Research Article

Linas Jurksas*

What Factors Shape the Liquidity Levels of Euro Area Sovereign Bonds?

https://doi.org/10.1515/openec-2018-0009
Received June 7, 2018; accepted November 7, 2018

Abstract: The purpose of this paper is to determine the factors that shape the liquidity levels of euro area sovereign bonds. The values of liquidity measure and explanatory variables were calculated from the limit-order book dataset for almost five hundred bonds from six largest euro area sovereign bond markets. The created variables were used in a cross-sectional regression model. The results revealed that characteristics of sovereign bonds are indeed highly linked with bond liquidity levels, and these effects become even stronger during the regimes of lower market liquidity. Contrary to the statements of market participants and findings of many other studies, the magnitude of trading automation and obligatory requirements imposed on dealers were found to be negatively linked with the liquidity level of sovereign bonds.

Keywords: sovereign bonds, liquidity level, bond characteristics, trading features, cross-sectional regression.
JEL Classification: C21, G12, G14, G21.

1 Introduction

Which sovereign bond characteristics determine bond liquidity level? Is bond liquidity improved by quoting activity of automated algorithms? Are strict requirements imposed on dealers effective in improving liquidity? These and similar problematical questions are often raised by sovereign bond issuers, investors, analysts and regulators, but the answers are not clear-cut in the rapidly changing bond trading environment. Besides, the conclusions might differ under various market liquidity conditions.

Market liquidity, i.e., the ease and speed of trading, becomes a particularly acute concern for investors largely when a certain shock hits the market. While the current sovereign bond market condition is most often characterized as quite liquid, history has shown that liquidity dry-ups emerge much quicker than liquidity improvements, so market participants must always be prepared for the liquidity reversal. And when this reversal occurs, investors should be ready to change their quoting and trading actions because then different factors might be driving market liquidity than compared to regular circumstances. Meanwhile, policymakers need to proactively monitor liquidity developments and have a strategy on how to deal with situations when market liquidity evaporates.

The changing bond market microstructure due to technological advancement and the emergence of new market participants might pose additional risks to market resilience. Many institutions (International Monetary Fund, 2015; Bank of International Settlements, 2016) have warned that the pick-up of automated trading (i.e., algorithmic and high-frequency trading) and sophistication of quoting and trading techniques

Article note: This article is a part of Topical Issue "Business and Management" edited by Viktorija Skvarciany.

***Corresponding author: Linas Jurksas,** Vilnius University, Vilnius, Lithuania, E-mail: l.jurksas@gmail.com

have contributed to improved liquidity conditions, but these structural transformations might also have changed the nature of liquidity provision. These developments have also raised the uncertainty and fragility of markets. As a result, it is becoming more important to understand the functioning of the bond market from the microstructure perspective and determine how these changes affect the bond liquidity of sovereign bonds under different liquidity regimes.

The regulations enacted during the post-crisis period added further impetus for the changing structure of liquidity provision. The Basel and newly enacted MiFID II requirements affected banks' preferences for different assets and led to a more transparent fixed income trading environment (Galliani et al., 2014; the European Parliament and the Council, 2014). There are also concerns that the ban of uncovered CDS products resulted in a reduced interest of market participants for European government bonds and might have even contributed to poorer market liquidity conditions (IMF, 2013; ISDA, 2014). The proposal of European sovereign bond-backed securities and Europe 2020 projects could also affect the liquidity and issuances of underlying bonds (European Systemic Risk Board, 2018; Vassallo et al., 2018). So it is important for supervisors and policymakers to understand if the changing regulation landscape has affected or how additional requirements might affect the liquidity provision in the sovereign bond market.

The transformation of the sovereign bond market and its' liquidity should be of particular importance for governments that issue bonds. The outstanding nominal value of euro area government bonds has increased substantially during the review period, i.e., from 6.1 tn EUR in June 2011 to 7.3 tn EUR in December 2017 (ECB, 2017). From the theoretical perspective, the increased supply of bonds and stricter regulation should have contributed to the rise of yields, but additional demand factors, such as bond purchases by central banks, can counterweight the negative effects. However, these demand factors are of a temporary nature, while the impact of increased supply and strengthened regulation should be a long-lasting phenomenon. These problematic topics of the transformation of sovereign bond market microstructure and the changing liquidity conditions are not yet fully explored (especially with high-frequency microstructure measures) by current literature.

The purpose of this study is to determine what factors shape sovereign bonds' liquidity level. The analysis is carried out with variables derived from *Mercato dei Titoli di Stato* (MTS) dataset from June 2011 until March 2018. The novelty of this analysis is that a wide range of different microstructural indicators was constructed from high-frequency data for the cross-section of sovereign bonds. The dependent variable in this study is the order-book liquidity indicator which encompasses both cost and depth dimensions of market liquidity. The multitude of explanatory variables was divided into three separate groups: the characteristics of bonds, the trading features, and dealers' quoting obligations. These variables were used in univariate cross-sectional regression models with country-specific control variables. After comparing different liquidity characteristics among many euro area markets, sovereign bonds from the six largest euro area countries were chosen for further analysis: Germany, France, Italy, Spain, the Netherlands and Belgium. As the overall market liquidity fluctuated highly during this period, the results are compared between stressful and calmer liquidity conditions.

This paper consists of three main parts: the review of relevant literature; the description and examination of the data and methods that were used in this analysis; the results of univariate cross-sectional regression models. The main findings and several recommendations are provided in the concluding part.

