# 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 cover 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 document the strong non-linear relationship between changes in Italian sovereign risk and liquidity in the secondary bond market. We pinpoint which subset of bonds was the least affected by the worsening of the crisis, in terms of liquidity, and to what extent it was resilient to the deterioration of Italy's creditworthiness. We document that, under conditions of stress, a fraction of market makers withdraws from the market and frequent quote revisions do not necessarily translate into higher liquidity. We also examine how liquidity improved after intervention by the European Central Bank (ECB), through its Long-Term Refinancing Operations (LTRO) and 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 at the core of Euro-zone, such as France and Germany, due to the close linkages between their major banks and 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) through a series of policy actions, including the Long-Term Refinancing Operations (LTRO) and 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 (CDS) spreads, at various points during the crisis, and the reaction of the market to intervention by the troika: the ECB, the 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, it is important to analyze the microstructure and liquidity effects, over time, and across individual bonds, so that policy makers can assess the efficacy of their interventions 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 it is also a market 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 EU 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 versus zero-coupon bonds, fixed coupon versus 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 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-sectional 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 reactions 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. In 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 bond characteristics, we find in the cross-sectional analysis 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, that is the impact of a large change in the CDS spread is proportionally larger than that of a smaller change. We also conduct a panel regression analysis to document that liquidity levels are dependent on the credit risk perceptions of market participants as measured by the CDS spread

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. These effects are confirmed in a case study of the extreme changes in the CDS spread. Although many market makers withdraw from the market on these days, other continue their normal market-making activity.

The results of our study have several policy implications. First, our findings would be of interest to Euro-zone national treasuries wishing to identify the maturities of the most liquid bonds for their planned issuances. Second, they could also be used by the ECB (and the national central banks) to identify those segments of the market in which to intervene so that the reduction in the bid-ask spread for a bond of a given maturity would most benefit bonds of other maturities, thus achieving optimal impact from 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 to evaluate 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, as well as a panel analysis, 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 are hardly any detailed analyses of the micro-structure of the sovereign bond markets, in the 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, below, we provide a brief review of the existing literature so as 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 responses of the US Treasury markets to unanticipated macro-economic news announcements. They hypothesize that there are two stages in the market responses to announcement surprises, the first being a sharp, almost instantaneous, change in prices, with very little incremental trading activity, the second a further change in price accompanied by a surge in trading volume. They find corroborative evidence for this hypothesis in data taken 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 US Treasury market. They use a sample of intraday US 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 that POMOs' positive liquidity externalities increase as proxies for information heterogeneity increase.

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 from 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 was 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 global 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, and 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 for the Euro-zone sovereign bond market to estimate the permanent price response to trades. They show the relevance of information asymmetry for 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 price series for a limited sample of bonds over 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 have been found by Favero, Pagano and von Thadden (2010). More recently, Bai, Julliard and Yuan (2012) have studied how liquidity and credit risks have evolved in the Euro-zone sovereign bond markets since 2006. They conclude that bond spread variations 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 recent global financial crisis were mostly due to liquidity concerns but, since late 2009, they have been 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 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 the past, and thus 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, that is, after both Italy and Spain had 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 data sets used by previous researchers, both from MTS in Europe and BrokerTec in the US, including those used in the recent paper by Darbha and Dufour (2012), are based on quote and trade data, and typically record changes to the best three bid- 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 intraday order proposals, quote revisions and trader identity, leading to 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 will sharpen our understanding of the demand for and realization of liquidity. It also casts a spotlight on the intraday evolution of the liquidity effects, in particular on days when important macro announcements are made.

## 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 for fixed-income securities, mostly those issued by the national treasuries and local governments of twelve countries: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the 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 interdealer markets making up the MTS system, including EuroMTS (the "european market"), 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 interdealer 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

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

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 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 out of the whole 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 databases 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 databases 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, for primary dealers and dealers respectively, are not provided. Only *actual trading* events are observable and *trading intent* as a pre-trade measure cannot be measured. 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 set.

In contrast, the data set we analyze in the present study is at the fourth level, 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, henceforth called "proposals," can be followed in the database in terms of their "revisions" over time, thanks to a "single proposal" identifier.

Market participants can decide whether they want to trade a government bond on the European market or on that country's domestic market. While every Euro-zone bond is quoted on the domestic markets, only bonds that were issued for an amount higher than a certain threshold can be traded on the EuroMTS. Even though the two markets are not formally linked, most dealer participate in both venues, the previous literature (Cheung, de Jong and Rindi (2005), Caporale and Girardi (2011)) has shown that the two markets constitute essentially one single venue.[5] Thus, in our analysis we consider trading in *both* markets. Most of our liquidity measures do not depend on where the order placement

[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] By this we mean that an order could "trade-through" a better price if the trader sent the order to the market with the worse bid- or ask-price. However, MTS assures market participants that their trading platforms always show quotations from both the domestic and the European market, when available.

and trading activity takes place.[6]

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, that is, they issue standing quotes, which can either be 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 on the passive side, when their proposals are hit, and/or on the active side, when they submit orders aimed at hitting another primary dealer's standing quote, of the market. Primary dealers have market-making obligations that, in spite of some relaxations after 2007, still require each primary dealer not to diverge from the average quoting times and spreads, calculated among all market makers. In this market, the event of crossed quotes is guaranteed 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.[7] Other dealers with no market-making responsibilities can originate a trade only by "hitting" or "lifting" the 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' 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.[8] 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 across 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) on the European and domestic markets, for bonds that are traded on both venues. 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 to the trading platform engine only 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 market 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 the systems in other markets, 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 that

[6]Two notable exceptions are the *Quoted Spread* and the *Quantity at the Best Price*, as defined in the next section. The domestic market is chosen as the reference for a liquidity measure, when the measure differs between the European and domestic market.

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

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

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.[9]

While the data set does not suffer from misreporting issues that other databases such as TRACE suffer from, a few words on our data-cleaning procedures in the context of the MTS database are nevertheless in order.[10] 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 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, and even 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 amounts of originated contracts coincide with our corresponding calculations. 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 whole year. As Table 1 shows, the large majority (in numbers) of the bonds considered have short maturities (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, Certificato del Tesoro Zero-coupon (CTZ) or Zero coupon bonds, Certificati di Credito del Tesoro (CCT) or Floating notes, or Buoni del Tesoro Poliennali (BTP) or Fixed-income Treasury Bonds. The vast majority of the bonds we consider here belong to the BOT and BTP types. We exclude inflation or index-linked securities from our analysis.

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# IV Liquidity Proxies and Methodology

In the context of the Italian sovereign bond market, we first analyze the relationships between various liquidity proxies proposed in the literature, which are defined below. The liquidity proxies we employ 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 for estimating liquidity in the

[9] 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.

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

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 define 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.[11] Similarly, after adjusting for risk, bonds with a lower coupon have a propensity to be more liquid, in part because the lower coupon may be a 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 consider *Daily Trades*, *Traded Quantity*, *Revisions per Single Proposal* (number of total proposals updates over number of single proposals), *Single Proposals 5min* (as a proxy for the presence of primary dealers), *Quoted Quantity at the Best Bid- or Ask-Price*, and *Total Quoted Quantity*. It should be emphasized that only the first two of these 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 the quantities and prices of bids and offers. In general, the greater the value of each of these metrics, the more liquid is the bond. For instance, the greater the *Daily 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 is 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 data set. 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*, *Age*, *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. *Age* is the difference between the two last measures. *Coupon Type* refers to whether a bond is a coupon-bearing, zero coupon, or floating-rate bond.[12] *Amount Issued* is the amount issued of the bond in millions of euros. In case a bond was re-opened for additional issues, this variable would include any 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, $\textit{Traded Quantity}_i$ is the overall quantity traded for bond $i$, $\textit{Total Trades}_i$ ($\textit{Total Orders}_i$) represent the overall number of trades

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

[12] 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 in our analysis.

(orders) for bond $i$ that took place during the sample. *Daily* $Trades_i/Orders_i/Quantity_i$ is a per-bond measure, and equals the total number of trades/ orders/ quantity divided by the number of days for which $bond_i$ appears in the sample. In the time-series, *Total* $Trades_t$ and (*Total* $Orders_t$ indicate the overall number of trades (orders) taking place on all bonds on day $t$, while *Traded* $Quantity_t$ is the overall quantity traded on all bonds on day $t$. *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 less than the number of days in the overall sample because of early maturity, late issuance, or shorter duration.

In addition to the trading measures defined above, we have detailed information about individual dealer quotes, permitting us to compute quote-based measures. The quote-based measures are as follows: *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 given day. *Single Proposals 5min* 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 number of revisions per single proposal; it is the ratio of *Daily Revisions* to *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 occurring 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*, 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 euros (per 100 euros of face value).[13] *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 time the order arrives. Since orders might "walk" the book, once the quantity offered at the best bid- and ask-price is depleted, given the endogenous relationship between the quoted spread and the trading decision regarding the 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 $Roll_{it} = 2\sqrt{Cov(\Delta p_k, \Delta p_{k-1})}$, where $\Delta p_k$ is the price change between transaction $k$ and transaction $k-1$. Following the literature, we calculate the covariances during a 21-day window; we require at least three entries, which means, for example, either three days with three trades each or one day with seven trades, in the 21 days preceding the days for which the measure is calculated.[14]

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*,

[13]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. We conduct our analysis with the *Quoted Bid-Ask Spread*, and use the truncated version as a robustness check.

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

*Coupon Type*, *Amount Issued*, *Coupon Rate*, *Traded Quantity*, *Total Trades*, *Total 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. For example, *Single Proposals 5min* 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 is already defined on a daily basis, as in the case of *Traded Bonds* or *Traded Quantity.*

## IV.I Relationship to the Previous Literature

Most of the measures employed in our analysis have been presented in the literature or are otherwise intuitive; however, it is worthwhile to stress some of the salient features of their rendition in our study. Most liquidity studies in the existing literature focus on equity markets, with the majority of modern equity markets being limit-order driven. The subject of our study is one of the few current quote-driven markets for which detailed data are available. We need to take this institutional distinction into account in the calculation and interpretation of the measures we employ.

The larger equity markets are characterized by a high number of "messages" vis-a-vis the number of actual trades and the MTS market is no exception.[15] Moreover, quote changes outnumber trades so disproportionally that trade-based measures highly underperform quote-based measures, while contemporaneously reducing the sample by orders of magnitude. For this reason, we will mostly refer to quote-based liquidity measures in our study. *Average Revisions per Single Proposal* represents an improvement over its most direct counterpart in the limit-order literature, which is the number of limit orders submitted. Unless a data-set contains traders' IDs, a cancelled order and a subsequent order for the same security at a different price cannot be linked together, even though they might be coming from the same trader, whose valuation of the security has changed. A single proposal-specific ID allows us to follow the same market maker throughout the day and to calculate how often she revises her quote, that is to calculate the measure *Average Revisions per Single Proposal.* This measure makes it possible for us to differentiate between, say, two situations undistinguishable with other datasets: 1) several market makers competing for one bond, and 2) few very active market makers. However, even considering just the number of *Daily Revisions* – that is, considering all messages of revision of the quoted quantity and prices (which is similar to counting submitted limit orders in a limit-order driven market), is an improvement over its limit-order counterpart, since "proposals" only come from primary dealers. This way, we can distinguish between dealers' market-making activities and their trading interests.

MTS data include the number of dealers that can participate in the trading of a bond and the number of primary dealers who have the right to make market for that specific bond. These quantities are rough approximations for the participation of the dealers and primary dealers: they actually only indicate the maximum potential number of participants. Our measure *Single Proposals 5min*, on the contrary, measures at a 5-minute frequency the number of single proposal standing for each bond, thus proxying for the number of market-makers actively quoting the bond. The measure allows us to record the participation of primary dealers at any point in time and follow its evolution through time.

[15] See, for example, Hasbrouck and Saar (2009) on the INET system or Hendershott, Jones and Menkveld (2011) on the NYSE.

"Iceberg" or hidden orders are common in most current market structures of equity market. With our data, we are able to quantify both the visible and hidden part of the quantity that is offered by the market-maker, thus capturing the volume market-makers are actually willing to trade in the Italian sovereign bond market. Market makers can modify the liquidity available at the market by changing the quoted bid-ask spread or by changing the quantity available to traders. Failing to consider the latter or including only the visible portion in the quoted quantity leads to a serious under-estimation of the market liquidity, especially when only a few quoted price levels are available in the data-set. The availability of proposal-specific IDs implies that we can verify whether market-makers post bid- and ask-prices through the day, whether they are always at the best bid- or ask-price, or whether they are only active far from the market and for few hours during the day. This kind of analysis of market-maker competition and behaviour is not included in the present study and it will be the subject of a follow up paper.

# 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 euros, with a maximum of 30 billion and a minimum of 3 billion. The average maturity (*Maturity*) 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 32 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.

Turning to the trading activity variables, over the 377 days of our sample, the mean (median) bond trading volume is 5.37 (4.58) billion euros (*Traded Quantity*). Therefore, on average, the daily trading volume (*Daily Quantity*) during our sample period is 34 (26) million euros per bond. The trading volume as a whole, for all 148 bonds, is an average of around 2 (2) billion euros a day (Cf. Table 5, *Traded Quantity*). The daily trading volume in the Italian MTS market is much smaller than in the US Treasury market, by a couple of orders of magnitude, with the average traded quantity in the latter being around $500 billion per day.[16] 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)).[17]

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 began. Dufour and Nguyen (2011) report that the Italian segment of the MTS market volume as a whole, over their 1,641-day sample,

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

[17]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.

was 4,474 billion euros.[18] This translates into an average daily volume of 3.8 billion euros.[19] 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.[20]

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 euros to a maximum of 1.47 euros per 100 euros of face value, with an average of 0.37 euros per 100 of face value. Our largest spread is beyond the point of three sigma from its mean.

INSERT TABLE 3 HERE

Due to the endogeneity of the trading decisions of dealers, given the quoted spread, the effective spread is typically much lower than the quoted spread, and varies from 0.001 euros to 0.63 euros per 100 of face value. This is in line with the figure of 0.70 euros for the 99th percentile of the quoted spread, at time of trade execution, that 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 euros, with a mean (median) of 127 (123). Of this quantity, between 6 and 124 million euros are quoted at the best bid- or ask-price, with a mean (median) of 14 (12) million euros. 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, and these proposals are 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-long (=570-minute-long) business day. There is a high degree of heterogeneity in the number of revisions, since some bonds have proposals changing every five minutes, and others have single proposals being updated as often as every 10 seconds. Combining the number of single proposals and the number 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.[21]

[18] The sample spans the period from April 2003 through September 2007.

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

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

[21] 34,000 quote revisions/9.5 trading hours/3,600 seconds per hour = 0.99 quote updates per second.

