Our data-set allows us to present, separately, the dynamics of the quoted quantity and the quantity quoted at the best bid- and ask-prices. As Figure 2a shows, *Number of Single Proposals* and *Total Bid and Ask Quantity* behave synchronously. The number of dealers, proxied by the *Number of Single Proposals*, grows from one at the market-open up to the time-series median of 18 at 10:00; symmetrically, the total quoted quantity grows from 10 million euro to its time-series median of 122. The *Number of Market Makers* and the *Total Quoted Quantity* are stable throughout the day, with a minor drop at 14:30, i.e., when the U.S. market opens, to then slowly diminish until the market-close at 17:30. We can link Figure 1b and Figure 2a, since the bid-ask spread at the beginning of the day seems to be highly dependent on the presence of the market-makers and the competition between them.

The plot of *Quoted Quantity at the Best Bid- and Ask-price*, in Figure 2b, highlights a different pattern. Primary dealers seem to be more willing to make markets quoting competitive bid- and ask-prices during the first hours of trading, particularly before 10:30. At 9:00, the best bid- and ask-quantities reaches 15 million euros, but then shrinks in the following 90 minutes, to reach steady levels around 10:30 lasting until the market-close. The best ask- (bid-) quantity settles at a 13 (11) million euro level, indicating the higher willingness of dealers to sell than to buy Italian sovereign bonds, on average.

V.III Time-series evolution of liquidity

Our sample period covers the most relevant period of the Euro-zone crisis, when the creditworthiness of several European countries was seriously questioned by market participants. As we will show later, the liquidity in the MTS market was intimately related to news events, as well as the evolution of the CDS market and varied just as drastically, as Figures 3 and 4 show. Table 4 presents the descriptive statistics of the time-series of liquidity and trading measures, while Figures 3 and 4 provide a graphical illustration.

Figure 3 reports the traded quantity and the number of trades in the first panel, the bid and ask quantity in the second panel and the number of single proposals in the last panel. *Traded quantity* and *Number of Trades* are very noisy measures; yet, there is a clear reduction at the beginning of the sample period (July 2011), and a relative increase around the turn of the year (December 2011), with a peak in March 2012. The daily traded quantity oscillates between the time-series minimum of 1 billion euro to the maximum of 7 billion euro; however, the mean daily traded quantity is around 2 billion euro, and on 18 days tops the 95th percentile of 4 billion euro. Similarly, the number of daily trades in Italian bonds, averaging at 278 trades a day, varies from a minimum of 43 to a maximum of above 800.

INSERT TABLE 4 AND FIGURE 3 AND 4 HERE,

The total quantities quoted on the bid- and ask-side of the market drastically diminished in July 2011 and stayed at these lower levels for the rest of our sample, with the possible exceptions of an even more drastic reduction in November and December, 2011, as shown in Figure 3b. Although these shifts are consistent with the other liquidity metrics, the *Total Quoted Quantity* stays between 93 and 153 million euro, the 5th and 95th percentile of its empirical distribution, 90% of the days in the sample (cf. Table 4).

There are, however, five dates when the total quoted quantity approaches its time-series minimum of 11 million euro. These dates are: i) 5st of July 2011, when fears of a Greek default and Portugal's downgrade triggered a sell-off of Spanish and Italian bonds, ii) 8th of August 2011, when the ECB sent a letter to Italian Prime Minister Silvio Berlusconi, demanding a detailed list of reforms, which the markets perceived as a signal of distress, iii) 19th of October, when Greek citizens marched on their parliament, iv) 8th of November 2011, following Silvio Berlusconi's resignation, v) 23rd of March 2012, when Spanish Prime Minister Rajoy announced a 40 billion euro spending cut.

Reductions in the *Total Quoted Quantity* correspond to reductions in the number of *Total Single Proposals*, which moved from a median of 18 to the time-series minimum of 1. The number of revisions (not plotted) mirrors the other measures of market-making, and varies from a minimum of 57 per single proposals to a maximum of 2762. Figure 4 shows the evolution of the quoted bid-ask spread. The connection between the reduction in quoted quantity and the quoted spread can be seen, for example, considering the highest spike (456bp), which happened on November, 8th, 2011. On this date, the Italian Prime Minister, Silvio Berlusconi, lost his majority in the Parliament, which led to his resignation, and corresponds to a downward spike in the *Total Quoted Quantity.* The event clearly had medium term effects, as the bid-spread level persisted around 100 bp for about two months, before returning to the time-series median value of 43bp in January 2012, after the LTRO program was launched in December 2011.

The second panel of Figure 4 shows the dynamics of two (il)liquidity measures: the Amihud measure, which mirrors fairly faithfully the behavior of the bid-ask spread, and the Roll measure. Changes in the Amihud measure, from a minimum of .25bp/million to a maximum of 28.60bp/million, are less dramatic than changes in the quoted bid-ask spread. This can be attributed to the fact that the Amihud measure originates from actual trading and thus, corresponds more directly to the effective spread. As far as the Roll measure is concerned, while it should be closely related to the bid-ask spread, assuming a "bid-ask bounce, 78% of buy (sell) trades follow a buy (sell) trades in the Italian sovereign bond market, thus making the Roll measure perform poorly by infringing its key assumption.

V.IV A case-study of liquidity changes around a macro-economic event

As an example of how fast, and to what extent, liquidity dried up during the Euro-zone crisis, we turn to the evolution of liquidity around a turning point of the Euro-zone crisis. Figure 5 shows the five-minute bid-ask spread during the three-day window around the Italian Prime Minister Berlusconi's resignation, from November 8^{th} to 10^{th}, 2011.

INSERT FIGURE 5 HERE

The announcement of Berlusconi's resignation was released in the evening of November 8, 2011. On November 9, the overall market bid-ask spread had an average of 4.46 euro per 100 of face value, versus a time series average for the whole sample of 0.43, representing the time-series maximum. The intraday dynamics show that the situation degenerated considerably in the afternoon, when the bid-ask spread reached, for a prolonged time, a peak at 9 euros of bid ask spread per 100 of face value, i.e., an unimaginable, 10% bid-ask spread. This indicates the dealers' extreme requirements for a trade to take place. The peak in the spread followed a peak in the *Total Quoted Quantity.*

Figure 5b shows this quite clearly. On November 8th, the market-wide quoted quantity was very close to its time series minimum of 11. The situation improved the following day; however, dealers quoted an ask-quantity much higher than the bid-quantity, thus expressing to the market a willingness to sell much higher than their willingness to buy Italian sovereign bonds. On November 10th, the market improved dramatically compared to the previous day, the bid-ask spread narrowed, and dealers quoted an average total quantity of 70, far from the time-series minimum of 11.

VI Liquidity Effects During the Euro-zone Crisis

VI.I Cross sections

In this section, we estimate cross-section regressions to study the drivers of liquidity. Specifically, we explore whether each of our defined liquidity measures can be explained by product characteristics and trading activity variables. We estimate cross-sectional regressions where we use time-series averages of all variables. We analyze coupon-bearing bonds and non-coupon-bearing bonds separately, according to the following regressions:

$$\begin{aligned}
\text{Coupon: } LM_i =& \beta_0 + \beta_1 Age_i + \beta_2 AmountIssued_i + \beta_3 NTrades_i + \\
&+\beta_4 CouponRate_i + \beta_{5-8} DurationGroupDummies_i \\
&+\beta_9 \frac{Time\ to\ Maturity}{Maturity}_i + \beta_{10}\left(\frac{Time\ to\ Maturity}{Maturity}_i\right)^2 + \epsilon_i \qquad (1)\\
\text{Non Coupon: } LM_i =& \beta_0 + \beta_1 Age_i + \beta_2 AmountIssued_i + \beta_3 NTrades_i \qquad (2)\\
&+\beta_{4-7} DurationGroupDummies_i + \\
&+(\beta_8 AmountIssued_i + \beta_9 NTrades_i) \cdot FDummy_i \\
&+\beta_{10} \frac{Time\ to\ Maturity}{Maturity}_i + \beta_{11}\left(\frac{Time\ to\ Maturity}{Maturity}_i\right)^2 + \epsilon_i
\end{aligned}$$

where the variables are as defined as in Section III and $FDummy_i$ equals one when bond i is a floating-rate bond and zero otherwise.

LM_i is the ith liquidity measures. Our proxies for liquidity are: *Quoted Bid-Ask Spread*, *Effective Spread*, *Roll Measure*, *Amihud Measure*, *Depth* (Total and Best Quotes), *Quote Revisions*, *Total Single Proposals* and *Return Volatility*. The explanatory variables are the ratio of *Time to Maturity* and *Maturity*, *Amount Issued*, *Number of Trades*, and *Coupon Rate*, as presented in Section III. The results for the coupon-bearing bonds from equation 1 are presented in Table 5 Panel A, while the results for non-coupon bearing bonds, as per equation 2, are presented in Table5 Panel B.

INSERT TABLE 5 HERE

As far as coupon bonds are concerned, the two spread measures (quoted and effective spread) show similar results. The relationship between the *Time to Maturity* (or, conversely, *Age*) of the bond is highly non-linear. As shown in Figure 6, which plots the averages for the sample of 59 coupon-bearing bonds of the bid-ask spread and the time to maturity, it is clear that, within the same duration group, bonds that are on-the-run and bonds that are close-to-maturity have the lowest bid-ask spread, while those in their "mid-life" have higher spreads, an inverted U-shaped pattern.