2 The review of relevant literature

Various empirical studies have been conducted regarding the drivers of bond market liquidity. However, most of them concentrate on the US bond market, while there are relatively few papers about European sovereign bonds. And in most cases, these studies do not focus on the microstructure of the sovereign bond market and high-frequency trading regimes.

A broad overview of level and resilience of market liquidity across many bond markets is provided by International Monetary Fund (2015) and Bank of International Settlements (2016). International Monetary Fund (2015) groups possible drivers of market liquidity to structural and cyclical factors. The structural factors are mostly attributed to long-lasting technological changes, such as the shift of bond trading to electronic platforms where automated trading is prevalent, highly more complex regulations (e.g., on proprietary trading and transparency), evolving business models of banks, etc. Although these structural factors have led to a more transparent bond market, it also made the bond market liquidity less predictable and prone to herd behaviour due to, for instance, smaller bond issuances and reduced scale of market making activity. However, bond market liquidity has been positively affected by the cyclical factors, such as improving macroeconomic and financial conditions as well as unconventional monetary policy measures. In a similar study, Bank of International Settlement (2016) argues that the increasing fragility of markets is primarily driven by structural factors: the shift of bond trading to highly automated markets, more rigorous transparency requirements, reduced liquidity provision by market-makers and diminished dealers' risk-taking capacity. This is especially the case in the off-the-run sovereign bond market segment where formal arrangements of market-making are rare. The supply conditions are also tighter for larger transactions as they are less suitable for trading in transparent and highly automated electronic markets, so investors increasingly split larger transactions into smaller ones.

There are relatively few broad-based empirical studies trying to quantify the impact of underlying bond-specific factors on bonds' liquidity. Slimane and de Jong (2017) build liquidity scores for many bond issues by associating bid-ask spreads to intrinsic bond characteristics such as maturity, credit rating, industrial sector, outstanding volume, etc. Goyenko et al. (2009) compare the effect of bond with different maturities and the on-the-run status on liquidity conditions and conclude that the differences among effects become particularly acute during stressful market periods. Dunne et al. (2006) analyse euro-denominated government bond market by using MTS limit-order and transaction data. They estimate many liquidity measures: effective spread, order book depth, trade sizes, liquidity at the best bid and ask quotes. They find that liquidity conditions in the government bond market is highly related to the size of the issuer as well as various issuance techniques and that markets with stricter obligations have on average deeper order-books. Diaz and Escribano (2017) study the liquidity measures of the US treasury bonds and find that bond aging process drives the liquidity component of yields. For instance, the on-the-run status of bonds and time until maturity are strongly linked with the liquidity of that bond.

The European bond markets are analysed by Galliani et al. (2014) who try to assess main factors driving liquidity of corporate and sovereign markets. By using a regression model with quarterly data, they find that the main bond-specific liquidity determinants are the duration, the credit rating, issued amount and time-to-maturity: the smaller issues with higher duration as well as bonds issued a while ago and with lower issuer rating require higher liquidity premium. The explanatory power of these variables increases during stressful market periods. These authors also highlight the importance of changing the regulatory environment (particularly, the Basel III regulation on liquidity risk) that might lead to diverging liquidity conditions across different markets.

There are only several relevant studies using high-frequency bond market indicators. Fleming (2003) uses the US Treasury on-the-run securities data and finds that liquidity measures are correlated with one another, especially during overall poor liquidity conditions. Tsuchida et al. (2016), using tick-by-tick trade data, investigate the liquidity of Japanese government bonds. They group different liquidity indicators to four main categories: tightness (the bid-ask and effective spread), depth (the amount and volume of quotes), resiliency (the bid-ask spread divided by the quoted volume) and the trade volume (the trade size and turnover of each transaction). They reveal that the increasing use of automated trading and post-crisis financial regulation had a material impact on market liquidity, but it is hard to estimate the ultimate effect. Engle et al. (2011) add that the liquidity is highly affected by the price volatility that is caused by different market structures. Goldberg and Ronn (2018) argue that bonds exhibit greater sensitivity to the systemic factor during stressful market conditions when intra-market correlation tightens.

Regarding intraday liquidity analysis of European sovereign bond markets, several studies stand out. Schneider et al. (2016) analyse illiquidity risks, i.e., the liquidity dry-ups, and how and why they spill-over across various Italian government bonds at a one-minute frequency. These authors find that market liquidity is more fragile and less predictable when an asset is very illiquid and that the bonds with lower residual maturity are increasingly driven by the illiquidity spill-overs from the long-term bonds.

However, they do not find major differences between the less and more recently issued bond, so the on-the-run status (i.e., the most recently issued bonds) has no statistically significant effect. Pellizon et al. (2013) also calculate liquidity measures and underlying factors on high-frequency intervals and then aggregate them to daily factors. By employing MTS tick-by-tick data, they group all variables to three separate categories: 1) the characteristics of each bond, 2) variables indicating quote and trading activity, 3) composite liquidity measures, e.g., Amihud (2002) and Roll (1984) indicators. Using cross-sectional analysis, they find that the relation between liquidity measures and the time-to-maturity as well as the age of bond is strong and highly non-linear. Additional time-series and panel regression models revealed that liquidity measures are highly dependent on credit risk dynamics. However, Schneider et al. (2016) and Pellizon et al. (2013) focus only on one market (i.e., Italian sovereign bonds) and mostly on the stressful market periods. Darbha and Dufour (2015) analyse several European sovereign bond markets and document that liquidity components differ significantly during calm and stressful market periods. Also, they find that the more recently issued bonds with larger issue sizes demonstrate improved liquidity conditions.