While the previous measures could provide us with an idea of the overall market, 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 rest of the time she is competing with another market maker. The minimum value for the Amihud measure is 0.001 while its maximum is 18.37; therefore, on average, a one 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%. As a comparison, Friewald et al. (2012a) report that the average Amihud measure across corporate bonds, from October 2004 to December 2008, is 78.38bp/M$, while their median is 38.33bp/M$. In a related work, Friewald et al. (2012b) report an across-securties average Amihud measure of 942bp/M$, 7,626bp/M$, 3,256bp/M$, 53bp/M$, for, respectively, the ABS, CMO, MBS, TBA sections of the US securitized product market. On average, based on the Amihud measure, the MTS bond market for Italian government bonds is 29 times more liquid than the US corporate bonds market and 20 times more liquid than the most liquid section of the US securitized product market.

## V.II Intraday characterization of liquidity

Our measures exhibit 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 *Orders* and *Traded Quantity*. Although the MTS market opens at 8:00 am [Central European Time (CET)], trading activity remains muted until 9:00 am and reaches the daily average at around 10:00 am. Traded volume peaks at around 10:30 am, with a trade quantity of 58 million euros per five-minute interval. After 11:00 am, trade quantity drops to its daily average of about 25 million euros exchanged per five-minute interval, and remains reasonably constant until the market closes at 5:30 pm.

The *Quoted (Effective) Bid-Ask Spread*, shown in Figure 1b, is as high as 3.5 (1.8) euros per 100 euros of face value, following the opening of the market, and declines steadily until 9:30 am, when it approaches its time-series median of 0.43 (0.12) euros per 100 euros of face value.[22] The bid-ask spread stays constant throughout the remaining trading hours, until the market closes at 5:30 pm, when it spikes in the last five-minutes of trading, confirming the usual U-shape documented extensively in other markets.

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 quantities quoted at the best bid- and ask-prices. As Figure 2a shows, *Single Proposals 5min* and *Total Bid- and Ask-Quantity* behave synchronously. The number of dealers, proxied by the *Single Proposals 5min*, grows from one at the market-open up to the time-series median of 18 at 10:00 am; symmetrically, the total quoted quantity grows from 10 million euro to its time-series median of 122. *Single Proposals 5min*, proxying for the number of market makers, and the *Total Quoted Quantity* are stable throughout the day, with a minor drop at 2:30 pm, that is, when the US market opens, to then slowly diminish until the market closes at 5:30 pm. We can link Figure 1b and Figure 2a since the bid-ask spread at the beginning of the

[22]See next section for the time-series descriptive statistics

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 am. At 9:00 am, the best bid- and ask-quantity reaches 15 million euros, but then shrinks in the following 90 minutes, to reach a steady level around 10:30 am that lasts until the market closes. The best ask (bid) quantity settles at a level of 13 (11) million euros, indicating a greater willingness among 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 to the evolution of the CDS market, and varied just as drastically, as Figures 3 and 4 show. Table 5 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 *Trades* in the first panel, the bid- and ask-quantities 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 less than a billion euros and the maximum of 7 billion; however, the mean daily traded quantity is around 2 billion euros, and on 18 days tops the 95th percentile of 4 billion. 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 over 800.

INSERT TABLE 5 AND FIGURE 3 AND 4 HERE,

The total quantities quoted on the bid- and ask-side of the market diminished drastically in July 2011 and stayed at these lower levels for the rest of our sample period, with the possible exceptions of even more drastic reductions 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 euros, the 5th and 95th percentiles of its empirical distribution, on 90% of the days in the sample (cf. Table 5). Reductions in the *Total Quoted Quantity* correspond to reductions in the number of *Contemporaneous 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 2,762.

Figure 4 shows the evolution of the *Quoted Bid-Ask Spread.* The connection between the reduction in the quoted quantity and the quoted spread can be seen, for example, by considering the highest spike (456 bp), which happened on November 8, 2011. On this date, the Italian Prime Minister, Silvio Berlusconi, lost his majority in the parliament, which led to his resignation, and corresponded to a downward spike in the *Total Quoted Quantity.* The event clearly had medium-term effects, as the bid-ask spread level persisted at around 100 bp for about two months, before returning to the time-series median value of 43 bp in January 2012, after the LTRO program had been launched in December 2011.

The other two dates when *Bid-ask Spread* spiked while *Total Quoted Quantity* approached low levels were: i) July 12, 2011, when fears of a Greek default and Portugal's downgrade triggered a sell-off of Spanish and Italian bonds, and ii) August 8, 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.[23]

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 0.25 bp/million to a maximum of 28.60 bp/million, are less dramatic than the 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) trade 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 in the crisis. Figure 5 shows the five-minute bid-ask spreads during the three-day window around the Italian Prime Minister Berlusconi's resignation, from November 8 to 10, 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 *Quoted Bid-Ask Spread* had an average of 4.46 euros per 100 euro of face value, versus a time-series median 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, that is, an unimaginable 10% bid-ask spread. This indicates the dealers' extreme need to consummate a trade. The peak in the spread followed a peak in the *Total Quoted Quantity*.

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

[23]Other spikes of the *Bid-ask Spread* and downward spikes of the *Total Quoted Quantity* can be found in the graphs. However, since the different liquidity measures do not peak contemporaneously, we do not include them in this list.

# VI Liquidity Effects During the Euro-zone Crisis

## VI.I Cross-sectional Evidence

In this section, we estimate cross-sectional regressions to study the drivers of liquidity, in the Italian sovereign bond market. 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:

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

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

$LM_i$ is the $i$th liquidity measure. Our proxies for liquidity are as follows: *Quoted Bid-Ask Spread*, *Effective Spread*, *Roll Measure*, *Amihud Measure*, *Total Quoted Quantity*, *Revisions per Single Proposals*, *Single Proposals 5min* and *Log-Vol*. The explanatory variables are the ratio of *Time-to-Maturity* and *Maturity*, *Amount Issued*, *Daily Trades*, and *Coupon Rate*, as presented in Section III. The results for the coupon-bearing bonds from equation 1 are presented in Table 6 Panel A, while the results for non-coupon-bearing bonds, as per equation 2, are presented in Table 6 Panel B.

INSERT TABLE 6 HERE

As far as coupon bonds are concerned, the two spread measures (*Quoted Spread* and *Effective Spread*) show similar results. The relationships between them and the *Time-to-maturity* (or, conversely, *Age*) of the bond are 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 maturity group, bonds that are on-the-run and bonds that are close to maturity have the lowest bid-ask spreads, while those in their "mid-life" have higher spreads, reflecting 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 as independent variables. 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 maturity dummies (Maturity5 to Maturity30) 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 is the spread.

Darbha and Dufour (2012) find, for the period from January 2004 to July 2010, that the more recently issued bonds with larger issue sizes have smaller *Quoted Bid-Ask Spreads*, which we also confirm for our sample period, June 2011 to November 2012. On the other hand, bonds of a longer maturity (as measured by the dummies) have larger spreads. This is consistent with what Dufour and Nguyen (2012), and Darbha and Dufour (2012) find, and with what Goyenko, Subrahmanyam and Ukhov (2011) report for US Treasury bonds. Darbha and Dufour (2012) suggest that, during the period from August 2007 to July 2010, prior to the Euro-zone crisis, investors shifted funds into short-term bonds. Regarding depth, measured by *Total Quoted Quantity* and *Quoted Quantity at Best*, it is larger for on-the-run and close-to-maturity, larger bonds. Longer maturity affects depth measures negatively. This explains why the *Amihud Measure* (market impact) is higher for longer-maturity bonds.

For market-making activities, *Single Proposals 5min* is the average number of dealers measured at a five-minute frequency and *Revisions per Single Proposal* is how often quotes change. The results indicate that 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 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 *Single Proposals 5min* and *Daily Trades*, which is negative in the case of non-coupon bonds. The coefficients of the dummy variable for the floating rate bonds are positive for the quoted spread, the effective spread and the Amihud measure. This means that floating rate bonds have a lower liquidity than zero coupon bonds. Surprisingly, *Amount Issued* 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 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 produce similar results to those for the effective spread, *Daily Trades* is the only variable that is consistent with this conjecture. These results for the Roll measure are somewhat puzzling, but as we discussed above, a buy (sell) order follows a buy (sell) in 78% of trades, which violates the crucial assumption needed for the Roll measure to acts as a 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. These results are consistent with those for the quoted and effective spreads. The volatility of quote changes (as measured by *Log Var*) yields results that are similar to those for the Amihud measure, while lacking statistical significance.

### VI.II Time-series evidence

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

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

where $\Delta LM_t$ is the change in the liquidity measure from time $t-1$ to time $t$, $\Delta CDS_t$ 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 7.[24]

Table 7 shows that the regression model has 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 its square are positive and statistically significant. The magnitude of the coefficient suggests that a 100-bp credit differential is associated with an increase in the quoted spread of 31 bp, based on the linear factor, but the convexity effect would increase this impact by another 100 bp: this implies that, on average, an increase of 100 bp in the CDS spread generates an increase in the quoted bid-ask spread of 131 bp.

INSERT TABLE 7 HERE

The effect is also significant, but with a lower magnitude, for the *Effective Spread*. The change in the CDS spread and its square are also significantly related to the Amihud measure. The traded quantity is related negatively to the quoted and effective spread. This is possibly due to the endogeneity of the trading decision in relation to the quoted spread. *Traded Quantity* is also positively related to the *Revisions per Single Proposal* and to *Log Var*, but negatively to the *Total Quoted Quantity*. We interpret this as indicating 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. *Single Proposals 5 min* is negatively related to *Daily Trades* for zero coupon bonds and positively for coupon-bearing bonds, both in a univariate and a multivariate sense (Cf. Section VI.I).[25] If the sample is not split into two, the two effects approximately cancel each other out. We see this in the time series in Table 7 where *Traded Quantity* is not significant when regressing *Revisions per Single Proposals* on the explanatory variables.

Since we found a positive association (in the changes) between *Revisions per Single Proposal* and *Traded Quantity* in the 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

[24] We obtain 5-year sovereign CDS spreads from Thomson-Reuters-Datastream. We consider daily data of the Italian Dollar-denominated CDS.

[25] *Daily Trades* and *Traded Quantity* are highly correlated and the results do not change significantly if one measure is substituted with the other.

is puzzling. The scatter graph in Figure 7 shows the cross-sectional relation between *Revisions per Single Proposal* and *Daily 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 number of trades. This suggests that dealers make markets (with a greater frequency of quote revisions) even in bonds for which the market does not have a high trading interest, mostly 15-year and 30-year bonds. 3-year and 5-year bonds are almost flat, meaning that the average *Revisions per Single Proposal* is approximately constant as the number of trades varies.

The only bonds showing a positive association between *Daily Trades* and *Quote Revision per Single Proposal* 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 period of stress, 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 of primary dealers.

### VI.III Panel Analysis

In previous sections, we have presented evidence on the cross-sectional relationships between bond characteristics and liquidity measures, as well as its time-series market-wide correspondences between the changes in CDS spread and overall liquidity measures. We next conduct the following panel regression analysis, in order to assess how different bond maturities were affected by the CDS spread through time:

$$\begin{aligned}\Delta LM_{it} =& \beta_1 \Delta LM_{it-1} + \beta_2 \frac{Time\ to\ Maturity}{Maturity}_{it} + \beta_3 DummyTrade_{it} \\ &+ \beta_{\ldots} Below500_t \cdot MaturityDummy_i \cdot \Delta CDS_t \\ &+ \beta_{\ldots} Above500_t \cdot MaturityDummy_i \cdot \Delta CDS_t + c_i + \epsilon_{it}\end{aligned} \tag{4}$$

where $\Delta LM_{it}$ is the change in liquidity measure for bond $i$ from day $t-1$ to day $t$. As bonds do not generally trade every day, trade-based liquidity measures (*Effective Spread*, *Amihud Measure* and *Roll Measure*) for bond $i$ on day $t$ are included in our sample only if bond $i$ traded also on day $t-1$. Even though this diminishes the sample, it makes it possible to calculate meaningful differences for trade-based measures. ΔCDS is the daily change in CDS spread, $\frac{Time\ to\ Maturity}{Maturity}_{it}$ is the ratio between time-to-maturity and the initial maturity, and $DummyTrade_{it}$ equals 1 if the bond $i$ traded on day $t$.[26] $MaturityDummy_i$ for maturity $m$ (where $m$ belongs to the group presented in Table 1) is equal to 1 if bond $i$ belongs to the $m$-year maturity group and 0 otherwise and $c_i$ is a bond fixed effect.

[26]Since $\frac{Time\ to\ Maturity_{i,t}}{Maturity_i} - \frac{Time\ to\ Maturity_{i,t-1}}{Maturity_i} \approx -\frac{1}{Maturity_i} = -\gamma_i$ and $\frac{Time\ to\ Maturity^2_{i,t}}{Maturity^2_i} - \frac{Time\ to\ Maturity^2_{i,t-1}}{Maturity^2_i} \approx -\gamma_i^2 - \delta_i \frac{Time\ to\ Maturity_{i,t}}{Maturity_i}$ we add $\frac{Time\ to\ Maturity_{i,t}}{Maturity_i}$ as a right-hand side variable, while including bond-specific fixed effects. By doing so we capture the (inverse of) the quadratic relationship between the liquidity measures and the ratio of time-to-maturity to maturity, which follows from the results in Section VI.I.

It is worthwhile to stress that almost all the liquidity measures we calculate for the 148 bonds in our sample could be calculated every day, and therefore, changes from one day to the next could be easily determined. Exceptions to this statement are the trade-based measures, *Effective Spread*, and the *Amihud and Roll Measures*. This feature is different from most other bond markets, where it is difficult for many different maturities to determine daily changes in liquidity measures, especially those based on actual trades. Furthermore, due to the intensity of quotes available every single day throughout our sample period, the quote-based liquidity measures are based on a large number of observations.

We also include the following dummy variables: Below500, Above500 which equal 1 when the level of CDS spread is, respectively, below 500bp, and above 500bp and 0 otherwise. The reason to include them is that the impact of a change in the CDS spread could be different when CDS levels are below or above a certain level. The 500bp threshold has been indicated by the main Italian news agency, as a psychologically important barrier, indicating that the debt will likely spiral out of control if the spread will persistently remain above this threshold.[27]

INSERT TABLE 8 HERE

Table 8 presents the results from the panel regression as specified in Equation 4, with results from coupon-bearing bonds and zero-coupon bonds along with floating bonds in Panel A and B, respectively. The $t$-test are based on a robust covariance matrix and adjusted for clustering at a bond level, including a small sample and degrees of freedom adjustment (Greene, 2012). The first result the two panels show is, in fact, that the same changes in the CDS spread have a different impact on liquidity changes, conditional on different levels of the CDS. The larger the level of the CDS spread, the larger is the reduction in the liquidity for the same level of CDS changes. Moreover, for fixed-coupon bonds, the change in the *Quoted Spread* resulting from a change in CDS spread is directly proportional to the maturity of the bond, whether the CDS spread is below or above 500bp. For coupon-bearing bonds, even though the spread for 30-year bonds is three times that for 3-year bonds and twice that for 10-year bonds (cf. Table 6), the sensitivity of the quoted spread to the CDS spread is 5 times and 4 times as large, respectively, when the level of the CDS spread is above 500bp. Similarly, the 15 year bond bid-ask spread is 40% wider than the 10-year bonds, *ceteris paribus*, while the sensitivity of the change in the quoted spread to a change in CDS spread is 140% that of the 10-year bonds. A similar result involves 3-year bonds which have a quoted spread 13% smaller than the 5-year bonds, but have a sensitivity to CDS spread changes that is 25% higher than that of their 5-year counterparts. *Quoted Spread* seems not to change when the CDS spread is below 500bp, however, for 10-year bonds the relationship turns negative. The effect of a change in the CDS spread on the change in quoted spread is positive and significant for every maturity, when the CDS level is above 500 bp. Results for the *Effective Spread* are similar. The 10-year maturity is the point where liquidity, as measured by the bid-ask spread, is the least influenced by changes in the creditworthiness of the State.

