Article

Liquidity Spill-Overs in Sovereign Bond Market: An Intra-Day Study of Trade Shocks in Calm and Stressful Market Conditions

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Abstract: The purpose of this paper is to determine the liquidity spillover effects of trades executed in European sovereign bond markets and to assess the driving factors behind the magnitude of the spill-overs between different markets. The one minute-frequency limit order-book dataset is constructed from mid-2011 until end-2017 for sovereign bonds from the six largest euro area countries. It is used for the event study and panel regression model. The event study results revealed that liquidity spill-over effects of trades exist and vary highly across different order types, direction and size of the trade, the maturity of traded bonds, and various markets. The panel regression model showed that less liquid bonds and bonds whose issuer is closer by distance to the country of the traded bond have more substantial spillover effects and, at the same time, are also more affected by trades executed in another market. These results should be of interest to bond market participants who want to limit the exposure to the liquidity spillover risk in bond markets.

Keywords: high-frequency data; market liquidity; sovereign bonds; spillover

1. Introduction

While fixed income market traders and analysts do not pay much attention to the liquidity situation when markets are sufficiently liquid, it becomes a critical issue when market liquidity suddenly evaporates. These tail risk events of liquidity shocks are mainly characterized by the sharp reduction in the number of traders who stand ready to buy and sell particular bonds and become a real concern to fixed income investors who base their decisions on the available bid and ask prices in the market. Alongside the period of increasing connectedness in asset markets, it is often a case that spill-overs, when (il-)liquidity spreads across different bonds or even markets, become a risk to the orderly functioning of the whole fixed income market. Besides, as "investors" trading returns are increasingly shaped by several basis points margin in a low-interest-rate environment, liquidity shocks could highly increase liquidity premium embedded in bond prices—this would have a significant impact on the valuations of bonds. Because market liquidity, i.e., the ease and speed of trading, is crucial to the functioning of financial markets, there has been a surge of interest in the topic of market (il)liquidity in recent years. This has been mostly the case after the European sovereign debt crisis when market participants witnessed deprived liquidity conditions (European System of Financial Supervision 2016). Nevertheless, there are still many unanswered questions. What causes these sudden liquidity shocks in fixed income markets? Do these events affect only some particular bonds or the whole market? Is there a contagion effect that reverberates among different bonds? This study tries (at least to some extent) to shed light on this topic by analyzing the impact of sovereign bond trade shocks and how they spillover to other bonds and markets.

The novelty of this paper is several-fold. To start with, we employ the large intraday sovereign bond quoting and trading dataset that contains multi-year information of trade shocks and quoting activity. To be specific, we derive minute-frequency limit order-book from tick-by-tick sovereign bond market data of Mercato dei Titoli di Stato (MTS) from June 2011 until December 2017. This relatively long sample period lets us analyze how trade shocks affect liquidity in distinct market periods: exceptionally stressful market conditions from end-2011 until start-2012 (i.e., peak of European sovereign debt crisis), relatively calm market period of 2013–2014, the "Bund-Tantrum" in mid-2015, the spikes of market tensions after "Brexit" vote and US presidential elections in 2016, and etc. To compare the results among different sovereign bond issuers, many markets are selected: Germany, France, Italy, Spain, the Netherlands, and Belgium. The event study method is employed to analyze the spillover of trade effect because this method is less prone to variable selection bias and reverse causality issues common with more complex econometrical models when analyzing spill-over effects between many different bonds with high-frequency data. Additionally, panel regression model is used to answer the question of what factors affect the strength of liquidity spillover effect among markets. Rigobon (2019) made a significant research on the empirical literature about international spillovers and contagion and made a conclusion that there was no single technique that could help to give the answer to the full-fledged problem. The author pointed that empirical studies of spill-overs and contagion were quite complicated applied issues. Glosten and Milgrom (1985) analyzed the spread of bid and ask prices, paid the most attention to insiders and liquidity traders, and used the approach that a bid-ask spread can be an informative factor. Other authors focused more on critical moments, which are especially important at a government level, attracting more funds or making suitable monetary policy. Dungey et al. (2006), using a latent factor model, analyzed the emerging and developed markets focusing more on the Russian crisis. The results showed that both markets experienced a contagion effect. Brière et al. (2012) made a research with a considerable database to investigate the stability of correlation matrices in different asset segments with the contagion tests, which were neutralized with respect to the globalization effects. Liquidity contagion effect analyzed by Macchiati et al. (2020) and Cifuentes et al. (2005) while gravity model issues were investigated by Zhu and Yang (2008). Overall, the topic is very relevant and quite complicated, so it is essential to research this field from different perspectives. This study is focused on a vital market microstructure subject: how shocks of sovereign bond trades affect the prices and quantities of the limit order book. In the wake of the rapid increase of automated trading, there are relatively fewer transactions than the number of buy and sell orders submitted to the market, so an execution of a trade has more informational value for traders. Simultaneously, larger transactions are less suitable for trading on such increasingly automated markets as prices. Thus liquidity can instantly be moved against the participant who wants to trade. The trade execution should lead to an immediate liquidity spillover effect to the quoted prices and quantities of this bond because the trade can be executed only inside the central limit order book of the MTS market. Moreover, the sovereign bond markets are much more decentralized and fragmented than equity markets, so it is important to understand if a shock—trade of a particular bond—affects the liquidity situation only of the traded bond or does it also reverberate to other bonds of the same issuer, or maybe it even spill-overs to the sovereign bonds from other markets. In fact, the sudden liquidity dry-up for one bond might lead to a contagion effect that could become a severe threat to the functioning of the whole sovereign bond market and is critical to the financial stability. As a result, the liquidity spillover effect of trades is a rarely examined but increasingly important topic for investors, analysts, regulators, policymakers, and issuers of sovereign bonds.

This paper consists of four main parts: the review of relevant literature; the description and examination of the data and methods that are used in this analysis; the results of event studies and discussion of liquidity spillover effects; findings from a panel

regression model of possible factors that explain the magnitude of spillover effects between different European markets.