In an extensive analysis, Holden et al. (2014) research various topics related to market liquidity, including microstructure factors that might have an impact on market liquidity. After the review of other researches, they conclude that different types of bond markets, the transparency requirements, tick size regimes and the automation level of the market considerably affect bond market liquidity. For instance, the reduction of tick size and ex-ante limit-order transparency lead to narrower bid-ask spreads, but also smaller and more frequently updated orders, but ex-post transparency requirements are much more important. Meanwhile, automated trading should improve overall liquidity and price efficiency but might also lead to a less resilient market with constant liquidity dry-ups and order anticipation strategies that harm 'slower' traders.

After reviewing the most relevant studies, it is possible to conclude that current literature is relatively limited with quantified assessments of wide-range of factors that characterise liquidity conditions of sovereign bonds. Also, other studies rarely concentrate on the microstructure of bond markets and how different bond characteristics lead to different liquidity levels on both stressful and calm market conditions. However, the review of relevant studies helped to produce a hypothesis of the possible signs of factors that could shape the liquidity of sovereign bonds (see Table 1 under Section 3).

3 Data and research methods

This chapter describes the data as well as dependent and explanatory variables that will be used in the econometrical model. Data filtering procedure is then elaborated. Finally, the cross-sectional regression model is briefly described.

3.1 Data

The data used in this analysis is provided by MTS that is the biggest dealer-to-dealer platform for European sovereign bonds (MTS, 2017). The core of this trading platform is the central limit order-book where trades are automatically executed when the price of bid order crosses the price of ask order or vice versa. The analysis is carried out with the historical MTS data from June 2011 until March 2018 that encompass both stressful and calm market periods for different European sovereign bond markets. The preparation for the minute frequency order book somewhat follows Darbha and Dufour (2015).

Three different MTS datasets are used in this analysis: the bond reference, tick-by-tick order-book and trade data. The bond reference data contains information about characteristics of all traded bonds: the issuance and maturity dates, types and countries of issuers, coupon types and rates, number of dealers enabled to trade a particular bond, minimum tick sizes, etc. The order-book (called 'proposals') data covers tick-by-tick limit-order information (i.e., the price and quantity of each order) and subsequent order revisions by dealers on a microsecond time stamp for every quoted bond. Similarly, the trade (called 'fills') data encompass tick-by-tick information about each executed transaction.

In order to employ the cross-sectional regression model, data values are averaged and winsorized for each bond. At first, order-book and trade data is sampled to discrete 1-minute intervals and then averaged (by winsorizing 5% of highest and lowest minutely values) to obtain daily measures for each sovereign bond. Then calculated statistics are joined by bond ISIN with daily bond reference data. Finally, these metrics are averaged (by again applying winsorizing procedure) across all trading days to get one value for each bond and the full sample period. In this way, the calculated variables do not suffer from outliers but retain valuable information on the full sample period for each bond. A similar procedure was performed by Pellizon et al. (2013) in order to use the variables in the cross-sectional regression model.

The explanatory variable used in this analysis is the order-book illiquidity-score that is calculated according to this formula (Jurkšas et al., 2018):

$$\text{Illiquidity-Score}_{5,t} = \frac{\frac{1}{5}\sum_{j=1}^{5} P_{t,Ask(J)} - \frac{1}{5}\sum_{j=1}^{5} P_{t,Bid(J)}}{\sum_{j=1}^{5} Q_{t,Ask(J)} + \sum_{j=1}^{5} Q_{t,Bid(J)}} \quad (1)$$

where:

t – the time at which the limit-order book is calculated;
P – the price of the limit-order at time t;
Q – the quantity that can be traded at a given quoted price at time t;
'Ask' and 'Bid' – the side of the limit-order book;
j – the priority number of the offers in the limit-order book (i.e., from 1st to 5th best Ask/Bid price and its corresponding quantity).

This measure encompasses two main liquidity dimensions: cost and depth. According to BIS (2016), market liquidity is a concept with multiple dimensions, so one should try to derive a composite liquidity metric. The order-book illiquidity-score principally indicates the average transaction costs of the five best buy and sell orders, relative to their quantities, i.e., how, on average, the bid-ask spread would be impacted if the quantities of the five best bids and five best asks would be transacted. In this sense, the order-book illiquidity score highly represents the widely used price impact indicator of Amihud (2002), although the latter measure is most often calculated with the transaction and not limit-order data. In general, the lower the order-book illiquidity-score and the average bid-ask spread, and the higher the corresponding quoted quantity, the more liquid is the bond.

As can be seen from Table 1, the explanatory variables are grouped into three different buckets according to the type and origin of the variable. Additionally, the mean value across of cross-section of sovereign bonds is provided in the next column. The expected effect on overall illiquidity-score (that is also provided in the Table 1) is based on the literature review and authors' intuition. For instance, sovereign bonds with longer remaining maturity should be less liquid as they are often bought to be kept until redemption, while the on-the-run bonds are regarded as benchmark bonds by most trading platforms, so such bonds should be more liquid. Meanwhile, bonds with higher trading activity – the number of trades, order revisions and dealers – as well as the larger nominal issuance value should lead to improved liquidity conditions and thus lower value of illiquidity-score. High share of hidden volume of standing limit-orders implies that other traders should be less worried about this 'small' order, and therefore liquidity conditions should be better compared with the situation when the full size of the order is revealed to the market. Market regulators and policymakers often argue that obligatory requirement imposed on market participants should lead to improved market liquidity.