INSERT FIGURE 6 HERE

In our estimations, we include the ratio of time-to-maturity to maturity and its square. The coefficients are both significant, and the signs clearly confirm the initial conjecture from the graphs. The parameters imply that the spread increases from the issue day and reaches its maximum at one-fourth of the total maturity, then declines as the maturity date approaches. Since the base case is the 3-year maturity group, the duration dummies (5yGroup to 30yGroup) show the positive relationship between spread and maturity. The number of trades has a negative sign, meaning that the larger the trading activity, the smaller the spread.

Darbha and Dufour (2012) find, for the period January 2004-July 2010, that the more recently issued bonds with larger issue sizes have a smaller bid-ask spread, which we also confirm for our sample period, June 2011-November 2012. On the other hand, longer duration bonds (as measured by the dummies) have larger spreads. This is consistent with what Dufour and Nguyen (2012), and Darbha and Dufour (2012) find, and Goyenko et al. (2011) report for US Treasury bonds. Darbha and Dufour (2012) suggest that, during the period August 2007- July 2010, prior to the Euro-zone crisis, investors shift funds into short-term bonds. Regarding depth, total quoted quantity and quantity at best quotes, it is larger for on-the-run and close-to-maturity, larger bonds. Longer maturity affects negatively depth measures. This explains why the Amihud measure (market impact) is higher for longer maturity bonds.

For market making activities, *Contemporaneous Single Proposals* is the average number of dealers measured at a five-minute frequency and average revision is how often quotes change. The results indicate market-making activity is higher for bonds with a longer maturity. Market-making activity follows a convex relationship with time-to-maturity, mirroring the results for the bid-ask spread, with a larger number of dealers for on-the-run and close-to-maturity bonds. The number of trades positively affects the number of market-makers, but negatively affects the number of quote revisions. We will return to this issue in the sub-section VI.II

The cross-sectional regressions for floating-rate and zero-coupon bonds yield similar results to those for coupon bonds. The only case in which we observe a sign opposite to what we expect is the relation between the number of single proposals and the number of trades, which is negative in case of non-coupon bonds. The coefficients of the dummy variable for floating rate bonds are positive for quoted spread, effective spread and Amihud. It means that floating-rate bonds have lower liquidity than zero-coupon bonds. Surprisingly, the issued amount is never significant in any of these regressions.

It should be noted that the non-linear relationship between the relative time to maturity and the number of revisions is valid for zero-coupon-bonds. The same relationship for the number of single proposals, which was significant for coupon-bearing bonds, fails when zero coupon bonds are considered.

The Roll measure estimates the bid-ask bounce which is an approximation of effective spread. Although the Roll measure should have similar results to those for the effective spread, the number of trades is the only variable that is consistent with his conjecture. These results for the Roll measure are somewhat puzzling, but as we discussed above, a buy(sell) order follows a next buy(sell) in the 78% of trades, which violates the crucial assumption needed for the Roll measure to proxy for the bid-ask spread.

The Amihud measure has a negative relation with age and the number of trades, and a positive relation with maturity. The results are consistent with those for the quoted and effective spreads. The volatility of quote changes (Log Var) yields results similar to those for the Amihud measure, while lacking statistical significance.

VI.II Time series

Having established whether each of our defined liquidity measure can be explained cross-sectionally by product characteristics and trading activity variables, we turn our attention to examining the dynamics through time of these liquidity measures and how this evolution is related to changes in credit risk measured through the CDS and to the traded quantity. More specifically, we investigate if the relationship between liquidity measures and credit risk is linear or is characterized by some convexity effects, that is large changes in the credit risk have a proportionally larger impact than small changes on the various liquidity measures. To investigate this, we regress the changes of the different liquidity measures on the changes in the CDS spread, its square and the traded quantity. Equation 3 details our regression model:

$$\Delta LM_t = \beta_0 + \beta_1 \Delta CDS_t + \beta_2 \left(\Delta CDS_t\right)^2 + \beta_3 TradedQuantity_t + \epsilon_t \tag{3}$$

where ΔLM_t is the change in the liquidity measure from time $t-1$ and time t, ΔCDS_t is the change in the CDS and $TradedQuantity_t$ is the quantity traded in the market on that day. We estimate the regression in Equation 3 for nine different liquidity measures and the results are reported in Table 6.

Table 6 shows that the regression model significant explanatory power for several variables with an R^2 in the case of the effective spread equal to 0.1257. Consistent with our intuition, we find that both the quoted spread and the effective spread are strongly related to the CDS variable. Both the change in the CDS spread and the square of the change in the CDS spread are positive and statistically significant at the 1% level. The magnitude of the coefficient suggests that a 100 basis point credit differential is associated with an increase of the quoted spread of 31 basis points, based on the linear factor, but the convexity effect would increase this impact by another 100 basis points: this implies that on average, an increase of 100bp in the CDS spread generates an increase of the quoted bid-ask spread of 131bp.

INSERT TABLE 6 HERE

The effect is also significant but with a lower magnitude for the effective spread. The change on the CDS spread is also significantly related to the Amihud measure. The traded quantity is related negatively only to the effective spread at 1% level and is not related to the quoted spread. This is possibly due to the endogeneity of the trading decision in relation to the quoted spread.

The traded quantity is also positively related to the revisions per single proposal and Log Var, but negatively to the total quantity. We interpret this to indicate that when more informed traders come to the market, market makers are less willing to take the opposite side. Usually, a large traded quantity is associated with large price swings, which corresponds to the result that quote volatility (Log Var) has a positive correlation with traded quantity.

The number of single proposals is negatively related to the number of trades for zero coupon bonds and positively for coupon bearing bonds, both in a univariate and multivariate sense. If the sample is not split into two, the two effects approximately cancel out. We see this in the time series where number of trades is not significant.

Since we found a positive association (in the changes) between revisions per single proposal and number of trades in our time-series analysis in this section, the negative relation (in levels) found between quote revisions and the number of trades in the cross sectional analysis in the previous section is puzzling. The scatter graph Figure 7 shows the cross-sectional relation between revisions and the number of trades. The distribution is bi-modal or U-shaped. Bonds with up to four average daily trades show a negative relation between quote revisions and the number of trades. It suggests that market makers are making markets (frequency of quotes revision) even in bonds for which the market does not have a high trading interest. Those are mostly 15-year and 30-year bonds. 3-year and 5-year bonds are almost flat, meaning the average revision is approximately constant, while the number of trades varies.

The only bonds showing a positive association between number of trades and the frequency of quotes are those with a 10-year maturity. This means that dealer activity differs across maturity groups. This can be interpreted as a reflection during the stress period of the primary dealer's obligation to make markets even under stressed conditions. Although market-maker obligations were relaxed after 2007, MTS monitors the average quoting times and average spreads, which must be in line with market averages computed across all dealers. Regardless of the relaxation of the obligations, dealers are still required to maintain reasonable market-making activity. Hence, market-makers post two-sided quotes while keeping market-making risk as small as possible. This is a special feature that the sovereign bond market exhibits, even under stressed conditions, as a result of regulation.

VI.III Granger Causality:

In the previous regression analysis, we show that there is a relationship between changes in the liquidity measures and changes in the CDS spread. However, this analysis does not indicate if it is the increase of credit risk that drives the reduction of liquidity in the bond market or vice-versa, i.e., if the low liquidity in the bond market increases the CDS spread. Which of the two markets contributes most to the other is a question that we attempt to resolve using a simple Granger causality test, i.e., a statistical notion of causality based on the relative forecasting power of two time-series: Time series j is said to "Granger-cause" time series i if past values of j contain information that helps predict i above and beyond the information contained in past values of i alone. The mathematical formulation of this test is based on linear regressions of ΔLM_{t+1} on ΔLM_t and ΔCDS_t.

Specifically, let ΔLM_t and ΔCDS_t be two stationary time series. We can represent their linear inter-relationships with the following model:

$$\Delta LM_{t+1} = k_{LM} + \sum_{i=0}^{N} a_i^{LM} \Delta LM_{t-i} + \sum_{j=0}^{M} b_j^{LM} \Delta CDS_{t-j} + e_{t+1}^{LM}$$

$$\Delta CDS_{t+1} = k_{CDS} + \sum_{i=0}^{N} a_i^{CDS} \Delta CDS_{t-i} + \sum_{j=0}^{M} b_j^{CDS} \Delta LM_{t-j} + e_{t+1}^{CDS} ,$$

where e_{t+1}^{LM} and e_{t+1}^{CDS} are two uncorrelated white noise processes, and $a_i^{LM}, a_i^{CDS}, b_j^{LM}, b_j^{CDS}$ are coefficients of the model. Then, ΔCDS Granger-causes ΔLM when the b_j^{LM}a are different from zero. Similarly, ΔLM Granger-causes ΔCDS when the b_j^{CDS}s are different from zero. When both of these statements are true, there is a feedback relationship between the time series.[19]

The results of the Granger causality test are reported in Table 7. As the table shows, considering the whole sample, CDS spreads Granger cause liquidity in the bond market. Indeed, for almost all

[19] We use the "Bayesian Information Criterion" (BIC; see Schwarz, 1978) as the model-selection criterion for determining the number of lags in our analysis. Moreover, we perform F-tests of the null hypotheses that the coefficients $\{b_j^{LM}\}$ or $\{b_j^{CDS}\}$ (depending on the direction of Granger causality under consideration) are equal to zero.

the liquidity variables considered, b_j^{LM} is statistically different than zero at the 1% level. However, this result is not robust. If we split the sample in two parts: before and after the introduction of the LTRO with a long maturity and the effort made by the ECB "to save the Euro" and therefore to reduce the spread, the results are fairly different.