2. Literature Review

Although there is no analogous event study of liquidity spillover of trades with high-frequency European sovereign bond data, this chapter reviews the several strands of academic literature that is relevant for conducting this study: the microstructure of fixed income market, liquidity indicators of bonds, contagion effects among different asset markets, and liquidity spillover of sovereign bonds. It should be noted that while there are many studies on intraday market liquidity, most of them still concentrate on equity markets and particularly on US markets He et al. (2020); Rappoport and Tuzun (2020); Honkanen and Schmidt (2017); Rindi and Werner (2017); Sheng et al. (2017); Shaikh (2018); Righi and Vieira (2014); Bein (2017); Diebold and Yilmaz (2009), given its size and the availability of high-frequency data. Some research papers are focused on the future market. Fassas and Siriopoulos (2019) studied the Greek market using the high-frequency data and tried to identify the relationships between spot and future prices. The authors revealed strong bi-directional dependence in the intraday volatility and pointed to the improvement of futures' pricing efficiency in the Athens financial market. But there is still relatively little research specific to liquidity spillover effects, especially on European sovereign bond markets.

Before analyzing the liquidity spill-over effects, it is important to analyze the liquidity spill-over effects. It is important to analyze the liquidity spill-over effects, and it is essential to understand the microstructure of the whole fixed income market. Bank for International Settlements (2016a) gives a comprehensive overview of the evolution of fixed income markets. For instance, it documents that the share of electronic trading in sovereign bond and other fixed-income markets is gradually increasing (mainly due to the rise of automated and high-frequency trading). However, the market structure is still fragmented between inter-dealer and dealer-to-client segments. Bond trading still lags development compared to other asset classes due to, more significant heterogeneity and complexity. Nevertheless, while the impact of automated trading on market liquidity is highly debatable, technological improvements enabled dealers to better monitor how the flow of orders changes in response to news and other shocks. Regarding European sovereign bond markets, a pan-European trading protocol of the central limit order-book has become a dominant feature (e.g., MTS market). However, it is still less technologically advanced and less liquid than the US sovereign bond market.

Market liquidity in different asset markets has been analyzed from various perspectives. One of the first inclusive studies is the paper of Kyle (1985), who states that there are three main liquidity dimensions: (1) tightness (cost of buying and selling a position); (2) depth (the size of order-book or amount of quotes); (3) resiliency (the speed of recovery of tightness and depth). While these three dimensions vary significantly depending on the size and type of trade, all measurements are essential for frequent traders. Tsuchida et al. (2016) also group metrics to these three categories, and distinguish volume, i.e., the trade size and turnover of each transaction. These authors find that the shock of economic indicator announcement has a negative effect on all liquidity dimensions. In contrast, the shock of monetary policy announcement has a positive impact on the volume indicators. Albagli et al. (2015) found significant monetary policy effects on developed and emerging bond markets.

Other import studies describing various liquidity metrics and dimensions are Sarr and Lybek (2002); Fleming (2003); Goyenko et al. (2009); International Monetary Fund (2015); Diaz and Escribano (2017); Broto and Lamas (2020); O'Sullivan and Papavassiliou (2019); Clancy et al. (2019); Barth and Kahn (2020); Jiang et al. (2020); Gupta et al. (2018); Kandil (2018) and White et al. (2018).

An overview of various liquidity indicators as well as microstructure of the European sovereign bond market is provided by Pellizon et al. (2013); Mahanti et al. (2008);

Brunnermeier and Pedersen (2008); Chordia et al. (2007); Dunne et al. (2015); Galliani et al. (2014); Han and Pan (2017); Holden et al. (2014); MTS (2017); Kurosaki et al. (2015). By employing MTS tick-by-tick data, authors compose three types of indicators that they include in econometric models: (1) Bond-specific characteristics: coupon type, time-to-maturity, issued amount; (2) activity variables: number of trades and volumes, revisions per single order, quantities at the best bid and ask; (3) liquidity measures: bid-ask spread, a measure developed by Amihud (2002), measure composed by Roll (1985), and etc. With the help of an event-type method, Pellizon et al. (2013) found that dealers still withdraw from the bond market during periods of stress despite contractual agreements with market operators, especially for the longer-term and less liquid bonds. Besides, the liquidity of less liquid bonds has a contagion effect on the broader market, while rapid increase of automated trading (proxied by order revisions) has not led to market resiliency improvement. In a similar study, Darbha and Dufour (2015) describe the European government bond market's microstructure and analyze how liquidity measures evolve during stressful and normal market conditions.

Regarding the studies about spillover effects in fixed income markets, the critical distinguishing feature is the determination of the impulse factor that reverberates through the markets. While liquidity spillover is quite a rare research topic, spillover of bond yields or prices has been well documented. Dufour and Nguyen (2011) analyze sovereign bond markets of the euro area countries for the pre-crisis period to assess the price responses to trades in different markets. They reveal that investors indeed require higher yields for bonds that exhibit more enormous trading impacts. Claeys and Vašíček (2014), using the variance decompositions of vector auto-regression model, studied bilateral linkages between EU sovereign bond spreads and tried to determine the origins of the shock, i.e., the specific sovereign bond market from which the spillover emanates to other markets. Their results indicate that the spillover effect increases substantially during stressful market periods. This effect varies highly across countries, e.g., financially stronger countries, such as the UK, Sweden, and Denmark, are much less affected by shocks from other EU countries. Bowman et al. (2015) examine the effects of FED's unconventional monetary policies on sovereign yields in seventeen emerging markets. Their event study findings suggest that the US monetary policy shocks significantly affect the sovereign yields in other countries. However, the strength and persistence of the effect vary significantly across the emerging markets. Papadamou et al. (2020) also investigated unconventional monetary policy effects, but they focused more on the economic variables and financial markets. The authors revealed a unified positive impact of quantitative easing (QE) on bond prices across different studies. The other interesting aspect was that a contagion effect from US QE to emerging markets was identified.