Table 1. Description of explanatory variables and expected sign of effect on illiquidity-score

Short name	Description	Mean value	Exp. sign
Group I: Bond characteristics			
Residual maturity	Residual maturity until redemption, in years	6.10	+
Time after issuance	Period of time after issuance until the trading day, in years	4.14	+
On-the-run status	Proportion of days when a bond has the shortest period of time after issuance in five separate maturity buckets (<=1.5 year; >1.5 and <=3.5; >3.5 and <=6.5; >6.5 and <=11; >11 years)	0.44	–
Issuance volume	Nominal value of bonds' issue, in millions euro	16754	–
Dummy: coupon bond	Dummy variable equalling one when the bond has embedded non-zero coupon	-	+
Group II: Trading features			
Number of active dealers	Number of dealers that submit / revise limit-orders during one minute interval, daily average	8.76	–
Number of minutely revisions	Number of limit-order submissions during one minute interval, daily average	82.78	–
Invisible part of order	The proportion of limit-order that is not visible to other traders, in percent	18.25	–
Traded quantity	Traded quantity for particular bond during the day, in millions euro	18.03	–
Limit-order share of traded quantity	The share of the traded quantity during a day when a trade is executed by the incoming limit-order (not market-order)	0.04	~
Price volatility	Standard deviation of the log mid-price for particular bond in the limit-order book during one minute interval, daily average	0.07	+
Group III: Obligations imposed on dealers			
Number of enabled participants	Number of market makers and price takers enabled to trade a particular bond	47.70	–
Compliance time	Number of hours in a trading day when dealers must have an active quote	4.62	–
Maximum spread requirement	Proportion of trading days when there is a maximum quoted spread requirement for a particular bond	0.33	–
Minimum quantity requirement	Proportion of trading days when there is a minimum quantity quoting requirement for a particular bond	0.59	–
Minimum price tick size	Price precision of quote revision for one bond, in euro	0.006	+

3.2 Description and narrowing down of the data sample

The euro area average order-book illiquidity-score has fluctuated highly during the review period that covers both stressful and calm market periods (Fig. 1). At the start of the sample period, the liquidity conditions worsened significantly (i.e., the illiquidity-score spiked) due to the deepening euro area sovereign debt crisis. This is especially the case for medium and long-term bonds. Meanwhile, the period of 2013-2014 can be characterised as comparatively calm when the gap between liquidity metrics of different maturities narrowed considerably. Most important policy measures in the euro area have been undertaken from mid-2014: the introduction of negative policy rate in June 2014 and the start of quantitative easing in March 2015. Afterwards, there were many significant political and economic events that contributed to the temporary increase of illiquidity-score, e.g., the 'bund-Tantrum' in mid-2015, Brexit vote in June 2016, the US presidential election in December 2016, French presidential vote in April-May 2017, etc. As the illiquidity-score fluctuated highly during the sample period, it is important to determine if the relationship between illiquidity score and other variables holds during different market conditions. For this reasons, the analysis is additionally performed for two separate periods, i.e., when illiquidity score in a particular market was above and below its median value.

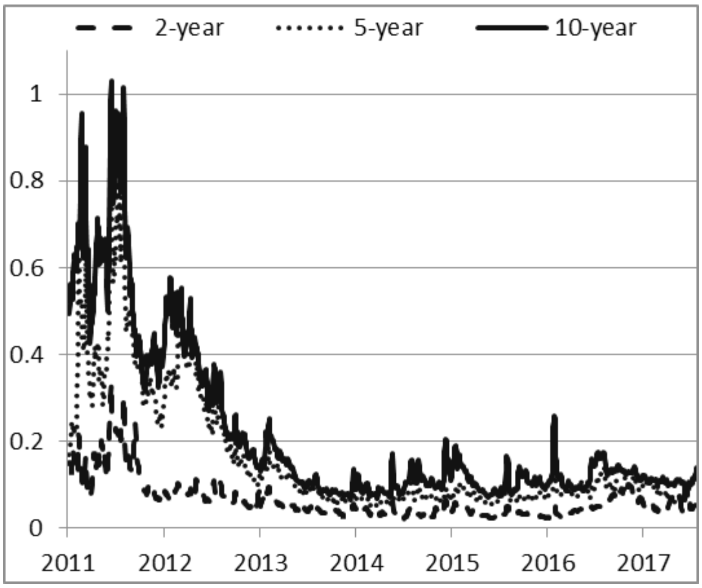

Fig. 1. Euro-area average order-book illiquidity-score for three different maturities. *Note: The lines depict 5-day moving averages of GDP-weighted euro area value of order-book illiquidity-score for sovereign bonds of 2-year, 5-year and 10-year maturity.*

While MTS data encompass trading behaviour in the twelve largest euro area sovereign bond markets, bonds from different countries exhibit very diverse liquidity levels and features. For instance, bonds issued by governments from Greece, Slovakia, Ireland, Portugal and Austria are on average less liquid than bonds from other markets, while the overall nominal value of Finnish bonds is comparatively very small compared to the remaining markets (not shown here). As a result, it was decided to carry out the further analysis with the bonds issued by governments from six euro area countries: Germany, France, Italy, Spain, the Netherlands and Belgium. Although these markets have the highest market capitalization in the euro area, they still have a lot of heterogeneity regarding credit risk, market depth, economic and financial developments, political events, etc. After removal of bonds from smallest markets, the data sample is reduced to 474 different sovereign bonds from six euro area markets.