As for the market-making measures, *Revisions per single proposals*, measuring the activity of market making, exhibits different patterns for long and short maturities. While dealers tend to pay more attention to 30-year bonds, an increase in the CDS level causes the attention to shift to 5- and 10-year bonds. Every basis point increase in the CDS spread causes single proposals to be reviewed 3 times less for 30-year bonds, 2 times less for 15-year bonds, and 1.2 times more for 5-year bonds,

[27] ANSA-Agenzia Nazionale Stampa Associata, December 23, 2011. The CDS spread is above 500bp in 83 out of 377 days of our sample (22%), cf. Figure 8.

when the CDS spread is below 500 bp. When CDS spread is above 500 bp, 10-year bonds are revised 1.2 times more per bp change in CDS, compared to when the CDS spread is below 500 bp, while 30-year bonds are revised almost 5 times less per basis point change. As for *Single Proposals 5min*, proxying for the presence of primary dealers on the market, it is approximately constant through different maturities and so is its sensitivity to changes in the CDS spread. *Total Quoted Quantity*, the liquidity provided by all market-makers, drops according to the level of credit risk, when CDS spread is above 500 bp, a 10bp increase in the CDS spread causes a reduction in quoted quantity of 0.9M-1.9M euro.

Non-coupon-bearing bonds exhibit the same signs as their coupon-bearing counterparts. A noticeable difference is that zero coupon bonds have a negative relationship between changes in *Revisions per Single Proposals* and in the CDS spread, as the number of revisions increases as CDS spread increases but only when the CDS spread level is below 500bp. Above this level, the number of revisions shrinks as CDS increases, possibly because primary dealers are focusing on coupon-bearing bonds with maturities between 3 and 10 years. However, similar to the results in Panel A, market-makers shrink in numbers as the CDS spread rises.

### VI.IV Granger Causality

In the previous regression analysis, we showed that there is a relationship between changes in the liquidity measures and changes in the CDS spread. However, the analysis did not indicate whether it was the increase in credit risk that drove the reduction of liquidity in the bond market or vice versa, that is, the low liquidity in the bond market increased the CDS spread. Which of the two economic variables contributes most to the other is a question that we now attempt to resolve using a simple Granger causality test, 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 $\Delta LM_t$ and $\Delta CDS_t$ on their $p$ lags.

Specifically, let $\Delta LM_t$ and $\Delta CDS_t$ be two stationary time series. We can represent their linear inter-relationships with the following model:

$$\begin{aligned}\begin{pmatrix}\Delta LM_t\\ \Delta CDS_t\end{pmatrix} &= \begin{pmatrix}K_{LM}\\ K_{CDS}\end{pmatrix} + \begin{pmatrix}a_{11_1} & a_{12_1}\\ a_{21_1} & a_{22_1}\end{pmatrix}\begin{pmatrix}\Delta LM_{t-1}\\ \Delta CDS_{t-1}\end{pmatrix} + \begin{pmatrix}a_{11_2} & a_{12_2}\\ a_{21_2} & a_{22_2}\end{pmatrix}\begin{pmatrix}\Delta LM_{t-2}\\ \Delta CDS_{t-2}\end{pmatrix} \\ &+ \begin{pmatrix}a_{11_3} & a_{12_3}\\ a_{21_3} & a_{22_3}\end{pmatrix}\begin{pmatrix}\Delta LM_{t-3}\\ \Delta CDS_{t-3}\end{pmatrix} + \cdots + \begin{pmatrix}a_{11_P} & a_{12_P}\\ a_{21_P} & a_{22_P}\end{pmatrix}\begin{pmatrix}\Delta LM_{t-P}\\ \Delta CDS_{t-P}\end{pmatrix} + \begin{pmatrix}\epsilon_{LMt}\\ \epsilon_{CDSt}\end{pmatrix}\end{aligned} \quad (5)$$

where $\epsilon_{\mathbf{t}} \sim N(\mathbf{0}, \mathbf{\Omega})$, and $a_{ij_p}$s are the $p$-lag coefficients of the model. Then, $\Delta CDS$ Granger-causes $\Delta LM$ when the $a_{12_p}$s are contemporaneously different from zero. Similarly, $\Delta LM$ Granger-causes $\Delta CDS$ when the $a_{21}$s are contemporaneously different from zero. When both of these statements are true, there is a feedback relationship between the time series.[28]

[28]We use the "corrected Akaike's information criterion" (see Hurvich and Tsai (1989)) as the model selection criterion for determining the number of lags in our analysis. We complement the decision by testing for the autocorrelation of the residuals. Moreover, we perform Wald tests of the null hypotheses that the coefficients $\{a_{12}\}$ or $\{a_{21}\}$ (depending on the direction of Granger causality under consideration) are equal to zero.

The results of the Granger causality test are reported in Table 9. As the table shows, considering the whole sample, CDS spreads Granger-cause liquidity in the bond market. Indeed, for almost all the liquidity variables considered, $a_{12_p}$s are statistically different than zero at the 1% level. However, this result is not robust. If we split the sample into 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 reduce the spread, the results are fairly different.

INSERT TABLE 9 HERE

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

One 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, it was able to reduce the credit perception of the state, 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, that is, order flows and order submission, especially under conditions of stress.

## VI.V A Case Study on Extreme CDS Spread Changes

Our time-series and Granger-causality analyses suggest that there is, indeed, a close connection between changes in credit risk, as measured by the change in the Italian sovereign CDS spread, and changes in the liquidity of the Italian sovereign bond in the MTS market. In order to establish the dynamics of market maker behavior and the evolution of liquidity in response to changes in the creditworthiness of the Italy sovereign, we conduct a simple case-study analysis. We determine whether, when facing high risk and uncertainty, market makers widen the bid-ask spread or simply withdraw from the market. Also, we investigate whether a reduction in the quoted bid- or ask-quantity occurs, and how long these effects last.

We look at the top 1% (4 most positive observations) and bottom 1% (4 most negative observations) daily changes in CDS spread and consider them the "day 0" of an event study. These eight days are suitable day 0 events for such an "event-study like" investigation, since we wish to focus on large CDS changes, as it follows from our previous analysis that the higher the change in creditworthiness, the larger should be the changes in liquidity levels. The details of the event days are presented in Table 10.[29]

[29] The event days correspond roughly to significant events as, for instance, when Italy was downgraded in September 2011, or when Berlusconi resigned in November 2011.

It is important to stress that only one extreme event took place after the ECB introduced the LTRO program: On June 29, 2012, the ECB was given the mandate of supervising European Banks; thus, the negative CDS change we observe can be interpreted as a reduction in Italy's sovereign risk as a consequence of enhanced European control. Moreover, none of the event days followed Mario Draghi's comment of July 2012, which means our case-study analysis refers to the period when the CDS Granger-causes liquidity in the MTS market, as shown in the previous section.

For each day $t$ of a 8-day window around each event day $d$, we calculated for every bond $i$ the "Abnormal Liquidity Measure"

$$ALM_{dit} = \frac{LM_{dit} - CLM_{di}}{CLM_{di}} \tag{6}$$

for $t$ going from -4 to 4, with $t = 0$ being the event date. $LM_{dit}$ is one of the liquidity measures used in the previous sections. For each bond, we use the median of the same liquidity measure in the $t = -19$ to $t = -9$ period as comparison, $CLM_{di}$. We then average $ALM_{dit}$ through the bonds that are quoted around event $d$ into $ALM_{dt}$, and calculate the related $t$-test. In Figure 9 and 11 we report $ALM_t$, the average of $ALM_{dt}$ through the 8 events, and the sign of the $t$-tests for $ALM_{dt}$ and their significance at a 10% level. As a robustness check, we repeat the analysis splitting the sample of bonds into coupon-bearing bonds and non-coupon bearing bonds, in quintiles based on their liquidity, as measured by *Quoted Bid-Ask Spread*.[30] Also, we analyzed separately large up- and down-movements of the CDS spread and the results are along the same lines.

The results of the analysis are shown in Figure 9 to Figure 11. As the previous sections showed, an increase in the CDS spread causes an expansion of the *Quoted Bid-Ask Spread*. This case-study quantifies the increase to be about 130% on the day of extreme CDS movements, with 7 out of 8 cases showing a positive and significant $t$-test value. However, the increase does not last, as the spread diminishes on day 1, while still being 60% higher on average than the pre-event period. The *Effective Spread* shows similar behavior. Splitting the sample into trading activity quintiles suggests that the effect on the days of extreme changes in the CDS spread on the bid-ask spread is proportionally larger the less a bond is traded.

INSERT FIGURES 9 TO 11 HERE

Figure 10 and 11 show the measures of market-makers' activity. Market makers evidently withdraw from the market on day -1 and even more so on day 0, *Single Proposals 5min* in Panels c and d drops 10% on day -1 and 15% on day 0, with 6 out of 8 cases showing negative and significant $t$-tests. However, already on day 2, their presence is almost fully restored: it seems that market makers resume market-making activities as soon as the uncertainty moderates. The evolution of *Total Quoted Quantity* in Figure 11 shows a very similar pattern to that of *Single Proposals 5min*. The reduction of depth is caused by the temporary withdrawal of market makers.

On the other hand, *Average Revisions per Single Proposal* during the extreme market conditions is generally higher than in the pre-event period. It jumps by 25% on day 1, and remains high until day 4. Market makers update their quotes more cautiously before the event and then, once the uncertainty diminishes, intensify their update by 25%, compared to the pre-event period. Panels c and d in Table 11 show the (logarithm of the) midquote-return variance, which shows a similar pattern to that of the *Quoted Bid-Ask Spread*, peaking on the days of the extreme CDS change and returning to usual levels on the following day.

[30] We report the results for the coupon-bearing bond subset only. The results for the remaining subset are similar.

The analysis of the market-making measures suggest that, while many market makers withdraw from the market in periods of increasing uncertainty, those who remain in the market keep updating their bid- and ask-prices at a normal pace, while sharply adjusting the bid- and ask-quotes. On the day following the large CDS change, the participation of market makers is restored, but their attention to the market, as measured by the frequency of update of their quotes, is highly enhanced, while the midquote does not change as drastically as in the previous day. A higher frequency of update indicates also a higher trading interest and competition among market makers.

## VII Conclusion

The Euro-zone sovereign debt crisis has been the most important development in the global economy of the past three years. At its heart, the crisis stemmed 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 to a greater extent after Mario Draghi's "whatever it takes" comment in July 2012, and the subsequent OMT program that was launched, that the markets alarm diminished. As a result, 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 whether the fundamental problems 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, were transmitted to the level of individual bonds, and how 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 world's largest electronic trading platform for sovereign bonds, which 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, and conclude that the crisis began with a spike in credit risk that was 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 in prices and the spike in bond yields, causing deep losses in the asset values of banks and investors holding 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.

We use a range of metrics to measure liquidity at the bond level, and this analysis indicates that 15- and 30-year bonds showed the widest bid-ask spreads under the stressed conditions, but 10-year bonds exhibited a relatively tight spread, suggesting that market makers differentiate between bonds of different maturities when illiquidity takes hold in the market. However, illiquid bonds have a contagion effect, 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 on 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 case-study analysis of extreme CDS changes highlights that, in the presence of high credit risk and uncertainty in the market, many market-makers prefer to withdraw from the market, especially for highly illiquid bonds. However, already on the day following the large shock in the CDS market, the presence of market makers is restored, while the increased frequency of quote updates indicates that they are more attentive to changing market conditions than before the CDS event.

Our Granger causality tests, aimed at investigating whether liquidity risk drives credit risk or vice versa, show that, prior to the introduction in 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 will be of interest to both the Euro-zone national treasuries and the ECB, helping them to identify the segments of the market in which to intervene so that the reduction of the spread on a single maturity will most benefit bonds of other maturities in the same and other countries, thus achieving the optimal impact from 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 bond markets and the timely disclosure of information, as well as to evaluate 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 to investigate how the liquidity effects vary across countries. We also hope to extend our data set into the subsequent period so as to conduct an event study of the effect of macro-economic announcements and central bank actions on liquidity.

# VIII Tables

Table 1: ***Maturity* and *Coupon Rate* by Maturity Group and Bond Type.** This table presents the distribution of the bonds in terms of *Maturity* and *Coupon Rate*, by maturity group (Panel A) and bond type (Panel B). Maturity groups were determined by the time distance between bond maturities and the closest whole year. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

Panel A

| 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 |

Panel B

| 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 bonds, ZCB)
[c] All bonds in this group are CCT, Certificati di Credito del Tesoro (floating bonds).