INSERT TABLE 7 HERE

In the first sub-sample we show that credit risk is indeed the driver of liquidity in the bond market, and an increase of the CDS reduces drastically the liquidity in the market. However, after December 2011, the opposite is true: the presence of market makers and the quoted quantity Granger causes the changes in the CDS. Although we cannot reject the hypothesis that CDS is no longer influencing liquidity measures in the second part of our sample.

A potential interpretation of this result is that the ECB could not change the solvency level of a State but by increasing the liquidity (or decreasing the "illiquidity") in the bond market through the LTRO was able to reduce its credit perception as measured by the sovereign CDS spread. Thus, the intervention not only vastly improved the liquidity of the Italian sovereign debt market, but also substantially decreased credit risk, suggesting that the intervention was successful in meeting its objectives, at least in the near-term. This result has several policy implications. First, by improving liquidity in the bond market, the ECB could indirectly ameliorate credit risk in the medium and long maturity bond and credit derivatives market. Second, the presence of a liquid and transparent electronic market is extremely important for the management of government bonds not only in terms of liquidity but also in terms of bond issuance costs, mostly during periods of distress. Finally, it shows how relevant the LTRO is in terms of market microstructure, i.e., order flows, order submission, especially under conditions of stress.

VII Conclusion

The Euro-zone sovereign debt crisis has been the most important development in the global economy over the course of the past three years. At its heart, the crisis stems from both liquidity and credit risk concerns in the market and led to a sharp spike in sovereign bond yields in the periphery and even threatened the core of the Euro-zone by late 2011. It was only after the launch of the LTRO program, and even more so after Mario Draghi's "whatever it takes" comment in July 2012, and the subsequent OMT program that was launched, that the markets alarm diminished, and sovereign bond yields dropped to sustainable levels in most countries by late 2012. Hence, there is no doubt that the ECB programs were a crucial factor in at least partially abating the crisis, although it is still an open issue as to whether the fundamental programs of the Euro-zone have been addressed. The question is how the effects of the crisis and the subsequent partial reversal as a consequence of central bank and fiscal actions got transmitted to the level of individual bonds and the interaction between illiquidity and credit risk played out.

This paper examines the role of the microstructure of the Euro-zone sovereign debt market using a unique, tick-by-tick data set obtained from MTS, the worlds largest trading platform for sovereign bonds, that allows us to track the individual orders of dealers and follow them over the course of the trading day. Our analysis of the Italian sovereign debt market permits us to analyze liquidity in the sovereign debt market at the micro-level and study the role of macro-economic events and central bank actions. In particular, we study the interaction between credit risk and illiquidity to conclude that the crisis began with a spike in credit risk being transmitted into unprecedented levels of illiquidity.

We argue that under stressful circumstances, dealers reduce their provision of liquidity to the market. This, in turn, accelerates the drop of prices and the spike in bond yields, causing deep losses in the asset values of banks and investors holding the sovereign bonds. Through a variety of channels, the holders of sovereign bonds reduce their risk- taking, exacerbating the problem and creating a negative feedback loop.

Our analysis of liquidity, using a range of metrics to measure it at the bond level, indicates that 15- and 30-year bonds showed the widest bid-ask spread under the stressed conditions, but 10-year bonds exhibited a relatively tight spread, suggesting that that market makers differentiate between bonds of different maturities when illiquidity takes hold in the market. However, illiquid bonds have a contagion effect on the whole market and cause a worsening of illiquidity in the broader market. We also document that under conditions of stress, frequent quote revisions do not necessarily translate into higher liquidity, even when obligations are imposed to market makers. This leads to erratic market-making behavior that can be detected only through the analysis of liquidity metrics such as the effective spread.

Our Granger causality tests to investigate whether liquidity risk is driving credit risk or vice versa show that prior to the introduction on December 2011 of the LTRO by the ECB, credit risk was exacerbating the illiquidity of the Italian sovereign bond market. Subsequently, the causality reversed, in that the improvement in liquidity (or the reduction in illiquidity) in the government bond market helped to significantly reduce the credit risk premium. Thus, the intervention not only vastly improved the liquidity of the market, but also substantially decreased credit risk, suggesting that the intervention was successful in meeting its objectives, at least in the near-term.

Our results are of interest to both the Euro-zone national Treasuries and the ECB to identify the segments of the market in which to intervene so that the reduction of the spread on a single maturity would most benefit bonds with other maturities of the same country and several other countries, so as to achieve the optimal impact of open market operations. Our analysis could be employed by market regulators (the national central banks) to address issues related to transparency in the organization of Treasury markets and the timely disclosure of information, as well as evaluating the performance of individual primary dealers.

In future research, we plan to extend our analysis to all Euro-zone markets to study the effects of contagion across markets and also investigate how the liquidity effects vary across countries. We also hope to extend our data set into the subsequent period to conduct an event study of the effect of macro-economic announcements and central bank actions on liquidity.

VIII Tables

Table 1: This table presents the distribution of 148 Italian government bonds in terms of maturity and coupon rate, between maturity groups as well as bond types. Maturity groups were determined by the time distance between bond maturities and the closest round year. The large majority in terms of numbers are short maturity (from 0 to 5 years).

Maturity Group	# Bonds	Coupon Rate	Maturity	MinMaturity	MaxMaturity
0.25	9	[a]	0.27	0.21	0.36
0.50	24	[a]	0.51	0.39	0.53
1.00	32	[a]	1.01	0.83	1.03
2.00	11	[b]	2.02	2.01	2.09
3.00	10	3.20	2.99	2.93	3.02
5.00	13	3.87	5.03	4.92	5.25
6.00	13	[c]	6.70	5.29	7.09
10.00	19	4.44	10.41	10.10	10.51
15.00	7	4.57	15.71	15.44	16.00
30.00	10	5.88	30.88	30	31.79
Bond Type	**N**	**Coupon Rate**	**Maturity**	**MinMaturity**	**MaxMaturity**
BOT	65	ZCB	0.73	0.21	1.03
BTP	59	4.36	12.06	2.93	31.79
CCT	13	Floating	6.70	5.29	7.09
CTZ	11	ZCB	2.02	2.01	2.09

[a] All bonds in this group are BOT, Buoni Ordinari del Tesoro (Treasury Bills)
[b] All bonds in this group are CTZ, Certificati del Tesozo Zero-coupon (Zero Coupon Bond)
[c] All bonds in this group are CCT, Certificati di Credito del Tesoro (Floating Bonds)

Table 2: This table presents the cross-sectional distribution of selected descriptive statistics for the 148 Italian bonds listed on the MTS market between June 2011 and November 2012. Coupon rate, amount issued (in B€) and maturity are time-invariant bond characteristics. Age is the average of the age throughout the sample. Traded quantity, number of trades and orders, and fill ratio are statistics covering the whole sample. Fill ratio is the percentage of orders that were at least partially filled. Trading days and sample days are the number of days the bond was respectively traded and present in the sample. Daily trades, daily orders and daily traded quantity are averaged through the days the bond is in the sample.

Variable	# Bonds	Mean	STD	Min	5^{th} Pct	25^{th} Pct	Median	75^{th}	95^{th} Pct	Max
Coupon Rate	59[a]	4.36	1.21	2.00	2.25	3.75	4.25	5.00	6.50	9.00
Amount Issued (B€)	148	14	7	3	4	8	12	18	26	30
Maturity (year)	148	5.87	7.96	0.21	0.27	1.02	2.02	7.08	30.00	31.79
Age (year)	148	2.38	3.46	0.01	0.09	0.26	0.73	2.91	10.07	18.32
Traded Quantity (B€)	148	5.37	3.75	0.56	0.87	2.68	4.58	7.40	12.00	22.53
Trades	148	705	577	38	97	311	516	951	1,822	3,359
Orders	148	849	736	38	103	341	618	1,153	2,472	3,777
Fill Ratio (% Orders)	148	87%	0.09	40%	72%	84%	88%	93%	95%	100%
Trading Days	148	135	85	5	17	68	118	215	286	306
Sample Days	148	229	133	5	29	110	221	377	377	377
Daily Trades	148	4.05	4.51	0.26	0.79	2.11	2.79	4.50	10.23	44.60
Daily Orders	148	4.71	4.94	0.29	0.84	2.44	3.27	5.12	10.85	47.60
Daily Quantity (M€)	148	34	33	1	4	17	26	41	85	323

[a] The sample includes 59 coupon bearing bonds and 89 between floating rate and zero-coupon bonds.

Table 3: This table shows the cross-sectional distribution of the liquidity measures. The sample consists of the 148 italian bonds listed on the MTS market between June 2011 and November 2012. Every bond contributes with one observation, namely the time-series average of the trading or liquidity measure. Daily revisions is the amount of daily quote revisions, in thousands. Total single proposals is the amount of single proposal throughout the day. Contemporaneous Single Proposals measur the number of single proposals standing at a 5 minutes frequency. Revisions per single proposal is given by daily revisions divided by total single proposals. Total quoted quantity is espressed in milions of euro of face value. Best bid (ask) proposals measures is the number of single proposals quoting the best bid (ask) price contemporaneously, sampled at a 5 minutes frequency. All variables are described in detail in Section IV.