3.3 Research method

The univariate cross-sectional regression model was used to test if a particular variable has a statistically significant relationship with the dependent variable, i.e., the order-book illiquidity-score. The univariate method was employed in order to analyse the effects of different variables separately and to avoid multicollinearity problem because several analysed variables are highly correlated (e.g., period of time after issuance and on-the-run status, number of traders and number of revisions, maximum spread requirement and minimum quantity requirement). Besides, the augmented Dickey-Fuller test was performed to find out if different variables are stationary, i.e., they have statistical properties that do not change with time. As some of the variables (e.g., number of active dealers, compliance time, number of enabled participants) were found to be non-stationary for different bonds in the sample, it was decided not to use time-series or panel models, but to proceed with the cross-sectional regression model. In this way, all variables (including dependent variable – illiquidity score) can be analysed in levels and thus the interpretation of results become less confusing. The formula of univariate cross-sectional model is as follows:

$$Y_i = \alpha + \beta \times X_{i\,+}\, u_i \tag{2}$$

where:
Y_i – dependent variable observed for bond i;
α – intercept;
β – coefficient of explanatory variable effect;
X_i – the explanatory variable observed for bond i;
u_i – error term.

Country-specific factors were added to each univariate regression. This procedure helps to control for the unobserved heterogeneity among bonds from different issuing countries (Ai et al. 2014) because the country-specific effects were found to be correlated with the level of different variables, including the dependent variable. The standard errors from the regressions were also clustered by issuing country because the estimate of the standard errors would have been greatly understated (and the significance of the variable – overstated) in settings with heterogeneous groups and no corrections (Cameron, Miller, 2015).

4 Results of the regression models

In this chapter, the main results of the univariate cross-sectional regression models of three different groups of variables are provided.

4.1 Bond characteristics

The univariate cross-sectional regression models revealed that the liquidity levels among sovereign bonds are determined by bond characteristics (Table 2). Particularly, the maturity of a sovereign bond has one of the highest determination coefficients among all constructed models and is negatively linked to the bond liquidity level. This result is quite intuitive because longer term bonds have longer durations, higher uncertainty regarding future repayment and are usually bought by investors who are willing to keep these bonds until redemption. Similarly, the longer after issuance, the lesser liquidity of bonds because quotation of bonds usually decreases during their lifetime. Galliani et al. (2014), as well as Diaz and Escribano (2017), also found that aging process drives the liquidity component of bond yields.

Nevertheless, contrary to the stated hypothesis and Diaz and Escribano (2017) finding, the on-the-run status of a bond was found to be statistically insignificant, possibly because newly issued bonds still need to accumulate liquidity in the secondary market and such bonds have higher remaining residual maturity than the bonds with off-the-run status. The issuance volume has a positive relationship with the liquidity conditions. This result is in line with the finding of Darbha and Dufour (2015) who argued that governments should issue bonds with larger nominal value or re-open old issues. However, this effect becomes statistically insignificant after clustering the standard errors by issuing country. Interestingly, zero-coupon bonds seem to be more liquid than bonds with embedded coupons, so governments should consider using this option more frequently.

These conclusions also hold when the cross-sectional regressions are run across two distinct periods, i.e., when liquidity is higher and lower in a particular country than its median value. In line with Goldberg and Ronn (2018) findings, the effects of majority of explanatory variables become somewhat stronger under less liquid market conditions as then investors possibly become more sensitive to various factors, including differences in bond characteristics. Specifically, dealers concentrate relatively more on bonds with shorter residual maturities, longer periods of time after bond issuance, as well as zero-coupon bonds. Goyenko et al. (2009) and Galliani et al. (2014) also concluded that the differences between bond characteristics become particularly acute during stressful market periods.

Table 2. Results of univariate cross-sectional regressions of bond characteristics on illiquidity-score

	Full sample	**Lower liquidity**	**Higher liquidity**
Explanatory variable:			
Residual maturity	0.02906***	0.03612***	0.02637***
	0.00	*0.00*	*0.00*
	0.568	0.626	0.625
Time after issuance	0.03023***	0.03922***	0.01751
	0.00	*0.00*	*0.13*
	0.251	0.283	0.151
On-the-run status	-0.07832	-0.11248	-0.00022
	0.16	*0.16*	*0.99*
	0.058	0.075	0.057
Issuance volume	-0.00001	-0.00001	-0.00001*
	0.25	*0.59*	*0.10*
	0.060	0.063	0.071
Dummy: coupon bond	0.13228***	0.17664***	0.11062***
	0.00	*0.00*	*0.00*
	0.162	0.174	0.174

Notes: The dependant variable is the mean value of daily order-book illiquidity-score measures for each bond. First line at each variable denotes the estimate of the effect of this explanatory variable in a country-specific cross-sectional model. Second line (in italics) shows p value that is calculated by clustering standard errors for each country. Third line denotes R squared. Asterisks indicate statistical significance at the 10% (*), 5% (**) and 1% (***) levels.