Table 2: **Cross-sectional Descriptive Statistics of Bond Characteristics and Trade-based Variables.** This table presents the cross-sectional distribution of selected descriptive statistics for our data set. *Coupon Rate*, *Amount Issued* (in B€) and *Maturity* are time-invariant bond characteristics. *Age* is the average age across the sample. *Traded Quantity*, *Total Trades* and *Total 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 over the days on which the bond appears in the sample. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

| 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 |
| Total Trades | 148 | 705 | 577 | 38 | 97 | 311 | 516 | 951 | 1,822 | 3,359 |
| Total 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: **Cross-sectional Descriptive Statistics of Quote-based Variables.** This table shows the cross-sectional distribution of the liquidity measures. 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 number of single proposals throughout the day. *Single Proposals 5min* measures the number of single proposals standing at a 5-minute frequency. *Revisions per Single Proposals (SP)* is given by the daily revisions divided by the total single proposals. *Total Quoted Quantity* is expressed in milions of euros of face value. *Best Bid- (Ask-) Proposals* measures the number of single proposals quoting the best bid-(ask-) price contemporaneously, sampled at a 5-minute frequency. All variables are described in detail in Section IV. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

| 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 |
| Single Proposals 5min | 148 | 17 | 2 | 13 | 14 | 16 | 17 | 18 | 20 | 22 |
| Revisions 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(x$10^6$) | 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 | 0.03 | 0.040 | 0.000 | 0.000 | 0.010 | 0.02 | 0.05 | 0.11 | 0.19 |

Table 4: **Cross-sectional Correlations of Bond Characteristics and Liquidity Measures.** This table presents the cross-sectional correlations between liquidity, trading, and quote variables, defined in Section IV. The correlations are calculated across the 148 bonds in our bonds. Each bond contributed with one observation, which was the time-series average for time-dependant variables. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

| | Non Coupon | Maturity | Age | Number of Trades | Traded Qty | Avg Rev | Single Prop | SP 5Min | Revisions | Tot Qty | Qty Best | Quoted Spread | Effective Spread | Log Var | Amihud | Roll |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 0.60 | 5.87 | 2.38 | 4.05 | 33.54 | 1247.62 | 49.01 | 16.98 | 34.20 | 126.96 | 13.67 | 0.37 | 0.13 | −16.06 | 2.71 | 0.57 |
| StdDev | 0.49 | 7.96 | 3.46 | 4.51 | 33.08 | 671.78 | 86.35 | 1.75 | 20.62 | 45.86 | 12.30 | 0.36 | 0.14 | 3.16 | 4.02 | 0.25 |
| N | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 |
| NonCoupon | 1.00 | −0.64 | −0.52 | 0.00 | 0.17 | −0.49 | −0.33 | −0.68 | −0.58 | 0.12 | 0.14 | −0.54 | −0.53 | −0.59 | −0.52 | 0.27 |
| Maturity | −0.64 | 1.00 | 0.80 | −0.22 | −0.34 | 0.76 | 0.33 | 0.38 | 0.73 | −0.23 | −0.14 | 0.87 | 0.89 | 0.57 | 0.92 | −0.07 |
| Age | −0.52 | 0.80 | 1.00 | −0.28 | −0.34 | 0.46 | 0.06 | 0.17 | 0.39 | 0.00 | 0.02 | 0.66 | 0.68 | 0.44 | 0.64 | 0.05 |
| NTrades | 0.00 | −0.22 | −0.28 | 1.00 | 0.95 | −0.20 | 0.05 | 0.17 | −0.04 | −0.07 | −0.07 | −0.29 | −0.29 | −0.15 | −0.26 | −0.36 |
| TradedQty | 0.17 | −0.34 | −0.34 | 0.95 | 1.00 | −0.32 | −0.01 | −0.03 | −0.19 | 0.04 | 0.03 | −0.44 | −0.42 | −0.37 | −0.39 | −0.23 |
| AvgRev | −0.49 | 0.76 | 0.46 | −0.20 | −0.32 | 1.00 | 0.42 | 0.47 | 0.96 | −0.38 | −0.31 | 0.72 | 0.73 | 0.56 | 0.75 | −0.11 |
| SingleProp | −0.33 | 0.33 | 0.06 | 0.05 | −0.01 | 0.42 | 1.00 | 0.39 | 0.57 | −0.09 | −0.09 | 0.21 | 0.21 | 0.21 | 0.25 | −0.15 |
| SP5Min | −0.68 | 0.38 | 0.17 | 0.17 | −0.03 | 0.47 | 0.39 | 1.00 | 0.61 | −0.28 | −0.33 | 0.33 | 0.32 | 0.54 | 0.31 | −0.43 |
| Revisions | −0.58 | 0.73 | 0.39 | −0.04 | −0.19 | 0.96 | 0.57 | 0.61 | 1.00 | −0.35 | −0.30 | 0.65 | 0.66 | 0.57 | 0.69 | −0.22 |
| TotQty | 0.12 | −0.23 | 0.00 | −0.07 | 0.04 | −0.38 | −0.09 | −0.28 | −0.35 | 1.00 | 0.83 | −0.41 | −0.40 | −0.22 | −0.38 | 0.17 |
| QtyBest | 0.14 | −0.14 | 0.02 | −0.07 | 0.03 | −0.31 | −0.09 | −0.33 | −0.30 | 0.83 | 1.00 | −0.26 | −0.26 | −0.14 | −0.23 | 0.27 |
| Spread | −0.54 | 0.87 | 0.66 | −0.29 | −0.44 | 0.72 | 0.21 | 0.33 | 0.65 | −0.41 | −0.26 | 1.00 | 0.98 | 0.73 | 0.95 | −0.08 |
| EffSpread | −0.53 | 0.89 | 0.68 | −0.29 | −0.42 | 0.73 | 0.21 | 0.32 | 0.66 | −0.40 | −0.26 | 0.98 | 1.00 | 0.69 | 0.95 | −0.06 |
| LogVar | −0.59 | 0.57 | 0.44 | −0.15 | −0.37 | 0.56 | 0.21 | 0.54 | 0.57 | −0.22 | −0.14 | 0.73 | 0.69 | 1.00 | 0.62 | −0.25 |
| Amihud | −0.52 | 0.92 | 0.64 | −0.26 | −0.39 | 0.75 | 0.25 | 0.31 | 0.69 | −0.38 | −0.23 | 0.95 | 0.95 | 0.62 | 1.00 | −0.06 |
| Roll | 0.27 | −0.07 | 0.05 | −0.36 | −0.23 | −0.11 | −0.15 | −0.43 | −0.22 | 0.17 | 0.27 | −0.08 | −0.06 | −0.25 | −0.06 | 1.00 |

Table 5: **Time-series Descriptive Statistics of Trade- and Quote-based Liquidity Measures.** This table shows the time-series distribution of trading, quoting, and liquidity measures, defined in Section IV. The sample consists of 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* is the total number of trades on the day, and *Traded Quantity* is the amount exchanged market-wide on a specific day. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

| 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 Revisions (m) | 377 | 40 | 11 | 1 | 24 | 32 | 38 | 48 | 61 | 70 |
| Single Proposals | 377 | 53 | 118 | 11 | 24 | 27 | 28 | 30 | 161 | 1060 |
| Single Proposals 5min | 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(x$10^6$) | 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 | 0.04 | 0.010 | 0.010 | 0.020 | 0.03 | 0.04 | 0.05 | 0.07 | 0.08 |
| CDS Spread (bp) | 377 | 407 | 105 | 147 | 179 | 342 | 427 | 490 | 550 | 587 |
| $\Delta$CDS | 377 | 0.27 | 16.53 | −51.77 | −24.27 | −8.28 | 0.25 | 8.68 | 25.67 | 77.53 |

Table 6: **Results for the Cross-sectional Regressions of Liquidity Measures on Bond Characteristics.** This panel presents the results from the cross-sectional regression (eq. 1) of time-averaged liquidity measures on bond characteristics and number of trades, defined in Section IV. The sub-sample consists of 59 Italian coupon-bearing bonds. Heteroskedasticity-robust t-statistics are reported in parentheses. $R^2$ values are reported below the parameter estimates. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

Panel A. Subsample: Coupon-Bearing Bonds

| Variable | Quoted BA Spread | Effective Spread | Revision per SP | SingleProp 5 Min | Qty at Best | Total Quoted Qty | Log Var | Amihud Measure | Roll Measure |
|---|---|---|---|---|---|---|---|---|---|
| Intercept | 0.324*** | 0.0894** | 1263.63*** | 15.1783*** | 16.1069*** | 153.2871*** | −15.2462*** | −0.6092 | 0.0449 |
| | (3.12) | (2.4) | (4.21) | (29.53) | (4.2) | (10.84) | (−19.09) | (−0.49) | (1.37) |
| AmountIssued | −0.009*** | −0.0031** | −22.5278** | −0.0269 | 0.3954 | 1.2102 | 0.0534*** | 0.0878* | −0.0018 |
| | (−2.86) | (−2.04) | (−2.47) | (−1.37) | (1.39) | (1.21) | (3.14) | (1.91) | (−1.52) |
| Daily Trades | −0.0305*** | −0.0093*** | −67.1164*** | 0.1293*** | −0.1478 | −1.1831** | −0.1309*** | −0.3267*** | −0.0031*** |
| | (−3.87) | (−3.86) | (−5.49) | (2.92) | (−1.21) | (−2.07) | (−2.97) | (−4.13) | (−3.45) |
| CouponRate | 0.0173 | 0.009* | 35.3669 | 0.0966 | 0.6782 | 1.827 | 0.155 | −0.2449 | −0.0016 |
| | (1.11) | (1.91) | (0.66) | (1.1) | (1.08) | (0.8) | (1.53) | (−1.32) | (−0.32) |
| Maturity5 | 0.0494* | 0.0273*** | −5.0086 | 0.4447** | −2.0459* | −3.6243 | −0.4577 | 0.5091* | 0.011* |
| | (1.75) | (2.77) | (−0.04) | (2.03) | (−1.78) | (−0.84) | (−1.38) | (1.8) | (1.87) |
| Maturity10 | 0.1709*** | 0.0712*** | 601.4*** | 1.0161*** | −4.4816* | −13.9486 | −0.7137** | 1.4882*** | 0.0378*** |
| | (3.57) | (3.99) | (3.35) | (3.57) | (−1.88) | (−1.63) | (−2.08) | (2.72) | (2.95) |
| Maturity15 | 0.3662*** | 0.133*** | 922.1*** | 0.845** | −4.9258** | −27.7892*** | 0.083 | 4.5867*** | 0.057*** |
| | (4.43) | (5.87) | (4.8) | (2.37) | (−2.07) | (−2.85) | (0.21) | (6.09) | (3.7) |
| Maturity30 | 0.7754*** | 0.3463*** | 1503.6*** | −0.0075 | −7.0392*** | −52.8494*** | 0.2079 | 11.1736*** | 0.0764*** |
| | (9.63) | (12.96) | (5.94) | (−0.02) | (−2.96) | (−6.03) | (0.43) | (10.33) | (2.88) |
| TTM/Maturity | 0.8934*** | 0.3108*** | −2.2882 | 7.101*** | −46.4992** | −170.9104** | −0.1452 | 7.1542*** | 0.1275** |
| | (4.58) | (4.69) | (0) | (4.42) | (−2.07) | (−2.2) | (−0.09) | (2.9) | (2.53) |
| $TTM/Maturity^2$ | −0.6005** | −0.2192*** | 951.319 | −4.3921** | 37.8226** | 134.7314** | 1.3772 | −1.9287 | −0.0979* |
| | (−2.66) | (−2.87) | (1.38) | (−2.66) | (2.04) | (2.09) | (0.91) | (−0.71) | (−1.81) |
| $R^2$ | 0.9464 | 0.9653 | 0.868 | 0.742 | 0.453 | 0.6916 | 0.5854 | 0.9587 | 0.6587 |
| 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 6: (continued) Panel B presents the results from the cross-sectional regression (eq. 2) of time-averaged liquidity measures on bond characteristics and number of trades, defined in Section IV. The sub-sample consists of 89 Italian zero coupon and floating rate bonds. Heteroskedasticity-robust t-statistics are reported in parentheses. $R^2$ values are reported below the parameter estimates.

Panel B. Subsample: Non-Coupon-Bearing Bonds

| Variable | Quoted BA Spread | Effective Spread | Revision per SP | SingleProp 5 Min | Qty at Best | Total Quoted Qty | Log Var | Amihud Measure | Roll Measure |
|---|---|---|---|---|---|---|---|---|---|
| Intercept | −0.2465*** | −0.0704*** | −341.5283 | 12.6867*** | 39.1301*** | 206.5771*** | −27.8936*** | −1.3515** | −0.0213*** |
| | (−3.46) | (−3.19) | (−1.59) | (22.89) | (3.22) | (7.31) | (−28.11) | (−2.24) | (−3.94) |
| AmountIssued | −0.0055 | −0.0024 | 10.1156 | 0.0757 | 0.0529 | 1.5281 | 0.053 | −0.0426 | 0.0006 |
| | (−1.01) | (−1.28) | (0.6) | (1.66) | (0.11) | (1.33) | (0.6) | (−0.94) | (1.17) |
| Daily Trades | −0.0028 | −0.0012** | 12.4135* | −0.0912*** | −0.3381 | −1.0386 | 0.016 | −0.0405* | 0.0001 |
| | (−1.66) | (−2.38) | (1.89) | (−4.21) | (−0.87) | (−1.65) | (0.65) | (−1.79) | (0.38) |
| Floating[a] | 1.3431*** | 0.6896*** | 87.75 | −1.1157 | −26.1124 | −204.6272 | 5.8115*** | 9.5042*** | 0.1491*** |
| | (6.77) | (6.84) | (0.36) | (−0.82) | (−1.43) | (−1.63) | (2.78) | (3.81) | (4.44) |
| Maturity0.5 | 0.0655 | 0.0251* | −80.99 | 1.0906*** | 0.2354 | 5.6021 | 0.9776 | 0.3876 | −0.0007 |
| | (1.66) | (1.95) | (−0.62) | (2.91) | (0.08) | (0.69) | (1.63) | (1.28) | (−0.21) |
| Maturity1 | 0.1581*** | 0.056*** | 272.1** | 1.6236*** | −3.33 | −2.6295 | 2.8753*** | 0.6755** | 0.0068** |
| | (4.44) | (4.64) | (2.23) | (4.85) | (−1.38) | (−0.34) | (5.64) | (2.51) | (2.3) |
| Maturity2 | 0.3249*** | 0.1025*** | 714.00*** | 1.6684*** | 11.3725 | 16.294 | 5.9406*** | 1.448*** | 0.019*** |
| | (5.21) | (5.42) | (3.61) | (3.32) | (1.36) | (1.06) | (6.29) | (3.15) | (2.72) |
| Floating*AmountIssued | −0.0303* | −0.0207*** | −22.82 | 0.0681 | 1.1121 | 8.9757 | 0.0908 | −0.1553 | −0.0056*** |
| | (−1.97) | (−3.35) | (−1.05) | (0.68) | (1) | (1.2) | (0.7) | (−0.89) | (−3.5) |
| Floating*Daily Trades | −0.0859** | −0.0706*** | 162.90*** | −0.0317 | 3.3486 | 32.4585 | 0.4827 | −1.0625** | −0.0121** |
| | (−2.21) | (−4.23) | (3.75) | (−0.14) | (0.97) | (1.59) | (1.38) | (−2.47) | (−2.03) |
| TTM/Maturity | 1.1035*** | 0.3377*** | 4729.05*** | 3.2101** | −86.0039* | −288.408*** | 27.2051*** | 4.6169** | 0.0963*** |
| | (5.63) | (5.38) | (8.26) | (2.05) | (−1.98) | (−2.92) | (8.51) | (2.43) | (5.48) |
| $TTM/Maturity^2$ | −0.8266*** | −0.2508*** | −4348.71*** | 1.238 | 64.2607 | 189.2162** | −22.3782*** | −2.1919 | −0.0882*** |
| | (−4.54) | (−4.26) | (−7.18) | (0.77) | (1.6) | (2.23) | (−7.18) | (−1.17) | (−4.38) |
| R−Squareest | 0.8725 | 0.8941 | 0.6603 | 0.7597 | 0.4351 | 0.5104 | 0.8622 | 0.7782 | 0.7201 |
| N | 89 | 89 | 89 | 89 | 89 | 89 | 89 | 89 | 89 |

[a] Floating coupon bonds have a maturity of 6 years
[*] Significant at a 10% level. [**] Significant at a 5% level. [***] Significant at a 1% level.