Variable	# Bonds	Mean	STD	Min	5^{th} Pct	25^{th} Pct	Median	75^{th}	95^{th} Pct	Max
Daily Revisions (m)	148	34	21	3	10	22	28	40	77	108
Total Single Proposals	148	49	86	21	23	24	27	32	144	706
Contemporaneous SP	148	17	2	13	14	16	17	18	20	22
Revision per SP	148	1,248	672	121	395	775	1,076	1,510	2,682	3,319
Total Quoted Quantity (M€)	148	127	46	69	77	114	123	133	169	524
Best Bid Proposals	148	1.5	0.2	1.1	1.2	1.3	1.4	1.6	1.9	2.0
Best Ask Proposals	148	1.5	0.2	1.2	1.2	1.3	1.4	1.7	2.0	2.2
Best Quantity (M€)	148	14	12	6	7	10	12	13	25	124
Bid Ask Spread (€)	148	0.37	0.362	0.001	0.022	0.091	0.25	0.44	1.26	1.47
Bid Ask Spread(9-17)(€)	148	0.31	0.313	0.001	0.019	0.081	0.21	0.36	1.08	1.30
Effective Spread (M€)	148	0.13	0.140	0.001	0.008	0.030	0.08	0.16	0.51	0.63
Return Variance(x10^6)	148	1.28	3.416	0.000	0.000	0.020	0.23	1.08	3.79	23.45
Log Var (%)	148	-16.10	3.20	-27.60	-21.70	-17.70	-15.30	-13.70	-12.50	-10.70
Amihud (bp/1M€)	148	2.71	4.023	0.001	0.025	0.213	0.82	3.15	12.98	18.37
Roll (%)	148	0.57	0.250	0.000	0.220	0.390	0.55	0.69	1.05	1.34

[a] All bonds in this group are BOT or CTZ

Table 4: This table shows the time series distribution of trading, quoting, and liquidity measures. The sample consists on the 377 days present in our sample. Each day participates with a cross-sectional (across bonds) average. However, traded bonds is the number of bonds actually traded on each day, trades it the total number of trades on the day, traded quantity is the amount exchanged market-wide on a specific day.

Variable	# Days	Mean	STD	Min	5^{th} Pct	25^{th} Pct	Median	75^{th}	95^{th} Pct	Max
Traded Bonds	377	54	11	16	35	48	55	61	71	79
Trades	377	278	116	43	114	201	260	345	494	837
Traded Quantity (B€)	377	2	1	0	1	1	2	3	4	7
Total Revision (m)	377	40	11	1	24	32	38	48	61	70
Single Proposals	377	53	118	11	24	27	28	30	161	1060
Contemporaneous SP	377	17	3	2	13	16	18	19	20	21
Revisions per SP	377	1446	463	57	834	1118	1332	1764	2304	2762
Total Quoted Quantity (M€)	377	121	21	11	93	112	122	132	153	182
Best Bid Proposals	377	1.50	0.20	1.00	1.20	1.40	1.50	1.70	1.80	2.00
Best Ask Proposals	377	1.60	0.20	1.00	1.20	1.40	1.50	1.70	1.90	2.00
Best Quantity (M€)	377	12.00	2.00	7.00	9.00	11.00	12.00	13.00	16.00	20.00
Bid Ask Spread (M€)	377	0.53	0.380	0.131	0.179	0.34	0.43	0.56	1.25	4.46
Bid Ask Spread(9-17)(M€)	377	0.45	0.367	0.115	0.137	0.27	0.35	0.49	1.07	4.51
Effective Spread	377	0.15	0.093	0.031	0.057	0.09	0.12	0.18	0.33	0.71
Return Variance(x10^6)	377	1.99	13.57	0.03	0.07	0.17	0.34	0.88	4.27	248.84
Log Var (%)	377	−0.90	1.30	−3.40	−2.60	−1.80	−1.10	−0.10	1.50	5.50
Amihud (bp/1M€)	375	3.49	3.720	0.250	0.560	1.33	2.23	4.39	9.77	28.60
Roll	377	0.51	0.11	0.22	0.33	0.44	0.52	0.58	0.68	1.09
CDS Spread (bp)	377	407	105	147	179	342	427	490	550	587
ΔCDS	377	0.27	16.53	−51.77	−24.27	−8.28	0.25	8.68	25.67	77.53

Table 5: This Panel presents the result from the cross-sectional regression (eq. 1) of time-averaged liquidity measures on bond characteristics and number of trades. The sample consists in 59 Italian coupon bearing bonds, quoted on the MTS market between June 2011 and November 2012. T-statistics in panel A are reported in parenthesis. R^2 is reported below the parameters estimates.

Panel A. Subsample: Coupon Bearing Bonds

Variable	Quoted Spread	Effective Spread	Revision per SP	SingleProp 5 Min	Qty Best	Total Qty	Log Var	Amihud Measure	Roll Measure
Intercept	0.324 **	0.089 **	1263.63 ***	15.178 ***	16.107 ***	153.287 ***	−15.246 ***	−0.609	1.036 ***
	(2.64)	(2.22)	(3.18)	(18.04)	(2.86)	(7.59)	(−16.76)	(−0.43)	(4.91)
AmountIssued	−0.009 **	−0.003 **	−22.528	−0.027	0.395 *	1.21 *	0.053	0.088 *	−0.009
	(−2.08)	(−2.17)	(−1.61)	(−0.91)	(2)	(1.7)	(1.67)	(1.75)	(−1.15)
NTrades	−0.031 ***	−0.009 ***	−67.116 ***	0.129 ***	−0.148	−1.183	−0.131 ***	−0.327 ***	−0.028 **
	(−5.05)	(−4.7)	(−3.43)	(3.12)	(−0.53)	(−1.19)	(−2.92)	(−4.66)	(−2.68)
CouponRate	0.017	0.009	35.367	0.097	0.678	1.827	0.155	−0.245	−0.023
	(1.03)	(1.63)	(0.65)	(0.83)	(0.88)	(0.66)	(1.24)	(−1.25)	(−0.78)
5yGroup	0.049	0.027 *	−5.009	0.445	−2.046	−3.624	−0.458	0.509	−0.06
	(1.19)	(2)	(−0.04)	(1.56)	(−1.07)	(−0.53)	(−1.48)	(1.05)	(−0.83)
10yGroup	0.171 ***	0.071 ***	601.383 ***	1.016 **	−4.482	−13.949	−0.714	1.488 **	0.038
	(2.73)	(3.47)	(2.97)	(2.37)	(−1.56)	(−1.35)	(−1.54)	(2.05)	(0.35)
15yGroup	0.366 ***	0.133 ***	922.097 ***	0.845 *	−4.926	−27.789 **	0.083	4.587 ***	0.028
	(5.12)	(5.67)	(3.98)	(1.72)	(−1.5)	(−2.36)	(0.16)	(5.53)	(0.23)
30yGroup	0.775 ***	0.346 ***	1503.565 ***	−0.008	−7.039 *	−52.849 ***	0.208	11.174 ***	0.146
	(9.53)	(12.98)	(5.71)	(−0.01)	(−1.89)	(−3.95)	(0.34)	(11.85)	(1.04)
TTM/Maturity	0.893 ***	0.311 ***	−2.288	7.101 ***	−46.499 ***	−170.91 ***	−0.145	7.154 **	−0.481
	(3.86)	(4.1)	(0)	(4.48)	(−4.39)	(−4.49)	(−0.08)	(2.67)	(−1.21)
$(\text{TTM/Maturity})^2$	−0.601 **	−0.219 ***	951.319	−4.392 ***	37.823 ***	134.731 ***	1.377	−1.929	0.226
	(−2.68)	(−2.98)	(1.31)	(−2.85)	(3.67)	(3.64)	(0.83)	(−0.74)	(0.58)
R^2	0.946	0.965	0.868	0.742	0.453	0.692	0.585	0.959	0.506
N	59	59	59	59	59	59	59	59	59

* Significant at a 10% level, ** Significant at a 5% level, *** Significant at a 1% level.

Table 5: (continued) Panel B presents the result from the cross-sectional regression (eq. 2) of time-averaged liquidity measures on bond characteristics and number of trades. The sample consists in 89 Italian zero coupon and floating rate bonds, quoted on the MTS market between June 2011 and November 2012. T-statistics are reported in parenthesis. R^2 is reported below the parameters estimates.