4.2 Bond trading features

Higher quoting activity does not always lead to more liquid sovereign bond market (Table 3). The number of dealers who submit orders as well as their order revision frequency is positively related to the value of illiquidity-score. This implies that a high number of dealers submitting large number of orders is not a prerequisite for improved liquidity of the particular bond because it is more important that this quoting activity leads to a competition between traders in narrowing bid-ask spreads and/or increasing volumes. Besides, the frequent order revisions might imply higher demand rather than supply of immediate liquidity, and the activity of sophisticated high-frequency algorithms might frighten away other market participants. Not surprisingly, these effects become more prominent during less liquid market conditions. Tsuchida et al. (2016) also argued that the ultimate effect of market automation on market liquidity is ambiguous and highly questionable.

The results of constructed cross-sectional regression models also revealed that the magnitude of orders' visibility (and thus the pre-trade transparency) is positively linked to the liquidity level of sovereign bond. This finding contrasts the statements of market participants that higher pre-trade transparency might detrimentally affect bonds' liquidity. The possible explanation of the obtained result is that reduced transparency might diminish dealers' willingness to provide liquidity if they do not see the full picture of the market. However, as this effect is more prominent during stressful market conditions, it might also mean that traders try to hide their orders mainly in the less liquid bonds and/or during illiquid market periods. So, as also stated by IMF (2015) and BIS (2016), the implications of transparency are often unclear because the direction of causality is not always straightforward.

The effects of trading features that are not so much related to the automation of the market are in line with the stated hypotheses. The sovereign bonds that are more often traded have higher liquidity levels because bonds with deeper order-books attract more dealers who want to execute transactions. Similar findings were obtained by Pellizon et al. (2013). Interestingly, the relative share of the order type of executed trades also matter: bonds that are traded more by price takers (who submit market orders) rather than market makers (who submit limit-orders) are characterized by lower liquidity levels, mainly during less liquid market periods. However, the explanatory power of this model is quite small. Meanwhile, the sovereign bonds with higher price volatility seem to be less liquid. As the determination coefficient of this model is highest among all constructed regressions, the price volatility seems to be the key factor in understanding sovereign bond liquidity levels, especially during the less liquid market regime.

Table 3. Results of univariate cross-sectional regressions of bond trading features on illiquidity-score

	Full sample	**Lower liquidity**	**Higher liquidity**
Explanatory variable:			
Number of active dealers	0.02616***	0.03909***	0.02154***
	0.00	*0.00*	*0.00*
	0.185	0.223	0.219
Number of minutely revisions	0.00202***	0.00242***	0.00157***
	0.00	*0.00*	*0.00*
	0.345	0.360	0.343
Invisible part of order	0.00163*	0.00211*	0.00111**
	0.09	*0.09*	*0.03*
	0.157	0.172	0.161
Traded quantity	-0.00491***	-0.00689***	-0.00229***
	0.00	*0.00*	*0.00*
	0.225	0.263	0.184
Limit-orders share of traded quantity	-1.42495***	-1.70522***	-0.52362
	0.00	*0.00*	*0.11*
	0.088	0.103	0.067
Price volatility	3.62476***	3.78455***	3.47832***
	0.00	*0.00*	*0.00*
	0.614	0.668	0.605

Notes: The dependant variable is the mean value of daily order-book illiquidity-score measures for each bond. First line at each variable denotes the estimate of the effect of this explanatory variable in a country-specific cross-sectional model. Second line (in italics) shows p value that is calculated by clustering standard errors for each country. Third line denotes R squared. Asterisks indicate statistical significance at the 10% (*), 5% (**) and 1% (***) levels.

4.3 Obligations imposed on dealers

Although variables depicting obligations imposed on dealers seem to have weakest links with the illiquidity-score, bonds with more stringent obligatory requirements are still found to be less liquid (Table 4). When dealers must submit a quote inside fixed bid-ask spread, and above minimum quoting quantity as well as for a particular number of hours, the liquidity level of such bond is not higher than for the bond that has no (or has less stringent) obligatory requirement. The number of enabled participants is also positively linked to the illiquidity-score, but this effect is statistically insignificant. While market makers have an obligation to provide liquidity in return for certain advantages, it does not mean that they are willing to actually improve liquidity. Market makers might only try to meet the ‘minimum’ requirements and not to compete with other traders for providing best quotes.

These results contrast Dunne et al. (2006) findings of a positive relationship between stricter obligations and bond order-book depth. However, the causality might also be a reverse one: the obligations can be imposed more often on such bonds that have (or are predicted to have) lower market liquidity, while most liquid bonds do not need any compulsory requirements. Only the lower minimum price tick size might lead to improved liquidity conditions because such bonds might attract investors that need a more sophisticated trading environment, e.g., high-frequency traders.

Table 4. Results of univariate cross-sectional regressions of obligatory requirements imposed on dealers on illiquidity-score

	Full sample	Lower liquidity	Higher liquidity
Explanatory variable:			
Number of enabled participants	0.0002	0.00264	-0.0061***
	0.89	*0.11*	*0.00*
	0.047	0.060	0.065
Compliance time	0.04468***	0.04645***	0.03956***
	0.00	*0.00*	*0.00*
	0.189	0.193	0.209
Maximum spread requirement	0.09518*	0.14496***	0.00551
	0.05	*0.00*	*0.94*
	0.151	0.167	0.157
Minimum quantity requirement	0.08859***	0.1222***	0.04164
	0.01	*0.00*	*0.50*
	0.154	0.168	0.159
Minimum price tick size	35.00231***	43.99282***	28.65611***
	0.01	*0.00*	*0.01*
	0.199	0.233	0.211

Notes: The dependant variable is the mean value of daily order-book illiquidity-score measures for each bond. First line at each variable denotes the estimate of the effect of this explanatory variable in a country-specific cross-sectional model. Second line (in italics) shows p value that is calculated by clustering standard errors by each country. Third line denotes R squared. Asterisks indicate statistical significance at the 10% (*), 5% (**) and 1% (***) levels.