Levisauskaite et al. (2015) studied the relationships between EU government bond markets and found that the common currency and geographic proximity influence the correlations in different markets. Another study by Bank for International Settlements (2016b) reveals that price impact from large incoming orders have increased for US and Italian sovereign bonds. Still, the more significant price sensitivity has no clear sign of contagion effect.

The spill-overs of liquidity have been mostly studied between different types of assets. For instance, Tang and Yan (2008) use data from the US corporate bond, stock, option, and credit default swap (CDS) markets for computing correlations between liquidity measures. Their central finding is that the role of a common liquidity factor across the markets is more important than generally assumed. In particular, the illiquidity emanating from the CDS markets is found to spillover to other markets and leads to a statistically significant increase in credit spreads. In a relatively similar study, Calice et al. (2013) analyzed the spillover effects between the credit and liquidity spreads in nine Eurozone sovereign bond markets and the sovereign CDS market. They found significant variation in the spillover effect between maturities and among countries, e.g., in several markets (Greece, Ireland, and Portugal), the sovereign CDS market's liquidity has a

substantial time-varying influence on sovereign bond credit spreads. Lin et al. (2013) investigated the liquidity risk spillover from equities to bond markets and found that the spillover of liquidity risk exists. International Monetary Fund (2015), relying mostly on the event studies, reveals that liquidity shocks spillover across different asset classes and that this effect has increased over time. Besides, the commonality of liquidity of different assets has increased due to widespread index investors' growth index. Moshirian et al. (2017) add that liquidity commonality is in weaker and riskier markets with poorer investor protection and less transparency. Smimou and Khallouli (2017) found that liquidity often spill-overs from smaller to larger more extensive German, French, and Italian markets in a similar vein.

Despite the increase of high-frequency bond data availability, still very few empirical papers analyze the liquidity spill-overs among different bonds and, especially on an intra-day basis. One notable exception is the study by Schneider et al. (2016), which focuses on illiquidity risks, i.e., liquidity dry-ups, and how they spillover across Italian government bonds of different residual maturities. These authors use mainly three liquidity indicators at one-minute frequency: bid-ask spread, price impact of particular trade, and depth across the limit order book. They find, for instance, that shorter-term bonds are increasingly affected by the liquidity spill-overs from the long-term bonds and that market liquidity is less resilient and predictable when the bonds are less liquid.

To conclude the relevant studies review, it is clear that the literature is scarce on the topic of liquidity spill-overs in sovereign bond markets. Besides, liquidity spill-overs of trades, especially on an intraday basis, has been almost an unexplored research area, possibly due to the limited availability of high-frequency trade and order-book data that is a prerequisite for the robust spillover analysis in the financial markets where prices and liquidity conditions adjust instantly after the trade is executed.

3. Data and Methodology

This chapter defines the data, derived dependent and explanatory variables, and liquidity indicators that will be used in the empirical analysis. Two research methods that will be employed in the analytical part—the event study and the panel regression model—are briefly described afterward.

3.1. Data

Two different datasets from MTS are used to study liquidity spill-overs of trades in European sovereign bond markets: inter-dealer tick-by-tick trade and limit order book data. Sovereign bonds can be traded over-the counter or on the electronic exchanges; the latter can be further divided into dealer-to-dealer (inter-dealer) and dealer-to-customer platforms (Bank for International Settlements 2016a). MTS is the largest interdealer platform for European sovereign bonds with the central limit order-book mechanism (MTS 2017). While relatively fewer trades are executed on the MTS interdealer market, the number of orders submitted to the central limit order-book is much higher. Order revisions outnumber trades so vastly that trade-based indicators considerably underperform order-based indicators (Pellizon et al. 2013).

The preparation for the minute frequency order book closely follows the Darbha and Dufour (2015). To analyze the spillover effects on a discrete and high frequency period, limit orders for each bond are sampled to one-minute intervals. At the same time, all trade stamps are assigned to the nearest minute interval, and traded quantities are summed for each bond. Gkillas et al. (2020) forecasted realized volatility of the oil market using high frequency data as well but those authors used different types of Heterogeneous Autoregressive models of realized volatility (HAR-RV) and focused more on indexes of financial stress as a proper tool for more accurate forecasting.

The study covers the period from June 2011 until December 2017 for six major European sovereign bond markets. This time period encompasses heightened market conditions during the euro area sovereign debt crisis in end-2011—start-2012, environment of very low or even negative bond rates, central bank asset purchases,

important political events (e.g., US and French presidential elections, "Brexit" vote) and various significant financial events (e.g., the "Bund-Tantrum"). During this period, the outstanding nominal value of -area sovereign bonds increased from around 6.1 tn EUR in June 2011 to 7.3 tn EUR in December 2017 (ECB 2017). Six European sovereign bond markets are chosen for the analysis: 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.

The most frequently used liquidity indicator in this study is calculated accordingly (Jurkšas et al. 2018):

$$Order-Book\ Illiquidity\ Score_{t,5} = \frac{Spread_{t,5}}{Quantity_{t,5}} = \frac{\frac{1}{5}\sum_{j=1}^{5} P_{t,Ask(J)} - \frac{1}{5}\sum_{j=1}^{5} P_{t,Bid(J)}}{\sum_{j=1}^{5} Q_{t,Ask(J)} + \sum_{j=1}^{5} Q_{t,Bid(J)}} \tag{1}$$

where:
t—the time in minutes at which the limit order-book is calculated (e.g., before, at, and after the trade is executed);
P—the price of the limit order book, i.e., the mid-point of ask and bid price;
Q—the quantity that can be traded at a given quoted price;
"Ask" and "Bid"—the side of the limit order-book;
j—number of the priority of the offers in the limit order book (from 1st to 5th best Ask/Bid price and its corresponding quantity).