Panel B. Subsample: Non-Coupon Bearing Bonds									
Variable	Quoted Spread	Effective Spread	Revision per SP	SingleProp 5 Min	Qty Best	Total Qty	Log Var	Amihud Measure	Roll Measure
Intercept	−0.246 ***	−0.07 ***	−341.528 *	12.687 ***	39.13 ***	206.577 ***	−27.894 ***	−1.352 **	0.916 ***
	(−3.79)	(−3.26)	(−1.89)	(26.67)	(4.82)	(7.5)	(−32.94)	(−2.04)	(5.69)
AmountIssued	−0.005	−0.002	10.116	0.076	0.053	1.528	0.053	−0.043	0.008
	(−0.65)	(−0.84)	(0.43)	(1.23)	(0.05)	(0.43)	(0.48)	(−0.49)	(0.38)
NTrades	−0.003	−0.001	12.413	−0.091 ***	−0.338	−1.039	0.016	−0.04	−0.011
	(−0.9)	(−1.21)	(1.46)	(−4.08)	(−0.89)	(−0.8)	(0.4)	(−1.3)	(−1.45)
Float6Y	1.343 ***	0.69 ***	87.748	−1.116	−26.112	−204.627 ***	5.812 ***	9.504 ***	0.431
	(9.05)	(13.97)	(0.21)	(−1.03)	(−1.41)	(−3.25)	(3.01)	(6.27)	(1.17)
ZCB.5Y	0.066	0.025	−80.987	1.091 **	0.235	5.602	0.978	0.388	−0.038
	(1.13)	(1.3)	(−0.5)	(2.57)	(0.03)	(0.23)	(1.29)	(0.65)	(−0.26)
ZCB1y	0.158 ***	0.056 ***	272.061 **	1.624 ***	−3.33	−2.63	2.875 ***	0.676	−0.222 *
	(3.32)	(3.54)	(2.06)	(4.66)	(−0.56)	(−0.13)	(4.63)	(1.39)	(−1.89)
ZCB2y	0.325 ***	0.103 ***	713.997 ***	1.668 ***	11.373	16.294	5.941 ***	1.448 *	−0.209
	(3.83)	(3.64)	(3.03)	(2.69)	(1.07)	(0.45)	(5.38)	(1.67)	(−1)
Float6y*AmountIsued	−0.03 **	−0.021 ***	−22.82	0.068	1.112	8.976 *	0.091	−0.155	−0.04
	(−2.48)	(−5.09)	(−0.67)	(0.76)	(0.73)	(1.73)	(0.57)	(−1.25)	(−1.32)
Float6y*NTrades	−0.086 ***	−0.071 ***	162.898 **	−0.032	3.349	32.459 ***	0.483	−1.063 ***	−0.097
	(−3.11)	(−7.69)	(2.13)	(−0.16)	(0.97)	(2.78)	(1.34)	(−3.77)	(−1.41)
TTM/Maturity	1.103 ***	0.338 ***	4729.05 ***	3.21 **	−86.004 ***	−288.408 ***	27.205 ***	4.617 **	−0.404
	(5.76)	(5.3)	(8.89)	(2.29)	(−3.59)	(−3.56)	(10.91)	(2.36)	(−0.85)
$(\text{TTM/Maturity})^2$	−0.827 ***	−0.251 ***	−4348.713 ***	1.238	64.261 **	189.216 **	−22.378 ***	−2.192	0.154
	(−3.9)	(−3.56)	(−7.39)	(0.8)	(2.43)	(2.11)	(−8.11)	(−1.01)	(0.29)
R^2	0.872	0.894	0.66	0.76	0.435	0.51	0.862	0.778	0.277
N	89	89	89	89	89	89	89	89	89

* Significant at a 10% level, ** Significant at a 5% level, *** Significant at a 1% level.

Table 6: This table presents the results from the time series regression of changes in liquidity levels on changes in the CDS spread, its square and the level of trading activity. 376 days participate to the estimation, due to the differencing. Heteroskedasticity-robust T-test statistics are reported under the parameters.

Variable	Quoted Spread	Effective Spread	Revision per SP	SingleProp 5 Min	Qty Best	Total Qty	Log Var	Amihud Measure	Roll Measure
Intercept	−0.0322**	−0.0065**	−0.8655	0.1351	0.0321	0.7061	−0.108	−0.2767	0.0008
	(−2.22)	(−2.12)	(−0.05)	(0.82)	(0.32)	(0.62)	(−1.64)	(−1.28)	(0.16)
CDS	0.0031**	0.0007**	−0.3492	−0.0157**	−0.0023	−0.1089**	0.0045	0.0362*	0.0001
	(2.01)	(2.14)	(−0.45)	(−2.21)	(−0.42)	(−2.36)	(1.1)	(1.85)	(0.47)
CDS^2	0.0001*	0**	0.0065	−0.0005**	−0.0002	−0.003**	0.0004***	0.001	0
	(1.81)	(2.07)	(0.27)	(−2.48)	(−1.12)	(−2.22)	(3.15)	(1.4)	(−0.92)
TradedQuantity	−0.0207**	−0.0123***	46.0991***	−0.2357	−0.1271	−2.1274*	0.1296**	0.0668	0.0086**
	(−2.14)	(−4.61)	(3.51)	(−1.46)	(−1.25)	(−1.91)	(2.49)	(0.4)	(2.41)
R^2	0.1124	0.1257	0.0234	0.0232	0.0081	0.0254	0.0463	0.0444	0.0165
N	376	376	376	376	376	376	376	376	376

* Significant at a 10% level, ** Significant at a 5% level, *** Significant at a 1% level.

Table 7: This table presents the results of the Granger-causality test. A VAR(p) is fitted for every period/variables combination. The variables are the changes in CDS and in the trading, quoting, and liquidity measures. The number of lags is determined considering minimization of the AICC and ensuring non-autocorrelation in the residuals. The null hypothesis is that the p cross elements linking for var1 on var2's p lags are contemporaneously equal to 0. Rejecting the null hypothesis means that Var2 Granger-causes Var1 in the sample period considered. The estimation has been conducted on the overall sample, until November 2011, and since Janruary 12. Such sample partitioning allows us to verify whether LTRO announcement and introduction caused a shift in Granger causality between the CDS and the liquidity measures.

Sample	Var 1 Caused by Var 2		Lags(p)	Test Value	P-Value
All	CDS	Bid Ask Spread	6	16.16	0.0129 **
All	Bid Ask Spread	CDS	6	22.64	0.0009 ***
Until November 2011	CDS	Bid Ask Spread	6	12.42	0.0532 *
Until November 2011	Bid Ask Spread	CDS	6	19.97	0.0028 ***
From January 2012	CDS	Bid Ask Spread	6	8.04	0.2350
From January 2012	Bid Ask Spread	CDS	6	4.42	0.6200
All	CDS	Effective Spread	3	6.35	0.0956 *
All	Effective Spread	CDS	3	11.56	0.0091 ***
Until November 2011	CDS	Effective Spread	3	6.62	0.0852 *
Until November 2011	Effective Spread	CDS	3	7.90	0.0480 **
From January 2012	CDS	Effective Spread	3	3.15	0.3684
From January 2012	Effective Spread	CDS	3	1.52	0.6772
All	CDS	Revision per SP	4	5.08	0.2792
All	Revision per SP	CDS	4	7.59	0.1080
Until November 2011	CDS	Revision per SP	4	7.06	0.1328
Until November 2011	Revision per SP	CDS	4	5.68	0.2243
From January 2012	CDS	Revision per SP	4	3.16	0.5312
From January 2012	Revision per SP	CDS	4	9.74	0.0451 **
All	CDS	Single Proposals (5min)	4	8.95	0.0625 *
All	Single Proposals (5min)	CDS	4	1.74	0.7829
Until November 2011	CDS	Single Proposals (5min)	4	4.82	0.3063
Until November 2011	Single Proposals (5min)	CDS	4	1.99	0.7380
From January 2012	CDS	Single Proposals (5min)	4	10.40	0.0342 **
From January 2012	Single Proposals (5min)	CDS	4	1.10	0.8942
All	CDS	Quantity at Best	3	2.14	0.5432
All	Quantity at Best	CDS	3	12.58	0.0056 ***
Until November 2011	CDS	Quantity at Best	3	3.80	0.2840
Until November 2011	Quantity at Best	CDS	3	10.88	0.0124 **
From January 2012	CDS	Quantity at Best	3	4.76	0.1900
From January 2012	Quantity at Best	CDS	3	1.49	0.6837

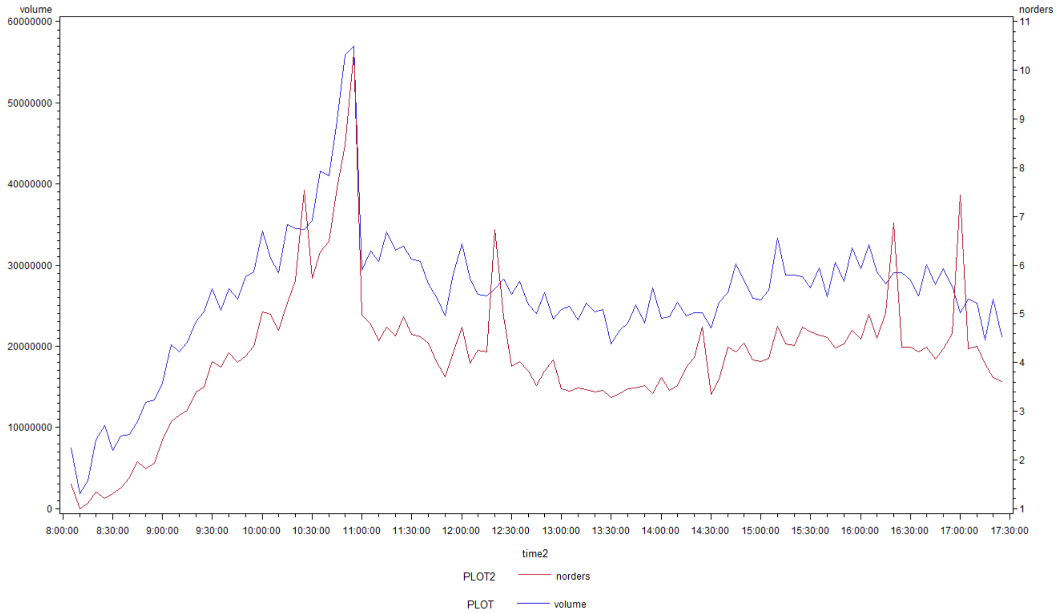
[*] Significant at a 10% level, [**] Significant at a 5% level, [***] Significant at a 1% level.