The effects of obligatory requirements imposed on dealers become relatively more important during less liquid market periods. For instance, the minimum quantity and maximum spread requirements become statistically insignificant when illiquidity-score is below its' median value, while the compliance time obligation becomes less binding. Galliani et al. (2014) also argued that trading requirements become relatively more important during stressed market periods. These results might also speak for the possible reverse causality, i.e., more liquid bonds do not need obligatory requirements, and this effect becomes even more evident when there is the run-to-liquidity under the stressful market regime. The only exception is the number of market participants (i.e., both market makers and price takers) that are enabled to trade that bond – this factor becomes statistically significant only during higher liquidity regime when it becomes positively linked to the liquidity level of the bond. A similar finding was obtained by Holden et al. (2014).

4.4 Robustness check

Robustness checks were carried out using univariate panel regression procedure with country-specific fixed effects. The same dependent and explanatory variables were used under this procedure, but the model was run with daily data, i.e., with the time-series dimension. Interestingly, the results of panel regression models (both estimates and p values) remained quantitatively similar to the above-depicted cross-sectional regression results[1]. This implies that the time-series dimension of daily data possibly does not add additional valuable information to this particular type of model. However, not all variables were found to be stationary during time (e.g., around 10% of analyzed bonds exhibit non-stationary illiquidity-score dynamics), meaning that several variables had to be integrated into panel models, while others – not. As this would make the comparison of the effects of different variables complicated and interpretation cumbersome, cross-sectional regression models are more suitable for the analysis with all variables in levels.

5 Conclusions

The univariate cross-sectional regression models with various explanatory variables from three separate groups – the characteristics of individual bonds, the trading features and dealers' quoting obligations – were used to analyse what factors shape sovereign bonds' liquidity levels. The results of first set of cross-sectional regression models confirmed the findings of other studies that characteristics of the sovereign bond are often tightly linked with bonds' liquidity levels. Specifically, the higher is the residual maturity of the bond and the longer period after issuance, the poorer is the liquidity conditions of particular sovereign bond. Also, zero coupon bonds have better liquidity conditions. These effects become even stronger during periods of lower overall market liquidity. Contrary to the findings of the majority of other studies, the on-the-run status and issuance size of a particular bond were found to be statistically insignificant.

The results of models with variables depicting trading features revealed that the automation magnitude in the market of a particular bond is usually negatively related to the liquidity level of this bond. The number of dealers who submit orders and the frequency of revisions are positively linked to the illiquidity-score, while the magnitude of orders' invisibility – negatively. These findings contrast the statements of market participants as well as many other scholars. The bonds that are more often traded (especially, due to incoming limit-orders) and/or exhibit lower price volatility usually have higher liquidity levels. Especially, price volatility seems to be the key factor in understanding sovereign bond liquidity levels, particularly during less liquid market periods.

The results of cross-sectional regression models with dealers' quoting obligations showed that mandatory requirements imposed by the market operator are usually associated with poorer liquidity conditions. The liquidity level is lower for bonds with a higher number of enabled market participants and minimum price tick size, as well as when various obligatory requirements (i.e., the submission of quotes for a particular number of hours, inside fixed bid-ask spread and above minimum quoting quantity) are being imposed on dealers. However, the variables depicting obligations imposed on dealers have weakest links with the illiquidity-score, and these links are often statistically insignificant, especially under poorer market liquidity conditions.

The findings of this study have several implications for market participants and policymakers. First, the results that shorter maturity bonds with smaller or no embedded coupons are the most liquid bonds (and thus have the lowest liquidity premium) should be of interest to national treasuries that are planning new bond issuances or re-openings of the older ones. Second, investors who want to trade the most liquid bonds should concentrate on bond markets characterised by lowest price volatility and highest historical trading (not necessarily quoting) activity. Third, the regulators and market operators should be cautious in trying to improve market liquidity by imposing requirements on transparency and dealers' quoting obligations because market liquidity is mainly shaped by competing quoting behaviour among dealers.

1 The estimates of only three variables were considerably different with panel regression model. The invisible part of order and number of enabled participants had relatively higher, while limit-orders share of traded quantity – smaller estimate than in the cross-sectional model. Still, the estimates of all three variables had the same sign as under the cross-sectional models. The detailed results of all panel regression models can be provided upon request.

References

Ai, C., You, J., Zhou, Y. (2014). Estimation of fixed effects panel data partially linear additive regression models. *The Econometrics Journal,* 17(1), 83-106. https://doi.org/10.1111/ectj.12011

Amihud, Y. (2002). Illiquidity and Stock Returns, Cross-section and Time-series Effects. *Journal of Financial Markets*, 5, 31–56. https://doi.org/10.1017/cbo9780511844393.010

Bank for International Settlements. (2016). Electronic trading in fixed income markets. *Report of Bank for International Settlements*, 1-44.