Table 7: **Results for the Time-series Regressions of Liquidity Measures on CDS Spread.** 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 of data contribute to the estimation, due to the differencing. Heteroskedasticity-robust t-test statistics are reported under the parameters. The estimated equation is $\Delta LM_t = \beta_0 + \beta_1 \Delta CDS_t + \beta_2 \left(\Delta CDS_t\right)^2 + \beta_3 TradedQuantity_t + \epsilon_t$, where $\Delta LM$ is one of our liquidity measures: *Quoted bid-ask Spread, Effective Spread, Revision per Single Proposal, Single Proposals 5min, Quoted Quantity at Best, Total Quoted Quantity, Log-Var, Amihud Measure, and Roll Measure*. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

| Variable | Quoted BA Spread | Effective Spread | Revision per SP | SingleProp 5 Min | Qty at Best | Total Quoted 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 |
| | (−2.22) | (−2.12) | (−0.05) | (0.82) | (0.32) | (0.62) | (−1.64) | (−1.28) | (0.03) |
| ΔCDS | 0.0031** | 0.0007** | −0.3492 | −0.0157** | −0.0023 | −0.1089** | 0.0045 | 0.0362* | 0 |
| | (2.01) | (2.14) | (−0.45) | (−2.21) | (−0.42) | (−2.36) | (1.1) | (1.85) | (0.67) |
| $\Delta CDS^2$ | 0.0001* | 0.00002** | 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) | (−0.27) |
| ΔTradedQuantity | −0.0207** | −0.0123*** | 46.0991*** | −0.2357 | −0.1271 | −2.1274* | 0.1296** | 0.0668 | 0.0016*** |
| | (−2.14) | (−4.61) | (3.51) | (−1.46) | (−1.25) | (−1.91) | (2.49) | (0.4) | (3.11) |
| $R^2$ | 0.1124 | 0.1257 | 0.0234 | 0.0232 | 0.0081 | 0.0254 | 0.0463 | 0.0444 | 0.0197 |
| 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 8: **Results for the Panel Regressions of Liquidity Measures.** This table presents the result from the panel regression (eq. 4). Panel A presents the result from daily data for 59 Italian coupon-bearing bonds. Liquidity variables, defined in Section IV, are regressed on the ratio between time-to-maturity and maturity, DumTrades, which equals 1 if the $i$ bond traded on day $t$ and zero otherwise, and the interaction between dummies for different maturities and ΔCDS, the change in cds, Below500 (Above500), which equals one when the CDS spread is below 500 (above 500) and zero otherwise. Bond-specific fixed effects are included in the analysis but their estimates are not shown. The statistical significance refers to $t$-tests based on a robust covariance matrix adjusted for clustering at a bond level. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

Panel A. Subsample: Coupon Bearing Bonds

| Variable | Quoted BA Spread | Effective Spread | Revision per SP | SingleProp 5 Min | Qty at Best | Total Quoted Qty | Log Var | Amihud Measure | Roll Measure |
|---|---|---|---|---|---|---|---|---|---|
| $\Delta LM_{it-1}$ | −0.3608*** | −0.4193*** | −0.4066*** | −0.2885*** | −0.3598*** | −0.3586*** | −0.4293*** | −0.4371*** | −0.07*** |
| TTM/Maturity | 0.0185* | 0.011 | 78.4203*** | 0.0972 | −0.1791 | −1.7206* | 0.1645*** | 0.4924 | 0 |
| DumTrades | −0.0532*** | – | −62.6959*** | −0.1775*** | −0.5053*** | −1.5202*** | 0.1659*** | – | −0.022** |
| | | | | | | | | | |
| Below500*ΔCDS*Maturity30 | −0.0005 | −0.0007 | −2.9973*** | −0.0134*** | −0.002 | −0.0401*** | −0.0027*** | −0.0565 | 0.0001 |
| Below500*ΔCDS*Maturity15 | −0.0012 | 0.0003 | −2.1246*** | −0.0124*** | 0.0007 | −0.0253*** | −0.0008 | 0.0379 | 0 |
| Below500*ΔCDS*Maturity10 | −0.0012*** | 0 | −0.9929 | −0.0104*** | −0.0038 | −0.0349*** | 0.0016** | 0.0177 | 0 |
| Below500*ΔCDS*Maturity5 | 0.0002* | 0.0004** | 1.1919*** | −0.0147*** | 0.0001 | −0.0598*** | 0.0063*** | 0.0047 | 0 |
| Below500*ΔCDS*Maturity3 | 0.0001 | 0.0004* | 0.0676 | −0.0141*** | −0.0041 | −0.0368** | 0.0025 | 0.0081** | 0 |
| | | | | | | | | | |
| Above500*ΔCDS*Maturity30 | 0.0321*** | −0.0026 | −4.8015*** | −0.0196*** | 0.0027*** | −0.0927*** | 0.0069*** | −0.2123 | 0.0002 |
| Above500*ΔCDS*Maturity15 | 0.0178*** | 0.0021*** | −2.7138 | −0.0203*** | −0.0008 | −0.1139*** | 0.0148*** | 0.1824 | 0 |
| Above500*ΔCDS*Maturity10 | 0.0074*** | 0.0018** | 1.2121* | −0.022*** | −0.0073* | −0.1471*** | 0.0119*** | −0.0068 | 0 |
| Above500*ΔCDS*Maturity5 | 0.0053*** | 0.002*** | −0.4606 | −0.0204*** | −0.0092** | −0.1482*** | 0.0139*** | 0.0155** | 0 |
| Above500*ΔCDS*Maturity3 | 0.0066*** | 0.0024*** | −0.3009 | −0.0208*** | −0.0159 | −0.188*** | 0.0165*** | 0.021 | 0 |
| Bond-FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.20 | 0.19 | 0.17 | 0.09 | 0.13 | 0.14 | 0.20 | 0.22 | 0.01 |
| N | 19369 | 6558 | 19369 | 19369 | 19369 | 19369 | 19369 | 6366 | 6374 |

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

Table 8: Panel B presents the result from daily data for 89 Italian non-coupon-bearing bonds quoted on the MTS system between June 2011 and November 2012. Liquidity variables, defined in Section IV, are regressed on the ratio between time-to-maturity and maturity, DumTrades, which equals 1 if the $i$ bond traded on day $t$ and zero otherwise, and the interaction between dummies for different maturities and ΔCDS, the change in cds, Below500 (Above500), which equals one when the CDS spread is below 500 (above 500) and zero otherwise. Bond-specific fixed effects are included in the analysis but their estimates are not shown. The statistical significance refers to $t$-tests based on a robust covariance matrix adjusted for clustering at a bond level.

Panel B. Subsample: Zero Coupon Bonds and Floating Bonds

| Variable | Quoted BA Spread | Effective Spread | Revision per SP | SingleProp 5 Min | Qty at Best | Total Quoted Qty | Log Var | Amihud Measure | Roll Measure |
|---|---|---|---|---|---|---|---|---|---|
| $\Delta LM_{it-1}$ | −0.3856*** | −0.4147*** | −0.3922*** | −0.2943*** | −0.439*** | −0.3854*** | −0.4338*** | −0.3766*** | 0.0186 |
| TTM/Maturity | 0.009** | 0.0045 | 21.074 | 0.5361*** | −0.4354 | 2.7107*** | 0.1724*** | 0.0778 | 0.0003 |
| DumTrades | −0.0339*** | – | −4.7184 | −0.026 | −0.1326 | 1.4802 | 0.3004*** | – | −0.001 |
| | | | | | | | | | |
| Below500*ΔCDS*Floating[a] | 0.0022*** | 0.0004 | 3.1435*** | −0.0066*** | 0.0001 | −0.1126 | 0.0102*** | 0.0276** | 0 |
| Below500*ΔCDS*Maturity2 | 0.0006*** | 0.0004** | 1.1733 | −0.0208*** | −0.0648*** | −0.2191*** | 0.0075*** | 0.0072** | 0.0001 |
| Below500*ΔCDS*Maturity1 | 0.0005*** | 0.0006*** | 2.266*** | −0.0215*** | −0.006 | −0.1556*** | 0.0092*** | 0.0046** | 0 |
| Below500*ΔCDS*Maturity0.5 | 0.0002*** | 0.0001 | 1.0026 | −0.0232*** | 0.0087 | −0.1468*** | 0.0092*** | −0.0005 | 0 |
| Below500*ΔCDS*Maturity0.25 | 0.0002** | 0.0002* | 8.322*** | −0.0342** | −0.0216 | −0.2064*** | 0.0063 | −0.0007 | 0 |
| | | | | | | | | | |
| Above500*ΔCDS*Floating[a] | 0.0118*** | 0.0046*** | −2.6366*** | −0.0242*** | −0.0173 | −0.1653*** | 0.0243*** | 0.0911 | 0 |
| Above500*ΔCDS*Maturity2 | 0.0099*** | 0.0015*** | −2.6081 | −0.0349*** | 0.0779 | −0.2498*** | 0.0237*** | 0.0278*** | 0.0001* |
| Above500*ΔCDS*Maturity1 | 0.0042*** | 0.0014*** | −6.8563*** | −0.0288*** | 0.0017 | −0.2459*** | 0.0233*** | 0.0206*** | 0 |
| Above500*ΔCDS*Maturity0.5 | 0.0024*** | 0.0007* | −1.0482 | −0.033*** | −0.0349 | −0.2828*** | 0.0256*** | 0.0061 | 0.0001 |
| Above500*ΔCDS*Maturity0.25 | 0.0011*** | 0.0003*** | −2.3545** | −0.0299*** | 0.0244 | −0.2209*** | 0.0218*** | 0.0041 | −0.0001*** |
| Bond-FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.22 | 0.20 | 0.16 | 0.10 | 0.19 | 0.15 | 0.22 | 0.19 | 0.01 |
| N | 14165 | 3774 | 14165 | 14165 | 14165 | 14165 | 14160 | 3667 | 3583 |

[a] Floating coupon bonds have a maturity of 6 years

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

Table 9: **Results for the Granger Causality Analysis.** This table presents the results of the Granger causality test. A VAR(p) is fitted for every period/variable combination. The variables are the changes in CDS and in the trading, quoting, and liquidity measures. The number of lags is determined by considering the minimization of the AICC while ensuring non-autocorrelation in the residuals. The null hypothesis is that the $p$ cross elements linking Var 1 to Var 2'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 was conducted on the overall sample, in the sub-period up to November 2011, and in the one since January 2012. Such sample partitioning allows us to verify whether the LTRO announcement and introduction caused a shift in Granger causality between the CDS and the liquidity measures. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

| 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 *** |
| Up to November 2011 | CDS | Bid-Ask Spread | 6 | 12.42 | 0.0532 * |
| Up to 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 *** |
| Up to November 2011 | CDS | Effective Spread | 3 | 6.62 | 0.0852 * |
| Up to 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 | Revisions per SP | 4 | 5.08 | 0.2792 |
| All | Revisions per SP | CDS | 4 | 7.59 | 0.1080 |
| Up to November 2011 | CDS | Revisions per SP | 4 | 7.06 | 0.1328 |
| Up to November 2011 | Revisions per SP | CDS | 4 | 5.68 | 0.2243 |
| From January 2012 | CDS | Revisions per SP | 4 | 3.16 | 0.5312 |
| From January 2012 | Revisions 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 |
| Up to November 2011 | CDS | Single Proposals (5min) | 4 | 4.82 | 0.3063 |
| Up to 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 *** |
| Up to November 2011 | CDS | Quantity at Best | 3 | 3.80 | 0.2840 |
| Up to 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 9: Granger Causality Analysis (continued)

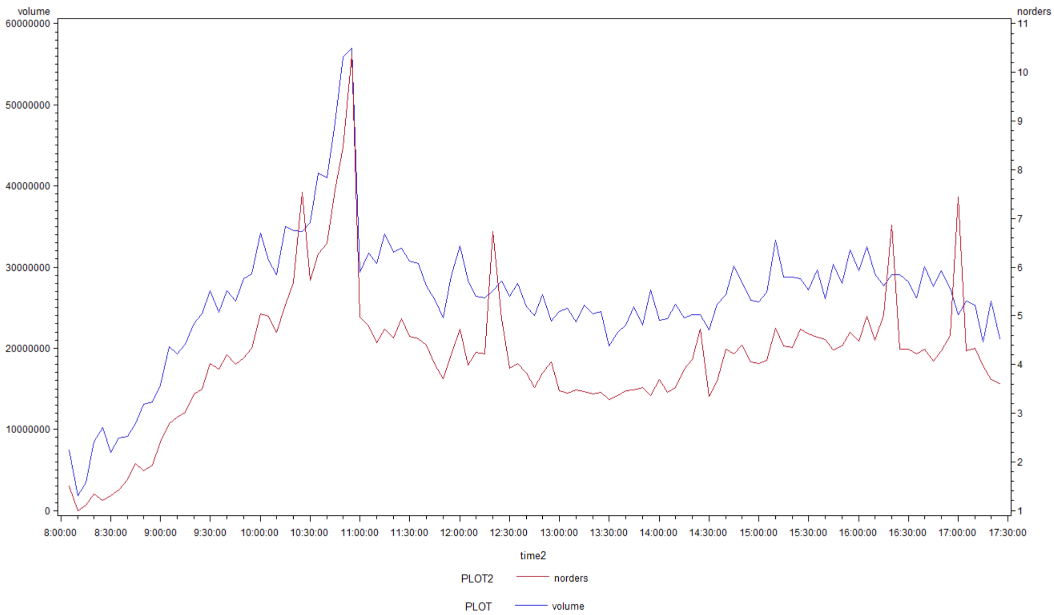
| Sample | Var 1 Caused by Var 2 | | Lags | Test Value | P-Value |
|---|---|---|---|---|---|
| All | CDS | Quoted Quantity | 4 | 7.52 | 0.1107 |
| All | Quoted Quantity | CDS | 4 | 2.56 | 0.6342 |
| Up to November 2011 | CDS | Quoted Quantity | 4 | 4.06 | 0.3977 |
| Up to November 2011 | Quoted Quantity | 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 |
| Up to November 2011 | CDS | Log Var | 4 | 0.98 | 0.9130 |
| Up to 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 ** |
| Up to November 2011 | CDS | Amihud Measure | 6 | 15.17 | 0.0190 ** |
| Up to 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 | 3 | 1.45 | 0.6929 |
| All | roll | CDS | 3 | 2.00 | 0.5721 |
| Until November 2011 | CDS | roll | 3 | 3.19 | 0.3635 |
| Until November 2011 | roll | CDS | 3 | 2.38 | 0.4972 |
| From January 2012 | CDS | roll | 3 | 1.45 | 0.6941 |
| From January 2012 | roll | CDS | 3 | 5.56 | 0.1352 |