Table 7: Granger-Causality Analysis (continued)

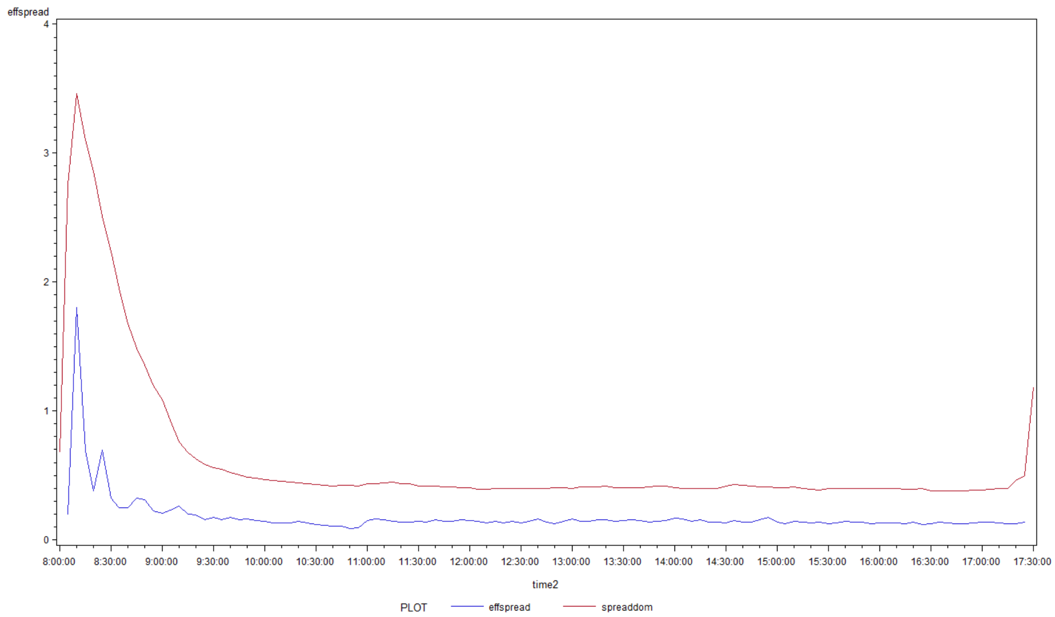
Sample	Var 1 Caused by Var 2		Lags	Test Value	P-Value
All	CDS	Quoted Quantity	4	7.52	0.1107
All	Quoted Quantity	CDS	4	2.56	0.6342
Until November 2011	CDS	Quoted Quantity	4	4.06	0.3977
Until November 2011	Quoted Quantity	CDS	4	3.05	0.5500
From January 2012	CDS	Quoted Quantity	4	8.32	0.0805 *
From January 2012	Quoted Quantity	CDS	4	0.21	0.9946
All	CDS	Log Var	4	0.96	0.9157
All	Log Var	CDS	4	4.22	0.3770
Until November 2011	CDS	Log Var	4	0.98	0.9130
Until November 2011	Log Var	CDS	4	4.13	0.3890
From January 2012	CDS	Log Var	4	5.09	0.2779
From January 2012	Log Var	CDS	4	2.06	0.7239
All	CDS	Amihud Measure	6	14.08	0.0287 **
All	Amihud Measure	CDS	6	13.94	0.0303 **
Until November 2011	CDS	Amihud Measure	6	15.17	0.0190 **
Until November 2011	Amihud Measure	CDS	6	8.16	0.2268
From January 2012	CDS	Amihud Measure	6	6.87	0.3333
From January 2012	Amihud Measure	CDS	6	6.73	0.3468
All	CDS	Roll Measure	3	2.79	0.4248
All	Roll Measure	CDS	3	2.26	0.5212
Until November 2011	CDS	Roll Measure	3	5.26	0.1536
Until November 2011	Roll Measure	CDS	3	1.12	0.7717
From January 2012	CDS	Roll Measure	3	0.77	0.8565
From January 2012	Roll Measure	CDS	3	1.13	0.7710

[*] Significant at a 10% level, [**] Significant at a 5% level, [***] Significant at a 1% level.

IX Figures

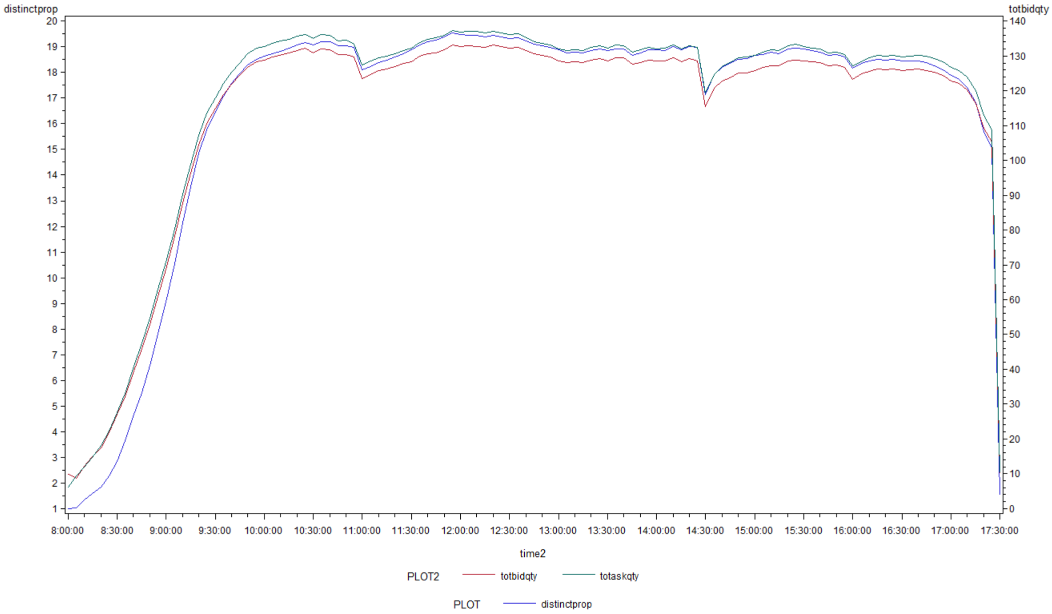


(a) Intraday Volume and Number of Orders

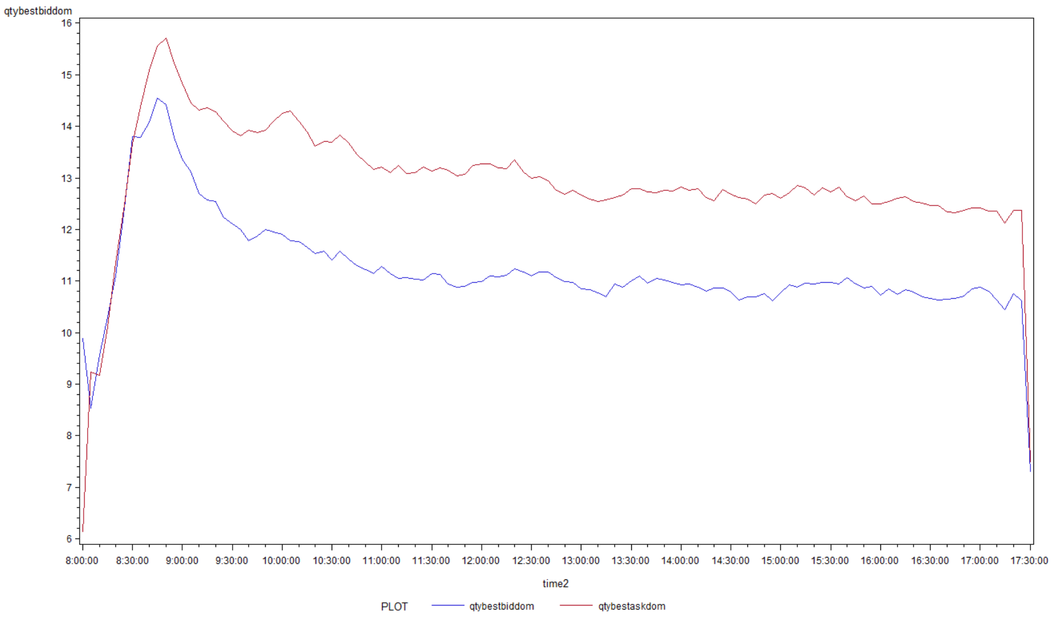


(b) Intraday Quoted and Effective Spread

Figure 1: Intraday Movements of Trading and Liquidity Measures. The measures are calculated with a 5-minutes frequencies and averaged across the days in the sample. Number of orders is the number of orders submitted, and volume is the executed quantity (millions of euros) of the orders .

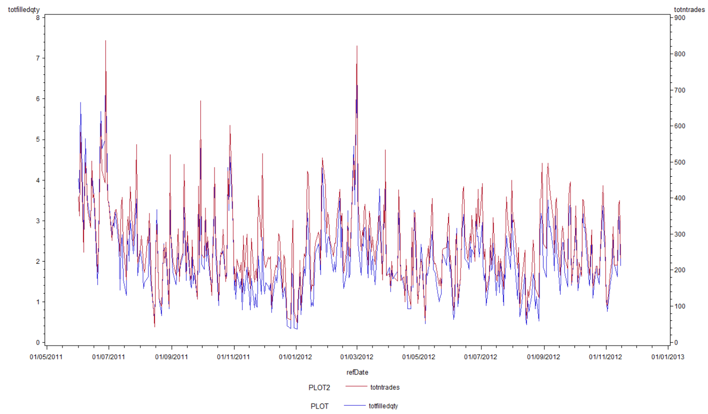


(a) Intraday Distinct Proposals and Quoted Bid and Ask Quantities

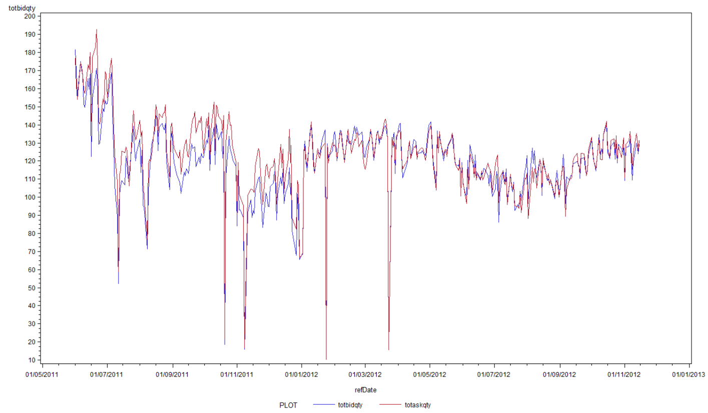


(b) Intraday Quoted Quantity at the Best Bid (blue) and Ask (red).