The order-book illiquidity score encompasses two main liquidity dimensions: cost and depth. The numerator is the average bid-ask spread of five best (i.e., closest to the mid-price) quotes. The denominator is the sum of quoted quantities corresponding to the five best ask and bid prices. In general, the lower the order-book illiquidity score and the average bid-ask spread, and the higher the corresponding quoted quantities, the more liquid the bond is. 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 average bid-ask spread would be impacted if the amounts of the five best bids and five best asks would be transacted. So order-book illiquidity score positively represents a widely used price impact indicator created by Amihud (2002), although the latter indicator is calculated with trade and not limit order data. Five best bid/ask prices are chosen because dealers can observe in real-time the five best prices (with corresponding quantities) on each side of the limit order book in the MTS trading platform. Besides, Bank for International Settlements (2016b) states that simple bid-ask spreads and quantities at the best bid and ask price are no longer a representative indicator of liquidity conditions due to increased automated trading. However, the limit orders with prices that are far away from the mid-price have a very low probability of being hit by another incoming order, so the prices and, especially, quantities might also not reflect true "dealers" intentions.

3.2. Research Methods

The event-type study is the primary method used in this paper to analyze the liquidity spillover effect of sovereign bond trades. The execution of trade acts as a shock to the market because relatively fewer trades are executed during the day, and the transaction directly affects the limit order book. A trade is executed when a standing limit order is crossed by incoming market-order (that is immediately filled or killed) or another limit order. So a buy-side transaction results in the removal of the limit order with the lowest bid price, while a sell-side transaction leads to the elimination of the limit order with the highest ask price. As a result, bid-ask spread widens and illiquidity-score increases immediately after the trade is executed. So the event-type study is an appropriate method to analyze how the execution of the trade immediately reverberates to the quoted prices and quantities of this bond and

helps to determine the average spillover effect across different bonds from the same or another country.

The results of this relatively simple statistical analysis method can be noticeably analyzed graphically. Besides, this method is less prone to possible errors and variable selection bias, which is often a case in more sophisticated econometrical models. International Monetary Fund (2015) argues that the event studies often help overcome the problem of reverse causality. The event studies are carried out by many authors, including Pellizon et al. (2013); Andrulytė and Jurkšas (2015); Blasi (2016); Tsuchida et al. (2016), etc.

The average value of a particular liquidity indicator (e.g., illiquidity score, bid-ask spread, quoted quantity) is calculated on a minute frequency from 15-min before until 15-min after a transaction of sovereign bond is executed. This time period is long enough to assess if the transaction resulted in a temporary or permanent liquidity spillover effect and if there was a particular dynamic of liquidity indicator even before the trade was executed. The average cumulative change (C_t) of a particular liquidity indicator before and after the transaction is calculated according to this formula:

$$C_{t,k} = \frac{1}{K}\sum_{k=1}^{K}\left(M_{t,k} - M_{0,k}\right) \tag{2}$$

where:
t—minutes after (+)/before (−) a trade is executed,
M_0—the value of bond liquidity indicator at the time of the trade,
M_t—the value of bond liquidity indicator at time t,
k—the number of observations at time t.

Several other critical computational transformations were performed. First, the cumulative changes of liquidity indicator at t minute before/after the trade were at first averaged across all observations on a monthly basis. This was done due to the computational efficiency (as it was not possible to calculate the limit order-book for the full sample period from 2011 at once). In this way, it was easier to compare the results during the time. Second, to reduce the effect of spurious outliers, winsorizing procedure was employed: 10% lowest and highest values were set to the value of the respectively 10 and 90 percentile of the liquidity indicator values among the bonds from the same country. Third, a simple mean of monthly winsorized cumulative liquidity changes was computed.

The average cumulative liquidity change was calculated for several different dimensions: the direction of the transaction, the buckets of bonds with different residual maturities, the size, and type of trade; across various markets. This distinction helps to comprehensively determine the bonds with the strongest spillover effects that emerge after the trades are executed.

In Section 5, a panel regression model is employed to assess the underlying reasons for the strength of trade liquidity spillover effects among different markets. This model is used to understand why after a transaction is executed in one market, the liquidity shock reverberates more strongly to some markets while less so, to others. So the dependent variable is the change of order-book illiquidity score in the market where no trades have been executed. Country-specific fixed effects were included in the panel regression model because fixing the group means (in this study—among bonds from various countries) helps in controlling the unobserved heterogeneity (Stock and Watson 2011) because bonds from different countries might be correlated with the level of the illiquidity score and the overall spillover effect.

4. Results of the Event Studies on Spillover Effects of Trades

This chapter presents four different graphical event studies of the spillover effects of trades: buy and sell-side of the transactions; bonds with different maturity (a term structure of liquidity spillover effect), various sizes of trades; across six euro area sovereign bond markets.

4.1. Direction of Trade

Before analyzing the liquidity spillover of trade, it is important to understand how different types of trades affect sovereign "bonds" prices and how this effect differs for the traded (direct impact) and non-traded (spillover effect) bonds. As market intelligence would confirm, buy-side transactions lead to the increase of the traded sovereign bond's mid-point price, while sell-side trades—to the decrease of the price up to several basis points (Figure 1). This effect seems to be permanent as the average price does not reverse even 15 min after the trade's execution. Importantly, the change of other bonds' prices from the same country as the traded bond is on average around five times smaller than the price change of the traded bond. However, the prices of other (non-traded) bonds change much more (and with different sign) before the trade is executed than the price of the traded bond, meaning that the change of bond prices enters the endogenous "investors" decision process of selecting particular bonds that should be traded, i.e., the bonds whose price decrease has a higher probability of being bought.
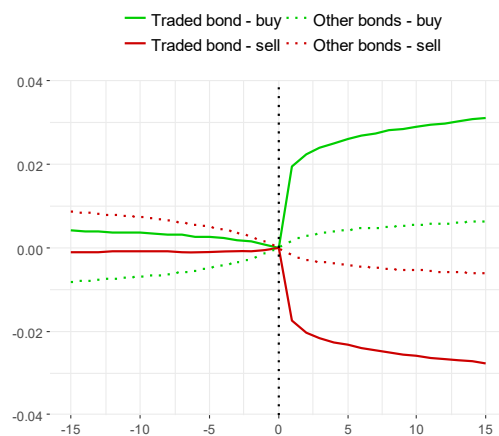

Figure 1. The trade effect on sovereign bond mid-point price 15 min before and after the trade was executed.