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

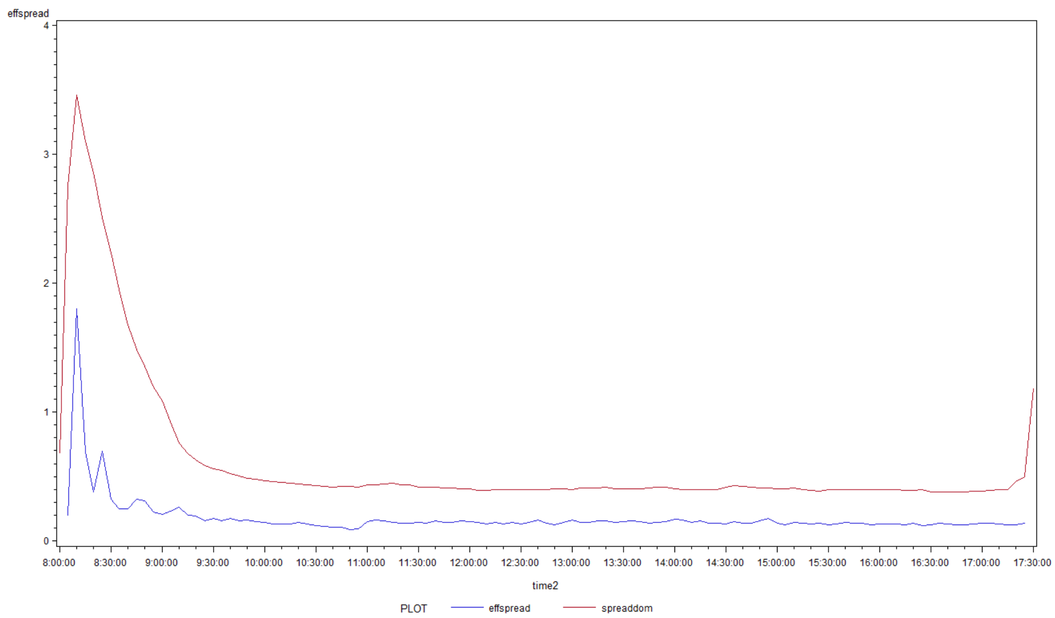
Table 10: **Event-Days for the Case Study** This table presents the event dates chosen as day 0 in our case-study analysis, and the corresponding CDS levels and changes in CDS level ($\Delta CDS_t = CDS_t - CDS_{t-1}$). Our data set consists of daily data for the 5-year US dollars denominated CDS contracts in the Italian Sovereign Bonds, from June 1, 2011 to November 15, 2012. Our CDS data are fromThomson-Reuters-Datastream.

| Date | $\Delta CDS_t$ | $CDS_t$ |
|---|---|---|
| August 08, 2011 | -49.47 | 336.21 |
| September 20, 2011 | 53.90 | 502.22 |
| September 27, 2011 | -51.77 | 445.77 |
| October 27, 2011 | -51.04 | 402.40 |
| November 01, 2011 | 77.53 | 517.06 |
| November 09, 2011 | 50.33 | 564.64 |
| December 08, 2011 | 52.58 | 524.44 |
| June 29, 2012 | -49.26 | 480.99 |

# IX Figures

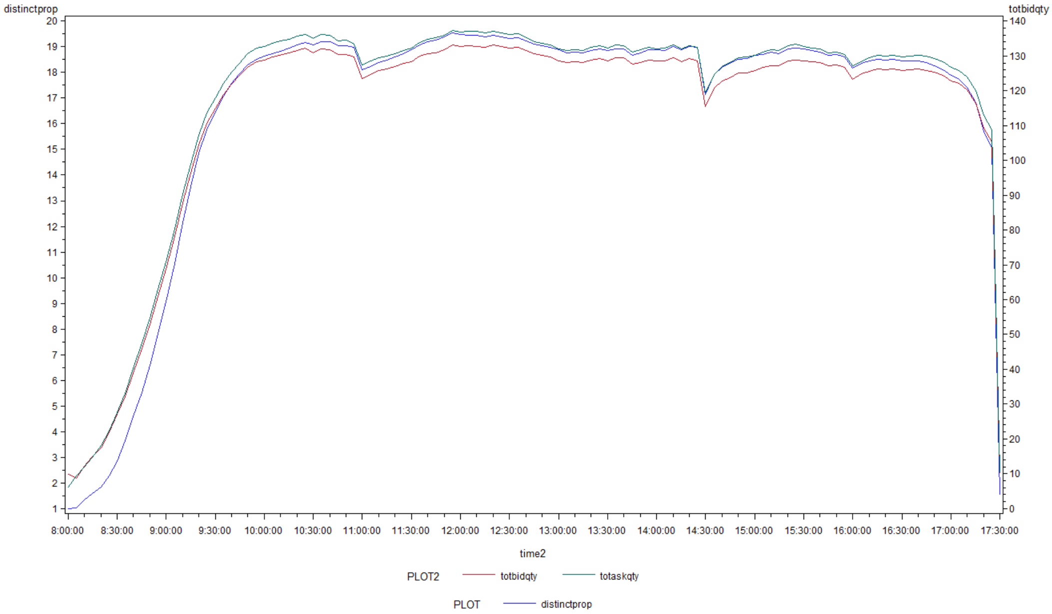



(a) Intraday Traded Quantity and Number of Orders

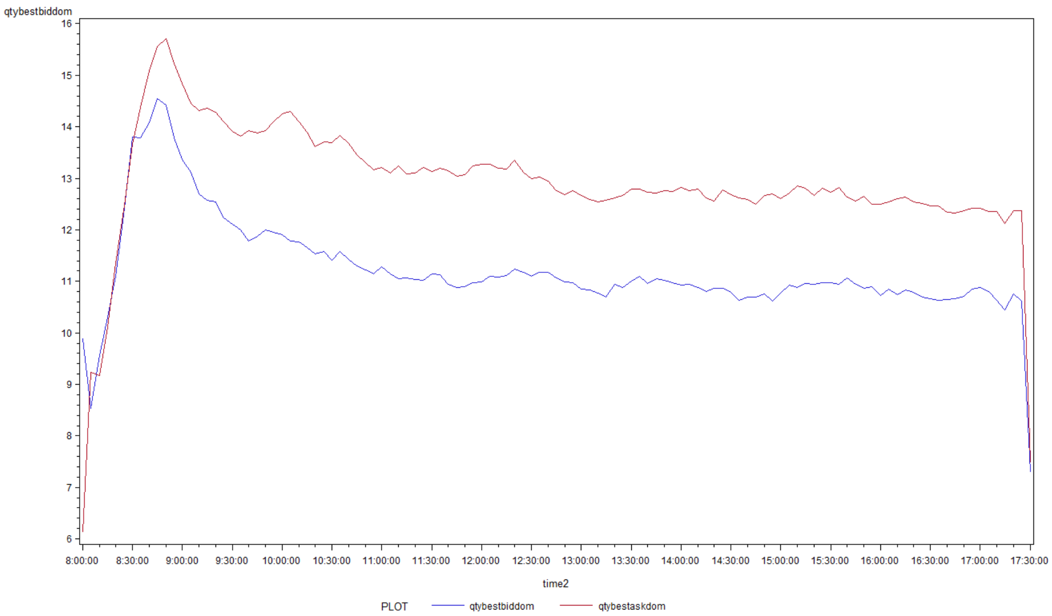



(b) Intraday Quoted and Effective Spread

Figure 1: **Intraday Movements in Trading and Liquidity Measures.** The measures are calculated with a 5-minute frequency and averaged across the days in the sample. *Number of Orders* is the number of orders submitted, and *Traded Quantity* is the executed quantity (millions of euros) of orders. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

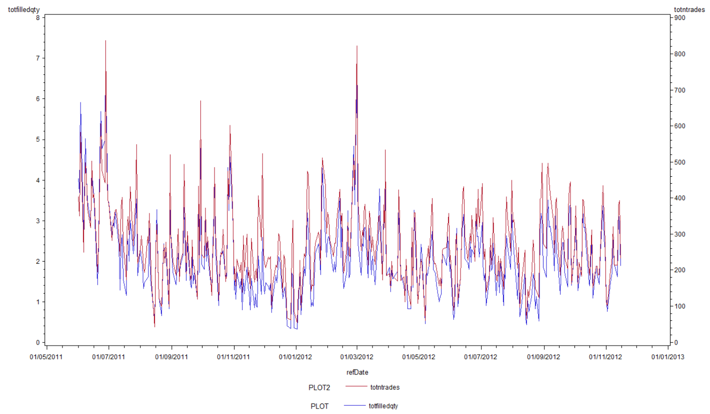



(a) Intraday Distinct Proposals and Total Quoted Bid- and Ask-Quantities

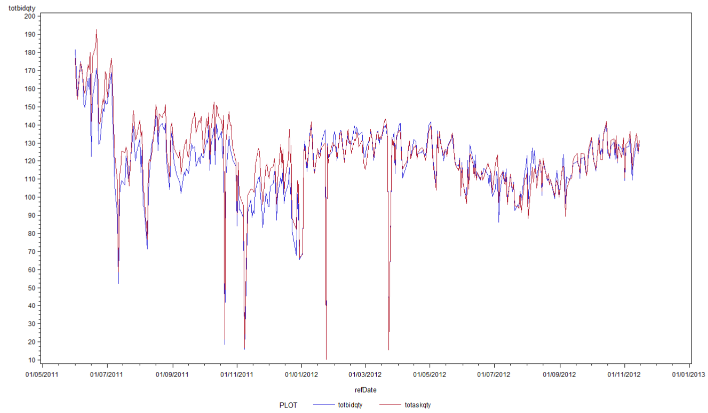



(b) Intraday Quoted Quantity at the Best Bid-(blue) and Ask-(red) Price.

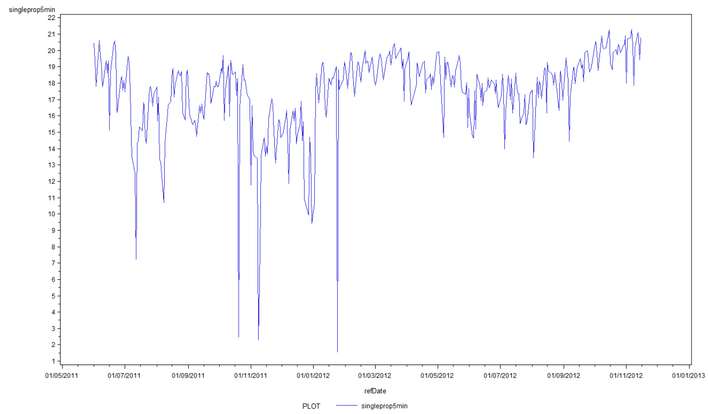
Figure 2: **Intraday Movements in Quoted Quantities**. The measures are calculated with a 5-minute frequency and averaged across the days in the sample. The *Quoted Quantities (Total and Best Bid/Ask))* are expressed in millions of euros. The market is open from 8:00 am to 5.30 pm. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.




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

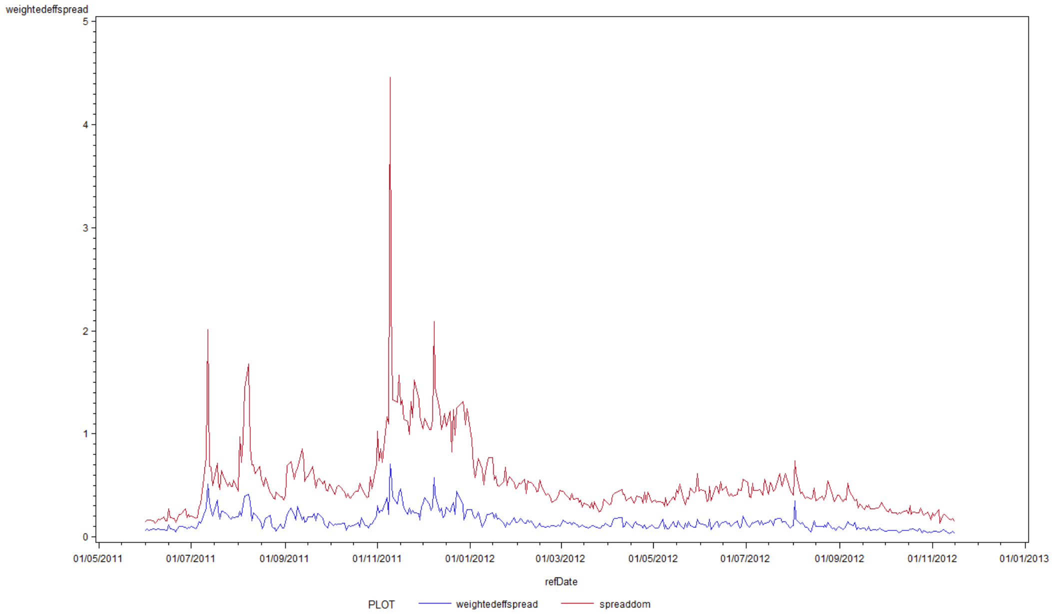



(b) Total Quoted Bid-(blue) and Ask-Quantities (red).

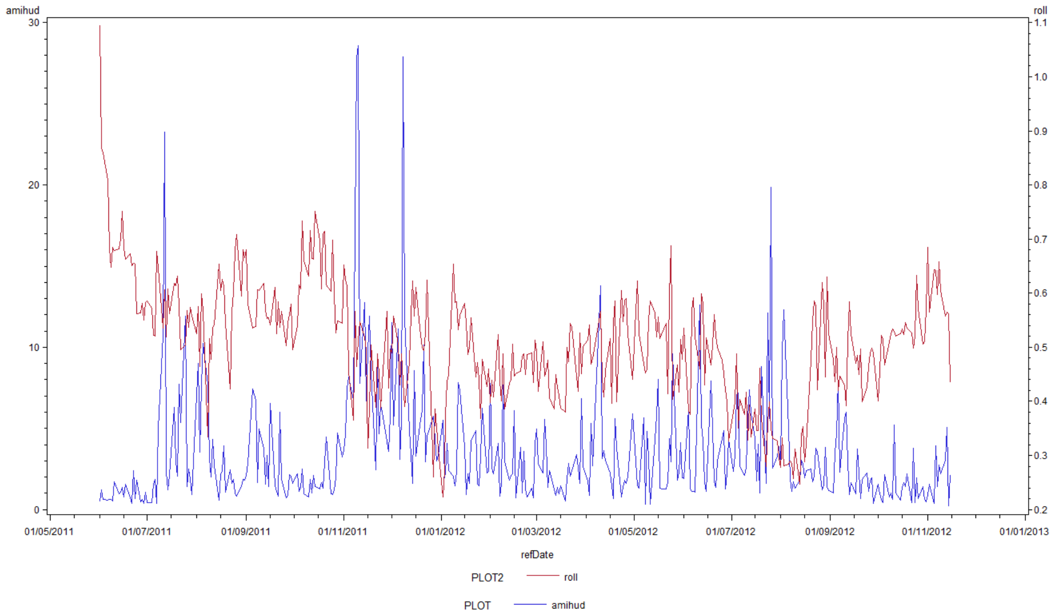



(c) Single Proposals

Figure 3: **Time-Series Evolution of Market-wide Liquidity Measures**. *Total Quoted Quantities* are expressed in millions of euros per bond; the *Traded Quantity* is the overall market quantity and is expressed in billions of euros.Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