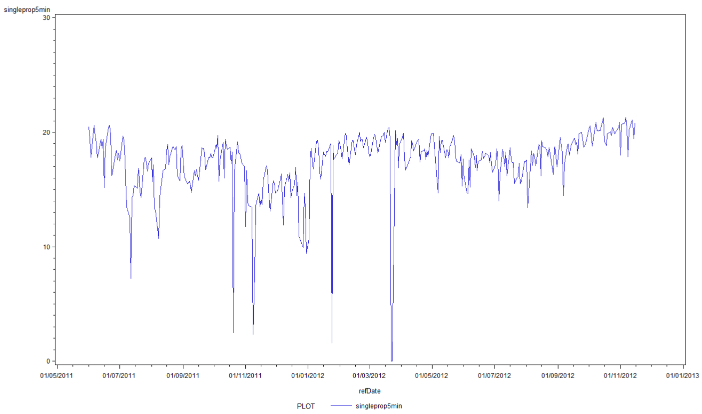
Figure 2: Intraday Movements of Quoted Quantities. The measures are calculated with a 5-minutes frequencies and averaged across the days in the sample. The quoted quantities are expressed in millions euro. The market is open from 8 to 17.30. The number of dealers, proxied by distinct proposals, grows from one at open to the time-series median of 18 at 10:00, symmetrically the total quoted quantity grows from 10 million of euro to its time-series median of 122. Number of market makers and total quoted quantity are stable throughout the day. Minor drop at 14:30 corresponds to US market openings, then slowly diminish toward market close.



(a) Traded Quantity (blue) and Number of Trades (red)

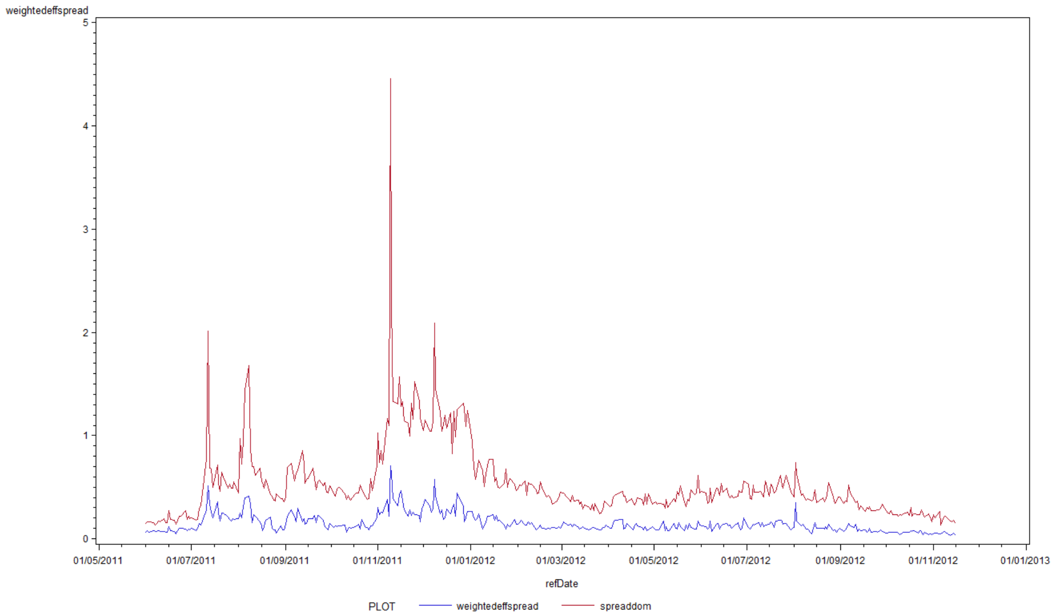


(b) Quoted Bid (blue) and Ask Quantities (red)

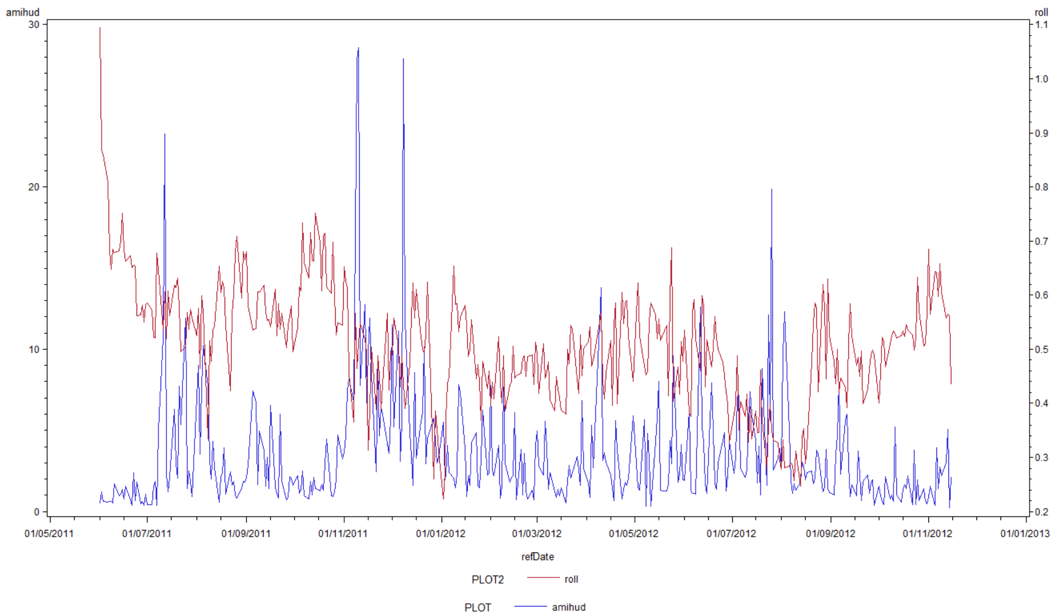


(c) Single Proposals

Figure 3: Liquidity Measures Along the Sample for Italian Bonds. The sample consists of 148 Italian bonds and 377 trading days. Quoted quantities are expressed in millions of euros per bond, the traded quantity is the overall market quantity and it is expressed in billion euros.
Daily traded quantity and number of trades (a), total quantities quoted on the bid- and ask-side of the market (b) are very noisy. All of them show a clear reduction in the last half of July 2011 and turns to increase around the turn of the year. Daily traded quantity and number of trades showed a peak around March 9, 2012 when Greece bailout was decided. Total quantities quoted and single proposal (c) showed mild increases around that time. Both (b) and (c) are characterize by a few big drop which indicate market makers' unwillingness of market making.