Although the trade effect on bond prices is opposite for buy and sell-side transactions (Figure 1), the impact is much more homogenous on liquidity. The liquidity diminishes only slightly after the sell-side trade rather than the buy-side transaction, and this difference becomes more evident in time (Figure 2). Notably, while the liquidity spillover from the prices of the traded to other bonds of the same country is noticeable, it is around ten times smaller than the effect on the traded bond's liquidity. The spillover effect is mostly visible on the first minute after the transaction is executed and entirely dissipates after around 5 min for the buy-side transaction and after about 15 min for the sell-side transaction, leaving the liquidity situation broadly unchanged. It is also worth stressing that before the transaction, the liquidity situation improves for the traded bond and deteriorates a bit for all other bonds. This observation again indicates that investors trade bonds whose liquidity is improving until the bond becomes sufficiently liquid for the trader.
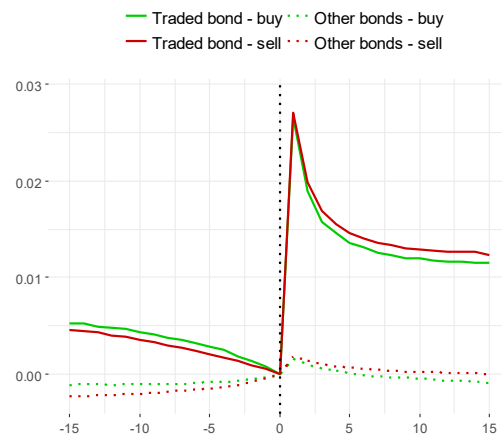
Figure 2. The trade effect on illiquidity-score 15 min before and after the trade was executed.

To a large extent, the bid-ask spread follows the pattern of illiquidity score. The average bid-ask spread of the traded bond increases most severely immediately after the trade is executed and decreases somewhat afterward. Still, the negative effect does not disappear even after 15 min (Figure 3). The spillover to the bid-ask spreads of other bonds is also visible but comparatively much smaller (around 15 times) than for the traded bond. Still, the spillover effect does not dissipate even after 15 min.
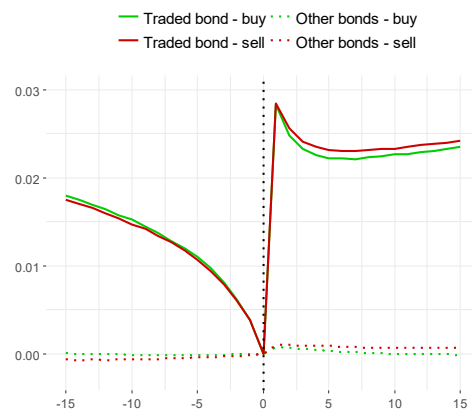
Figure 3. The trade effect on sovereign bond bid-ask spread (15 min before and after the trade is executed.

The impact of a trade shock on liquidity is also visible for the quoted quantities component of the illiquidity score. Quoted quantities of the traded bond decreased by almost eight million units on the first minute after the buy and sell-side transaction is executed (Figure 4). However, this effect completely disappears after several minutes and even attracts new traders to quote additional quantities. Interestingly, the quantities are decreasing sharply, while the bid-ask spread is tightening before the transaction is executed, possibly meaning that there is some kind of front-running behavior of market participants (e.g., leakage of information of incoming "clients" orders) that materialize in diminished quantities, especially before the sell-side transaction. A very similar pattern is visible for quantities of non-traded bonds from the same country as the traded bond, but around five times smaller in magnitude both before and after the transaction is executed.
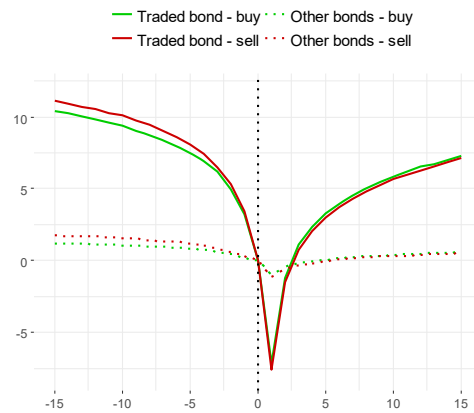
Figure 4. The trade effect on quoted quantities 15 min before and after the trade is executed.

4.2. Maturity Buckets

While the liquidity spillover effect seems to be relatively quiet small (i.e., on average, ten times smaller than the impact on the liquidity of the traded bond), there is a lot of heterogeneity across bonds with different residual maturities. The liquidity of bonds from the same country and residual maturity closer to the traded "bonds" maturity is affected most detrimentally (Figure 5). This effect is strongest the first minute after the trade is executed; afterward, this negative effect gradually dissipates. Meanwhile, the liquidity of bonds with very different residual maturity than the traded bond is almost unaffected, i.e., around five times less than the liquidity of bonds with similar maturity as the traded bond on the first minute after the trade.
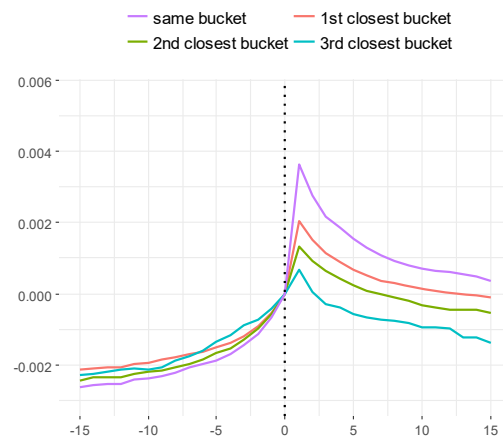

Figure 5. The spill-over effect on illiquidity score of different by residual maturity sovereign bonds 15 min before and after the trade is executed.