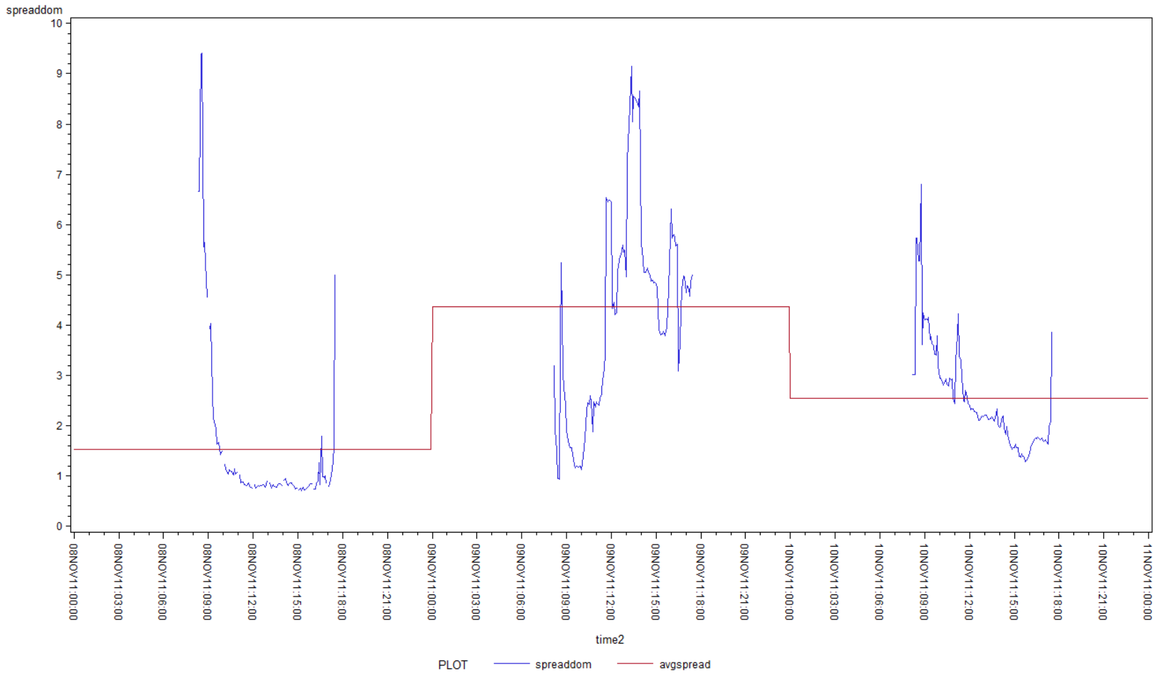



(a) Quoted and Effective Bid-Ask Spread

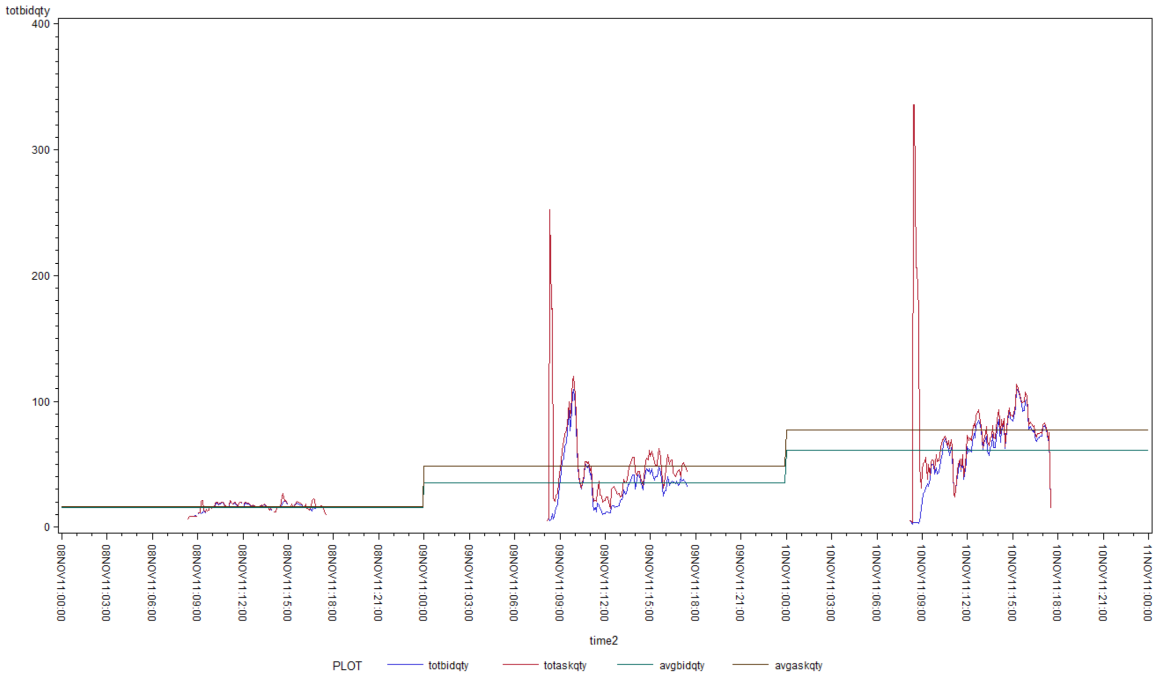



(b) Amihud and Roll Measure

Figure 4: **Time series evolution of market-wide liquidity measures.** The *Quoted Bid-Ask Spread*, and the *Roll and Amihud Measures* are averaged across the bond for every day in the sample. *Effective Spread* is a share-weighted average. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.




(a) Intraday Bid-Ask Spread Around November 9, 2011




(b) Quoted Quantity and Daily Averages Around November 9, 2011

Figure 5: **Intraday Movements of Liquidity Measures Around November 9, 2011.** Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

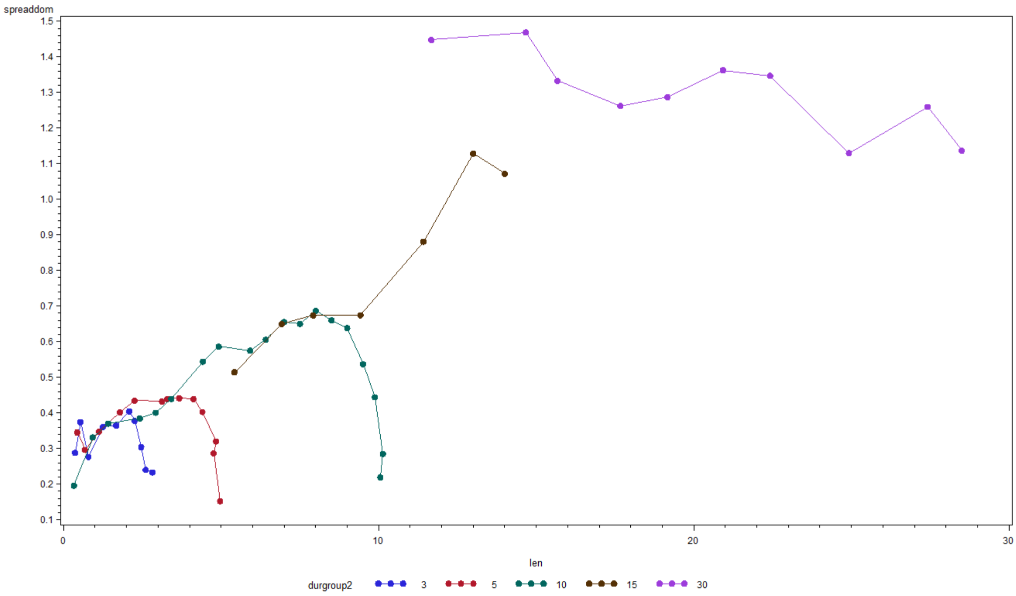



Figure 6: **Cross-sectional Relationship between *Bid-ask Spread* and *Time-to-Maturity*.** This figure shows the non-linear relationships between *Age* or *Time-to-Maturity* and *Maturity* in the cross-section. Every dot is one of the 58 coupon-bearing bonds in the sample. The y-axis is the *Quoted Bid-Ask Spread*, while the x-axis is the *Time-to-Maturity*. Different colors correspond to different maturity groups. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

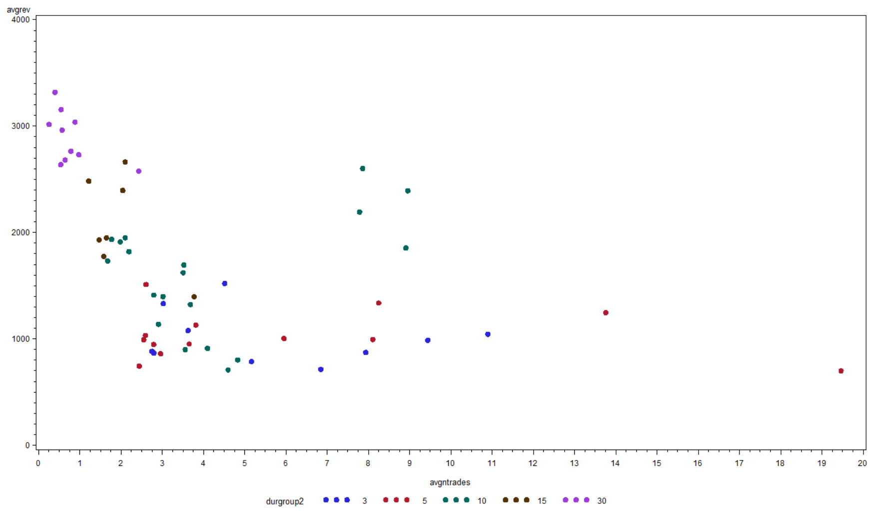



Figure 7: **Cross-sectional Relationship between *Revisions per Single Proposal* and *Daily Trades*.** This figure shows the non-linear relationship between *Revisions per Single Proposal* and *Daily Trades*. Every dot is one of the 58 coupon-bearing bonds in the sample. The y-axis is the *Quoted Bid-Ask Spread*, while the x-axis is the *Time-to-Maturity*. Different colors correspond to different maturity groups. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

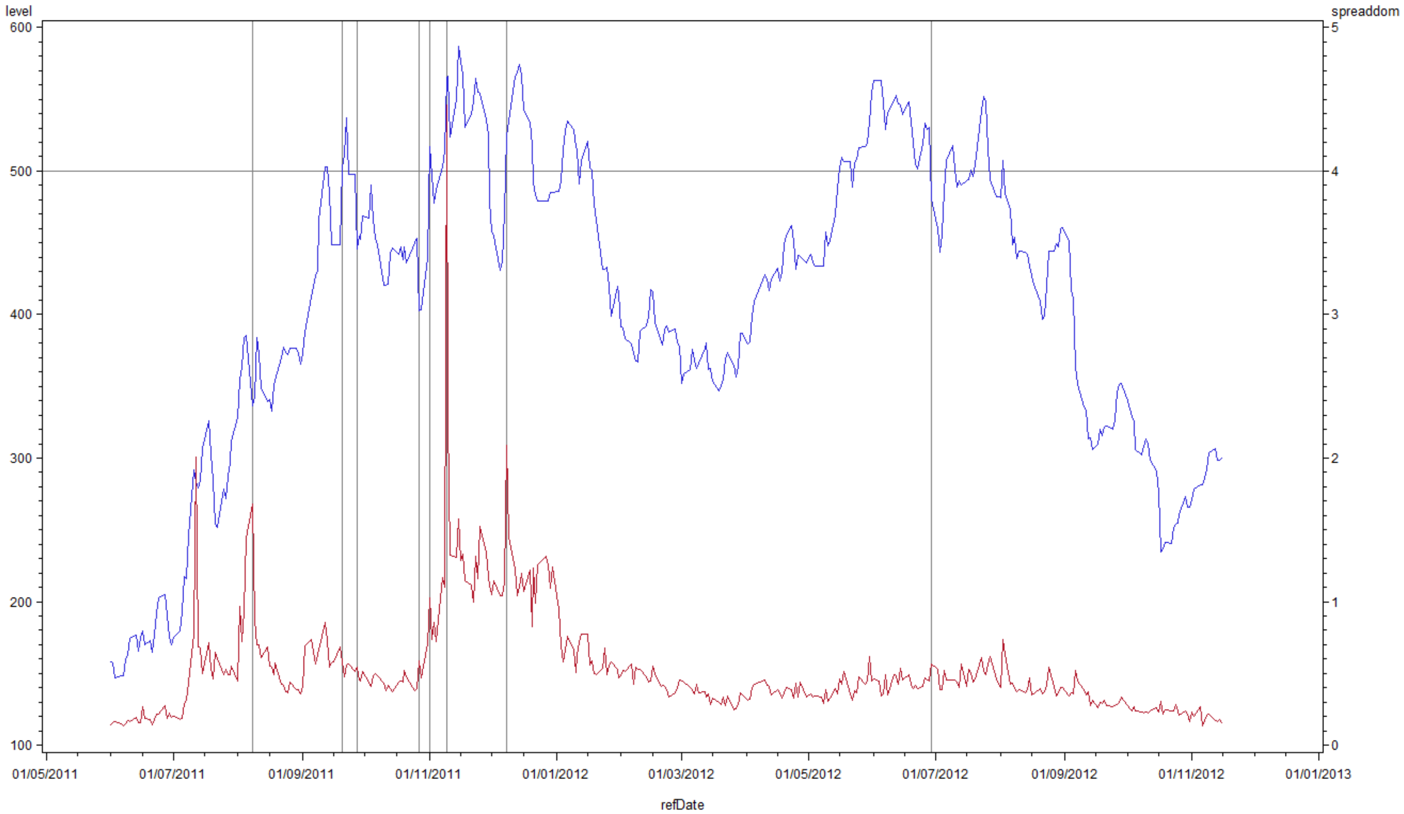
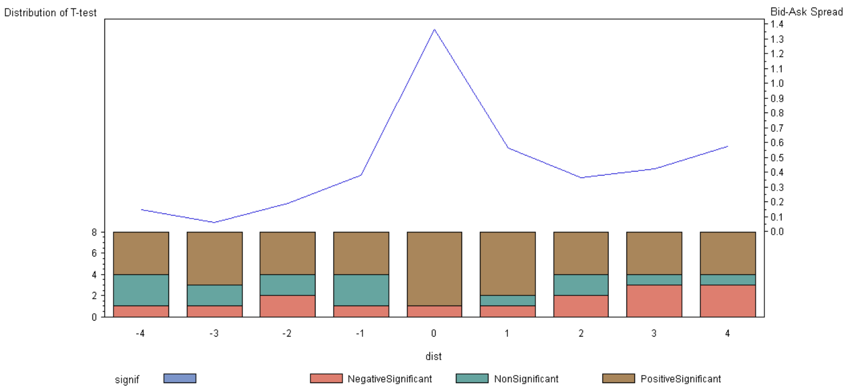
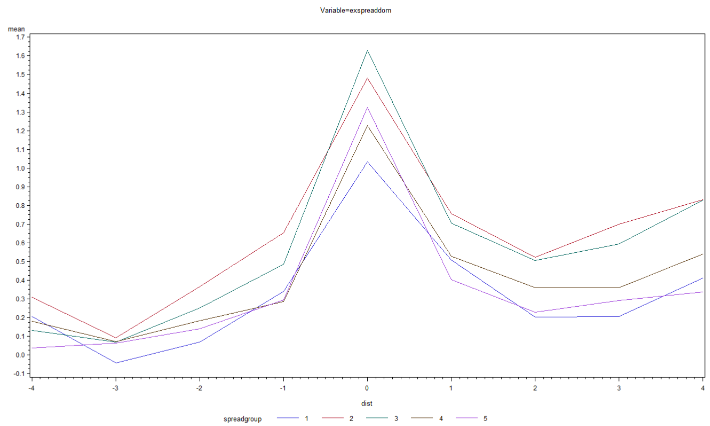



Figure 8: **Time series evolution of the CDS spread for Italian Government Bonds and Market-Wide Bid-Ask Spread.** This figure shows the evolution of the CDS spread for the Italian Sovereign based on the 5-year US dollar denominated CDS contract (left axis), and Bid-Ask Spread (right axis) for Italian Government Bonds. The day-0 dates used in the case study and presented in Table 10 are marked with vertical lines. The horizontal line shows the 500bp threshold used in the panel analysis.