Cameron, A. C., Miller, D. L. (2015). A Practitioner's Guide to Cluster-Robust Inference. *Journal of Human Resources*, 50(2), 317-372. https://doi.org/10.3368/jhr.50.2.317

Darbha, M., Dufour, A. (2015). Euro Area Government Bond Market Liquidity. *SSRN Electronic Journal*, 1-45. https://doi.org/10.2139/ssrn.2470944.

Diaz, A., Escribano, A. (2017). Liquidity measures throughout the lifetime of the U.S. Treasury bond. *Journal of Financial Markets*, 33, 42-74. https://doi.org/10.1016/j.finmar.2017.01.002

Dunne, P. G., Moore, M. J., Portes, R. (2006). European Government Bond Markets, Transparency, Liquidity, Efficiency. *City of London Corporation Monograph commissioned from CEPR*.

Engle, R., Fleming, M., Ghysels, E., Nguyen, G. (2011). Liquidity, Volatility, and Flights to Safety in the U.S. Treasury Market, Evidence from a New Class of Dynamic Order Book Models. *Federal Reserve Bank of New York Staff Reports*, 590, 1-55. https://doi.org/10.2139/ssrn.2195655

European Central Bank. (2017). Debt Securities Statistics. Available from Internet: https://www.ecb.europa.eu/stats/financial_markets_and_interest_rates/securities_issues/debt_securities/

European Parliament and Council. (2014). Directive on markets in financial instruments. Available from Internet: http://eur-lex.europa.eu/legalcontent/ EN/TXT/HTML/?uri=CELEX,32014L0065

European Systemic Risk Board. (2018). Sovereign bond-backed securities, a feasibility study. *Report by the ESRB High-Level Task Force on Safe Assets*, 1,51. https://doi.org/10.2849/262403

Fleming, M. J. (2003). Measuring Treasury Market Liquidity. *Economic Policy Review*, 9(3), 1-57. https://doi.org/10.2139/ssrn.276289

Galliani, C., Petrella, G., Resti, A. (2014). The liquidity of corporate and government bonds: drivers and sensitivity to different market conditions. *Joint Research Centre Technical Reports*, 1,38. https://doi.org/10.2788/70146

Goldberg, R. S., Ronn, E. I. (2018). Intra-Market Correlations in the Bond Markets, Extending Empirical Regularities from the Equity Markets. *The Journal of Fixed Income,* 27(3), 23-36. https://doi.org/10.3905/jfi.2018.27.3.023

Goyenko, R., Subrahmanyam, A., Ukhov, A. (2011). The Term Structure of Bond Market Liquidity and Its Implications for Expected Bond Returns. *Journal of Financial and Quantitative Analysis,* 46(1), 111-139. https://doi.org/10.1017/S0022109010000700

Holden, C. W., Jacobsen, S., Subrahmanyam, A. (2014). The Empirical Analysis of Liquidity. *Foundations and Trends in Finance,* 8(4), 263–365. https://doi.org/10.2139/ssrn.2402215

Jurkšas, L., Kapp, D., Nyholm, K., Von Landesberger, J. (2018). Euro area sovereign bond market liquidity since the start of the PSPP. *ECB Economic Bulletin,* 2018(2), 41-44.

International Monetary Fund. (2013). A New Look at the Role of Sovereign Credit Default Swaps. *Global Financial Stability Report*, 57–92.

International Monetary Fund. (2015). Market Liquidity—Resilient or Fleeting? *Global Financial Stability Report*, 49-81.

ISDA. (2014). Adverse Liquidity Effects of the EU Uncovered Sovereign CDS Ban. *Research Note*, 1–12.

Mercato dei Titoli di Stato. (2017). MTS Markets Overview. Presentation at World Bank. Available from Internet: http://pubdocs.worldbank.org/en/265741493316237603/Angelo-Proni-WB-Apr-2017.pdf

Pellizon, L., Subrahmanyam, M. G., Tomio, D., Uno, J. (2013). The Microstructure of the European Sovereign Bond Market, A Study of the Euro-zone Crisis. *SSRN Electronic Journal*, 1-51. https://doi.org/10.2139/ssrn.2242918

Roll, R. (1984). A Simple Implicit Measure of the Effective Bid-Ask Spread in an Efficient Market. *The Journal of Finance,* 39(4), 1127-1139. https://doi.org/10.2307/2327617

Schneider, M., Lillo, F., Pellizon, L. (2016). Modelling illiquidity spillovers with Hawkes processes, an application to the sovereign bond market. *Quantitative Finance,* 18(2), 283-293. https://doi.org/10.1080/14697688.2017.1403155

Slimane, M. B., De Jong, M. (2017). Bond Liquidity Scores. *The Journal of Fixed Income,* 27(1), 77-82. https://doi.org/10.3905/jfi.2017.27.1.077

Tibshirani, R. (1996). Regression Shrinkage and Selection via the Lasso. *Journal of the Royal Statistical Society*, 58(1), 267-288. https://doi.org/10.1111/j.1467-9868.2011.00771.x

Tsuchida, N., Watanabe, T., Yoshiba, T. (2016). The Intraday Market Liquidity of Japanese Government Bond Futures. *Institute For Monetary and Economic Studies Discussion Paper Series,* E7, 1-40.

Vassallo, J. M., Rangel, T., Baeza, M. A., Bueno, P. C. (2018). The Europe 2020 Project: Bond Initiative, an Alternative to Finance Infrastructure in Europe. *Technological and Economic Development of Economy,* 24(1), 229-252. https://doi.org/10.3846/20294913.2016.1209251