The liquidity spillover to non-traded bonds varies notably during time. The spill-over effect on the first minute after the trade is strongest during turbulent times (e.g., European sovereign debt crisis in 2011–2012, the "Bund-Tantrum" in mid-2015) and is almost negligible during calm market periods, e.g., 2013–2014 (Figure 6). The peak of spillover effect in end-2011 is almost ten times higher than at the beginning of 2014. Importantly, the liquidity of bonds with closer residual maturity to the traded "bonds" maturity is affected most significantly during the whole analyzed period, while the effect on the furthest by maturity bonds was even a bit negative for a couple of months in 2015. This probably speaks for the tight relationship between the spillover effect and the market risk sentiment (and therefore the magnitude of illiquidity score).
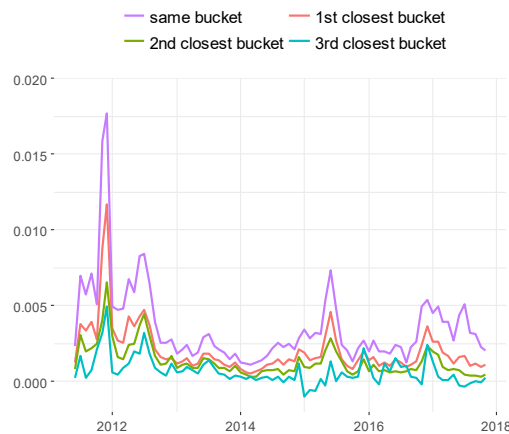
Figure 6. The spill-over effect on illiquidity score during time.

Both components of the illiquidity score of the non-traded sovereign bonds are negatively affected by the trade's execution, although this effect varies highly for bonds with different maturities. The quoted quantities (Figure 7) and the bid-ask spreads (Figure 8) are more severely affected for the bonds with similar residual maturity as the traded bond. This is probably since bonds with similar maturity are regarded as close substitutes. In contrast, bonds with different maturity might have quite unlike characteristics and features that attract distinct types of investors (so-called "preferred habitat" investors). Notably, the magnitude of spillover effect on bid-ask spreads varies more than on quantities among different maturity bonds, i.e., the quantities of bonds with different maturities change relatively more homogenously than the bid-ask spreads. Also, quoted quantities return to the pre-trade state in around five minutes, while the spillover effect for spreads decreases much more gradually.
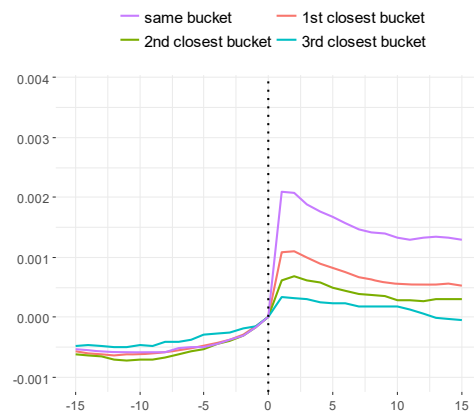

Figure 7. The spillover effect on bid-ask spreads of different by residual maturity sovereign bonds 15 min before and after the trade is executed.
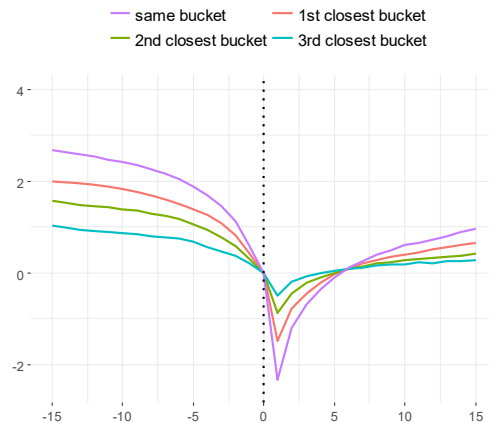
Figure 8. The spill-over effect quoted quantities of different by residual maturity sovereign bonds 15 min before and after the trade is executed.

4.3. Size of Transaction

The trade size of sovereign bonds also explains the difference in magnitudes of the liquidity spillover effect. The smallest value transactions have almost no liquidity spillover effect, while the largest transactions lead to a considerable detrimental effect (Figure 9). The differences of spillover effects between various sizes of transactions are also notable for both illiquidity score components: quoted quantities and spreads (not plotted here). The much higher spillover effect of the largest transactions holds during the whole review period, especially during stressful market conditions (Figure 10). As a result, the observed liquidity spillover effect should mainly be related to the largest transactions, while the smaller trades do not considerably affect liquidity. This result also implies that investors should deter from executing larger orders at once and divide them into smaller trades across longer time periods to reduce liquidity shocks.
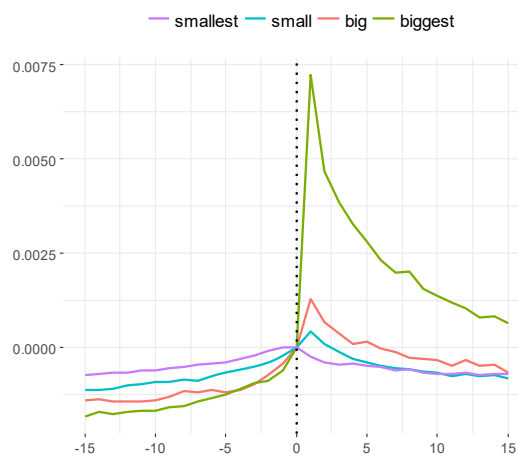

Figure 9. The spillover effect of different trade size on the illiquidity score of sovereign bonds 15 min before and after the trade is executed.
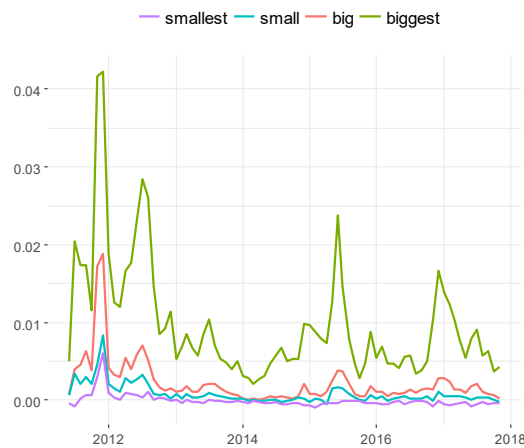
Figure 10. The spill-over effect of different trade size on the illiquidity score of sovereign bonds during time.