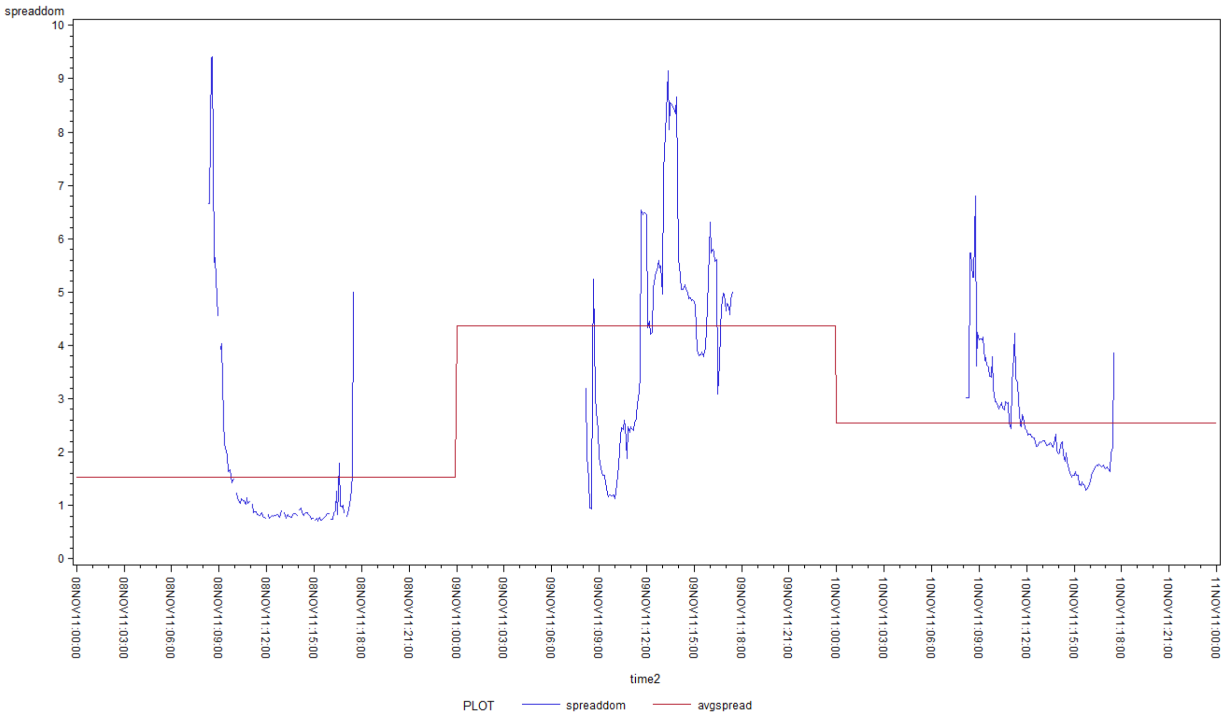


(a) Quoted and Effective Bid Ask Spread

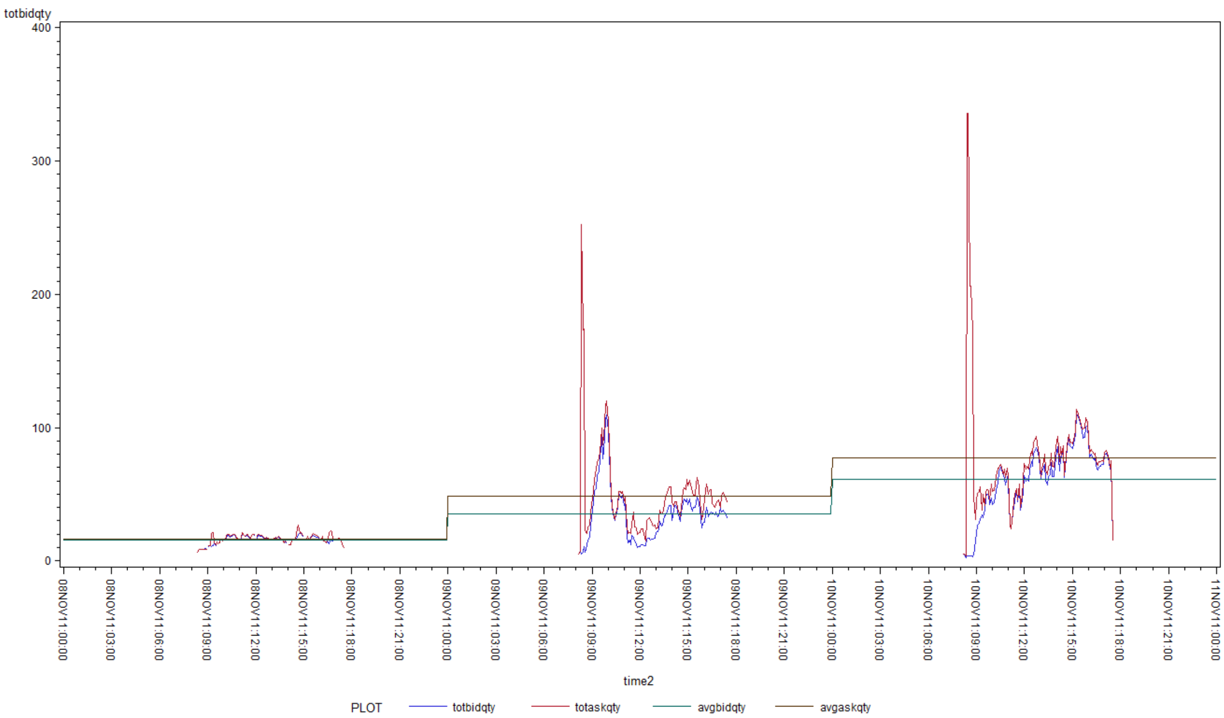


(b) Amihud and Roll Measure

Figure 4: Liquidity Measures Along the Sample for Italian Bonds. The sample consists of 148 Italian bonds and 377 trading days. Quoted Bid-ask spread, Roll and Amihud measures are averaged across the bond for every day in the sample. Effective spread are time-weighted average. The quoted bid-ask spread hit the highest spike (456bp) on November, 9th, 2011 when Silvio Berlusconi was losing the majority in the Parliament. The Amihud measure changes from 0.25bp to 28.60bp on the same day. The Roll measure behaved differently from effective spread because transactions are heavily skewed to sell side.



(a) Intraday Bid-Ask Spread Around the 9$^{\text{th}}$ of November 2011



(b) Quoted Quantity and Daily Averages Around the 9$^{\text{th}}$ of November 2011

Figure 5: Intraday Movements of Liquidity Measures Around the 9$^{\text{th}}$ of November 2011

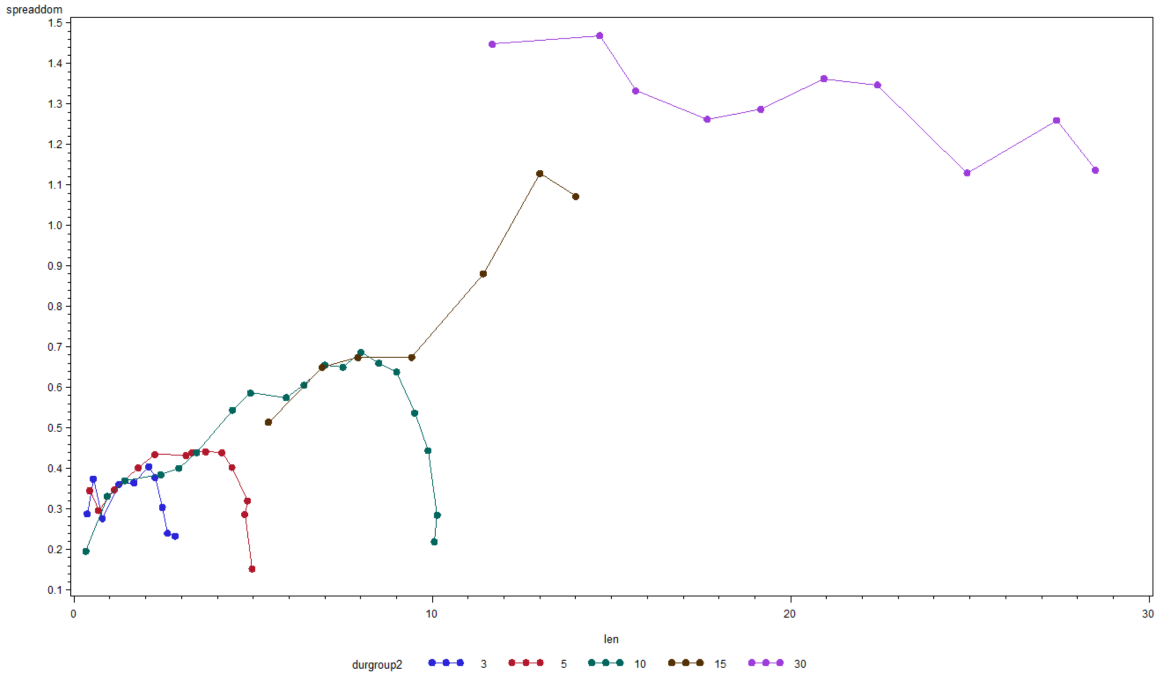


Figure 6: This figure shows the nonlinear relationship between age/time-to-maturity and maturity in the cross section. Every dot is one of the 58 coupon-bearing bonds in the sample. The y-axis is the bid ask spread, while the x-axis is the time-to-maturity. Different colors correspond to different maturity groups.

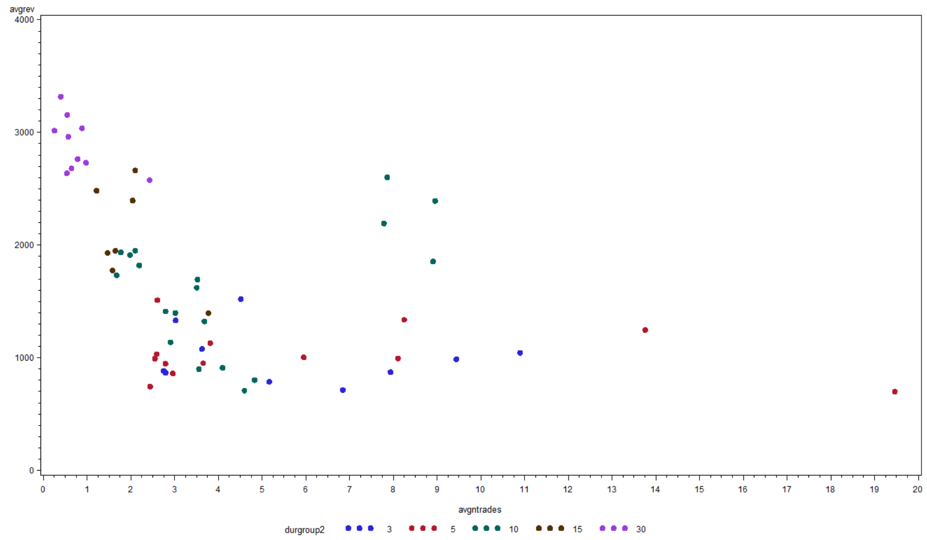


Figure 7: This figure shows the nonlinear relationship between average revision per single proposal and daily number of trades. Every dot is one of the 58 coupon-bearing bonds in the sample. The y-axis is the bid ask spread, while the x-axis is the time-to-maturity. Different colors correspond to different maturity groups.

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