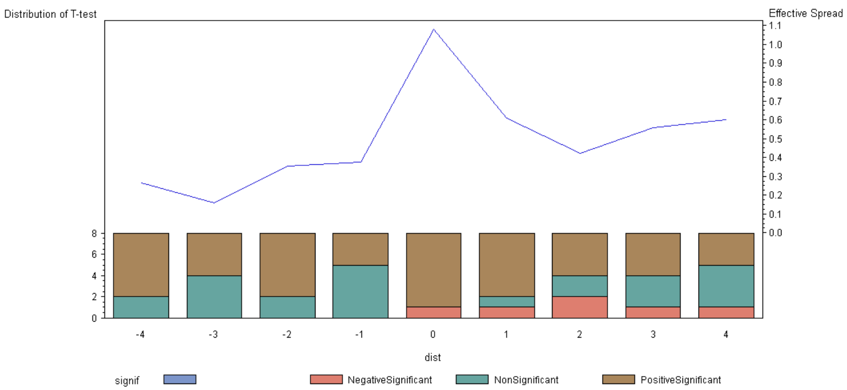
Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (Buoni Ordinari del Tesoro (BOT) or Treasury Bills or Certificato del Tesoro Zero-coupon (CTZ) or Zero coupon bonds, Certificati di Credito del Tesoro (CCT) or Floating notes, and Buoni del Tesoro Poliennali (BTP) or Fixed-income Treasury Bonds) from June 1, 2011 to November 15, 2012. Data for the 5-year Italian Dollar-denominated CDS spreads are from Thomson-Reuters-Datastream.



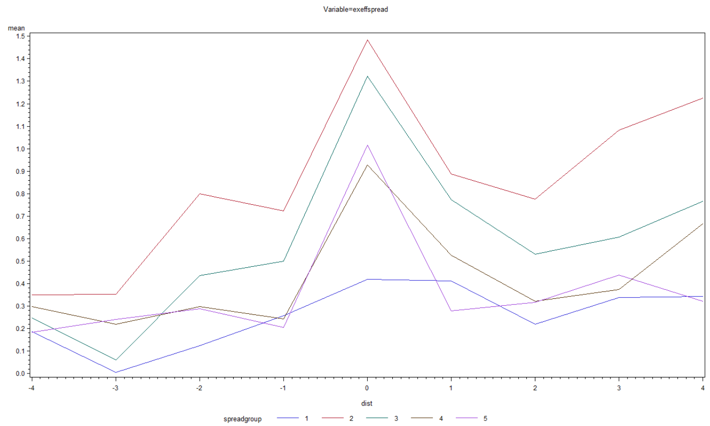

(a) *Bid-Ask Spread* – All Sample




(b) *Bid-Ask Spread* – Coupon-Bearing Bonds, by Activity Quantile

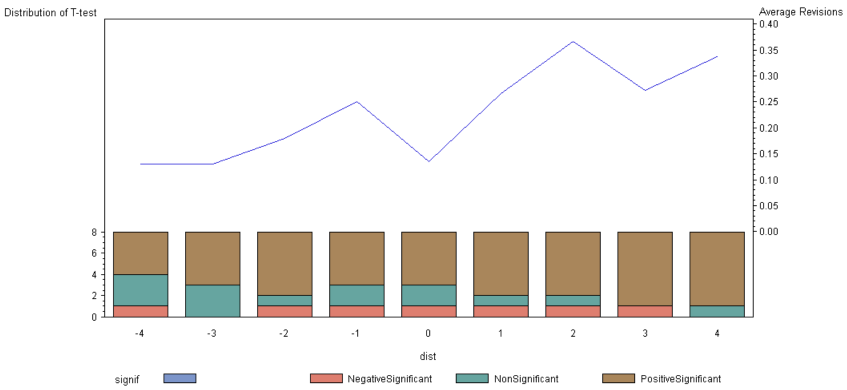



(c) *Effective Spread* – All Sample

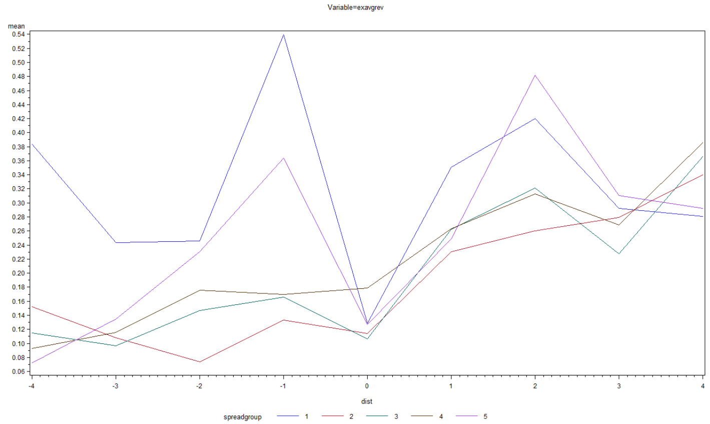



(d) *Effective Spread* – Coupon-Bearing Bonds, by Activity Quantile

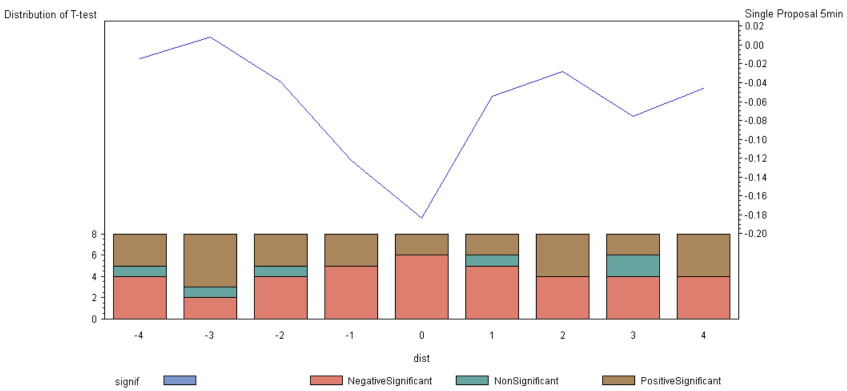
Figure 9: **Daily Movements of Liquidity Measures Around Extreme CDS Spread Changes.** Panels a and c show the results for the overall sample. The plot shows the mean of the abnormal measure, while the bars show the significance of the 8 event-specific tests at a 10% level. Panel b and d show the results for coupon-bearing bonds only. The analysis for coupon-bearing bonds was conducted separately on 5 trading-based quintiles. The measures were calculated for 4 days before and 4 days after the extreme CDS movement (day 0) and compared to the median of the same measure between day -10 and day -19. The day 0 dates are shown in Table 10. For the coupon-bearing bond subsample, the bonds are divided into quintiles using the distribution of *Bid-Ask Spread*, that is the quintile marked by 1 groups 20% of all bonds, with the lowest average bid-ask spread. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.



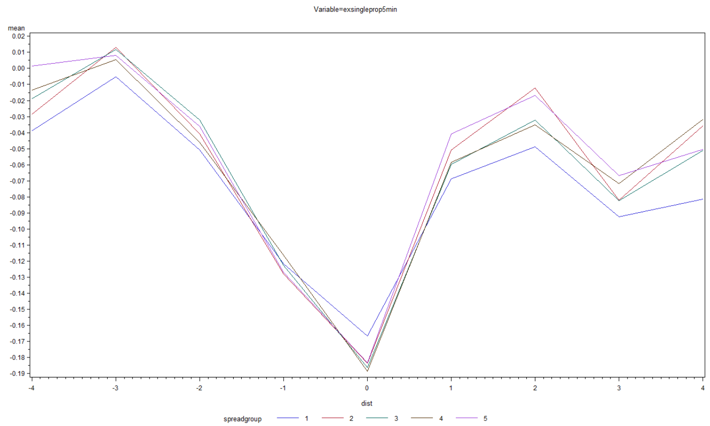

(a) *Average Revision per SP* – All Sample




(b) *Average Revision per SP* – Coupon-Bearing Bonds, by Activity Quantile

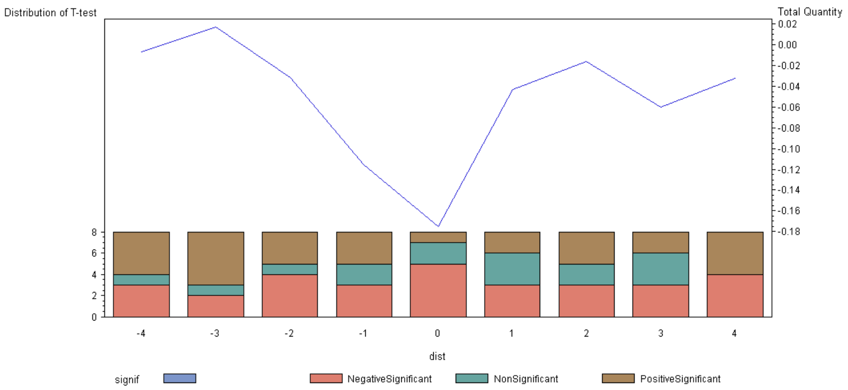



(c) *Single Proposals 5min* – All Sample

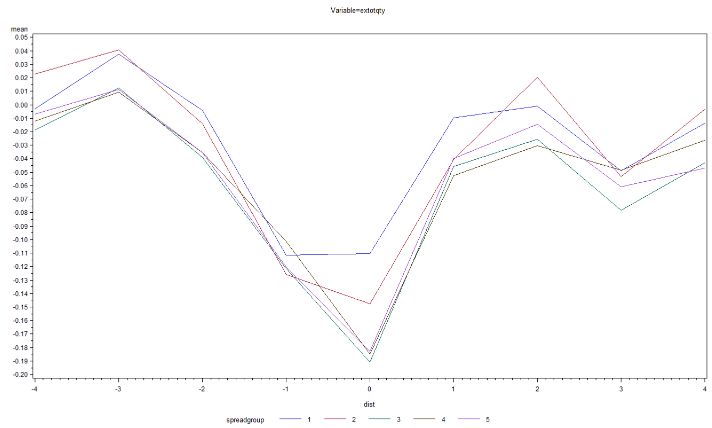



(d) *Single Proposals 5min* – Coupon-Bearing Bonds, by Activity Quantile

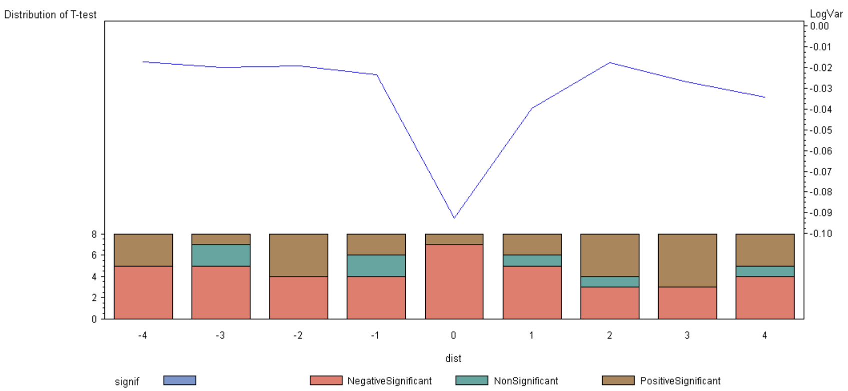
Figure 10: **Daily Movements of Liquidity Measures Around Extreme CDS Spread Changes.** Panels a and c show the results for the overall sample. The plot shows the mean of the abnormal measure, while the bars show the significance of the 8 event-specific tests at a 10% level. Panel b and d show the results for coupon-bearing bonds only. The analysis for coupon-bearing bonds was conducted separately on 5 trading-based quintiles. The measures were calculated for 4 days before and 4 days after the extreme CDS movement (day 0) and compared to the median of the same measure between day -10 and day -19. The day 0 dates are shown in Table 10. For the coupon-bearing bond subsample, the bonds are divided into quintiles using the distribution of *Bid-Ask Spread*, that is the quintile marked by 1 groups 20% of all bonds, with the lowest average bid-ask spread. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.



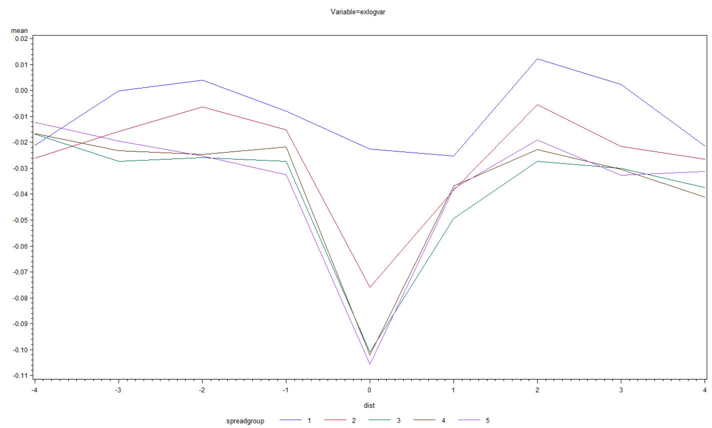

(a) *Total Quoted Quantity* – All Sample




(b) *Total Quoted Quantity* – Coupon-Bearing Bonds, by Activity Quantile




(c) *LogVar* – All Sample




(d) *LogVar* – Coupon-Bearing Bonds, by Activity Quantile

Figure 11: **Daily Movements of Liquidity Measures Around Extreme CDS Spread Changes.** Panels a and c show the results for the overall sample. The plot shows the mean of the abnormal measure, while the bars show the significance of the 8 event-specific tests at a 10% level. Panel b and d show the results for coupon-bearing bonds only. The analysis for coupon-bearing bonds was conducted separately on 5 trading-based quintiles. The measures were calculated for 4 days before and 4 days after the extreme CDS movement (day 0) and compared to the median of the same measure between day -10 and day -19. The day 0 dates are shown in Table 10. For the coupon-bearing bond subsample, the bonds are divided into quintiles using the distribution of *Bid-Ask Spread*, that is the quintile marked by 1 groups 20% of all bonds, with the lowest average bid-ask spread. Our data set consists of transactions, quotes, and orders for all 148 fixed-rate and floating Italian government bonds (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) from June 1, 2011 to November 15, 2012.

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