4.4. Issuing Country

The liquidity spillover effect varies highly among different markets. There are two notable country groups: the spillover is relatively small in sovereign bond markets from Germany, France, and Italy, while it is much more noticeable in smaller countries—Belgium, the Netherlands, and Spain (Figure 11). This segregation into two country blocks persists for both liquidity dimensions—the bid-ask spreads and quoted quantities (not plotted here)—as well as through time (Figure 12). The only notable exception is the more pronounced liquidity spillover in the Italian market during the European sovereign debt crisis. It is also important to note that the return of liquidity indicator to the pre-trade state is also very different among countries, i.e., the liquidity spillover effect is more permanent in Germany, France, and Spain, but seems to be temporary in Italy, Belgium, and the Netherlands.
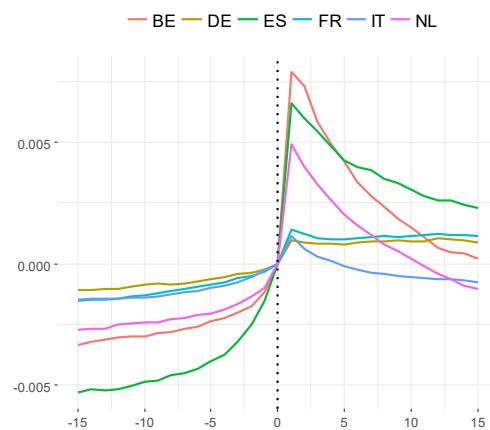

Figure 11. The spillover effect on illiquidity score of sovereign bonds in different countries 15 min before and after the trade is executed. Notes: BE—Belgium; DE—Germany; ES—Spain; FR—France; IT—Italy; NL—Netherlands.
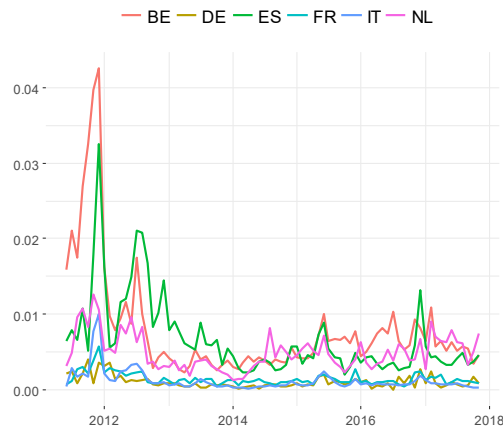
Figure 12. The spill-over effect on illiquidity score of sovereign bonds in different countries during time. Notes: BE—Belgium; DE—Germany; ES—Spain; FR—France; IT—Italy; NL—Netherlands.

5. Results of the Liquidity Spillover Effect from One Market to Another

This chapter focuses on the bilateral linkages among countries of the liquidity spillover effect. The first part reports the results of an event study of liquidity spillover from one market to, on average, all other markets. In the second part, the panel regression model results try to bring more light onto the possible determinants of these bilateral cross-country linkages.

5.1. Event Study of the Liquidity Spillover Effect from One Market to Another

Intuitively, a liquidity spillover effect of particular trade should be strongest for the bonds from the same market as the traded bond. It is the case with the spill-over effect of German trades (Figure 13) and French (Figure 14) sovereign bonds. This is especially evident immediately after the trade execution, because afterward the picture is potentially blurred by market-specific factors, e.g., the liquidity trend of Spanish bonds. The liquidity spillover effect to bonds from other countries is also visible, but this effect is around three times smaller than for the bonds from the same country. Interestingly, only Italian bonds seem to remain unaffected by the trades of German or French sovereign bonds, possibly because Italian bonds are the most traded bonds in the MTS market.
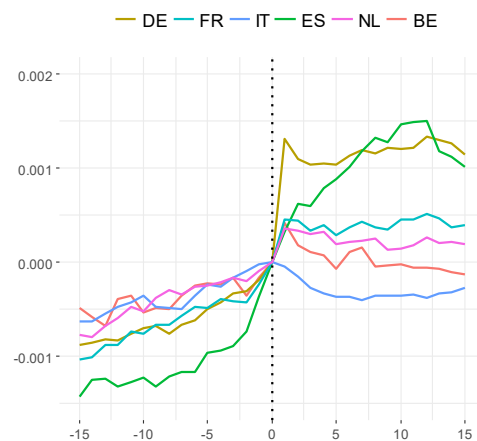

Figure 13. The liquidity shock spillover effect of trades of German sovereign bonds to different markets 15 min before and after the trade is executed. Notes: BE—Belgium; DE—Germany; ES—Spain; FR—France; IT—Italy; NL—Netherlands.

Figure 14. The liquidity shock spill-over effect of trades of French sovereign bonds to different markets 15 min before and after the trade is executed. Notes: BE—Belgium; DE—Germany; ES—Spain; FR—France; IT—Italy; NL—Netherlands.
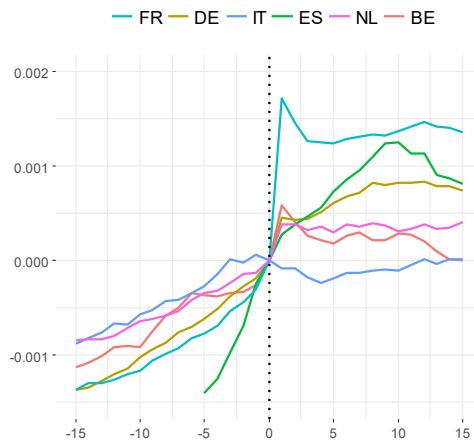
Similar conclusions can be reached regarding the spill-overs emanating from Italian trades (Figure 15) and Spanish (Figure 16) sovereign bonds. However, the liquidity spillover from Spanish bonds trades to all other markets is comparatively much smaller (only Italian bonds are somewhat affected), meaning that trades of Spanish sovereign bonds have little informational value for traders from other countries. Interestingly, the liquidity of Spanish bonds is also highly affected by Italian bonds' trades, while there is limited effect on the bonds from other markets.
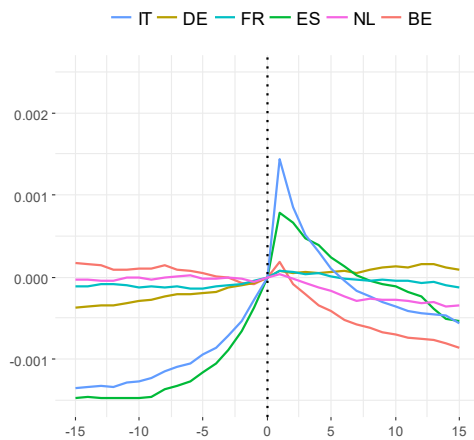

Figure 15. The liquidity shock spillover effect of trades of Italian sovereign bonds to different markets 15 min before and after the trade is executed. Notes: BE—Belgium; DE—Germany; ES—Spain; FR—France; IT—Italy; NL—Netherlands.

Figure 16. The liquidity shock spill-over effect of trades of Spanish sovereign bonds to different markets 15 min before and after the trade is executed. Notes: BE—Belgium; DE—Germany; ES—Spain; FR—France; IT—Italy; NL—Netherlands.

The spillover effect emanating from Belgium sovereign bonds trades (Figure 17) also seems to be comparatively small. In contrast, the spillover effect is a bit higher from the Netherlands sovereign bonds (Figure 18). After the trade is executed of the Netherlands sovereign bonds, the liquidity of German, French, and Belgian sovereign bonds are most negatively affected. At the same time, no effect is visible in Italian and Spanish markets. Meanwhile, the trades of Belgian sovereign bonds has only a marginal effect of bonds from all other markets; only the effect on own Belgian bonds is significant.

Figure 17. The liquidity shock spillover effect of trades of Belgian sovereign bonds to different markets 15 min before and after the trade is executed. Notes: BE—Belgium; DE—Germany; ES—Spain; FR—France; IT—Italy; NL—Netherlands.
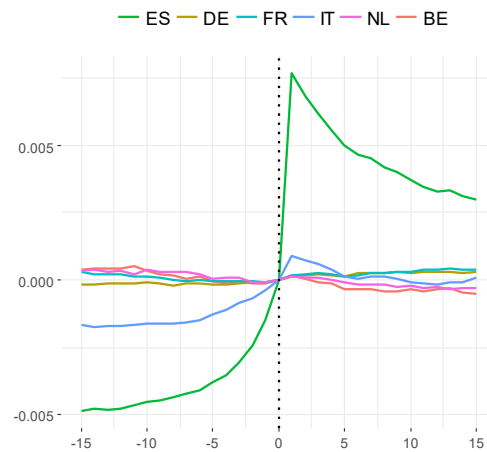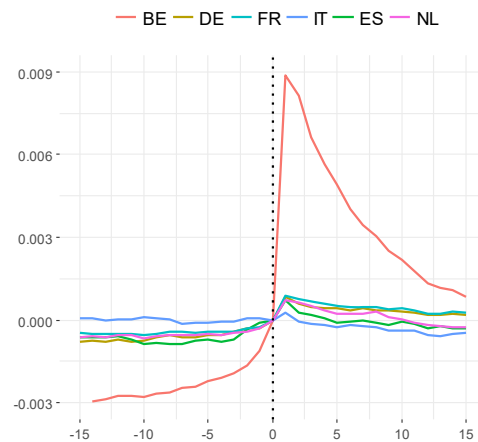
Figure 18. The liquidity shock spill-over effect of trades of Netherlands sovereign bonds to different markets 15 min before and after the trade is executed. Notes: BE—Belgium; DE—Germany; ES—Spain; FR—France; IT—Italy; NL—Netherlands.
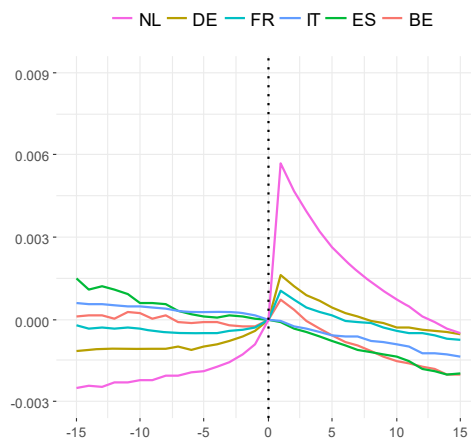
5.2. Panel Regression Model of the Underlying Factors of Liquidity Spillover Effect from One Market to Another

To determine the underlying reasons for the strength of liquidity shock spillover effect among markets, a panel regression model was employed. The dependent variable is the monthly average of the changes of order-book illiquidity score immediately after the transaction is executed. As the analysis was carried out with monthly data from June 2011 until December 2017, 79 monthly averages for bilateral linkages in 6 markets led to overall 2370 bilateral observations. Country-specific fixed effects were included in the model, and the standard errors were clustered because the panel consists of different markets with heterogeneous liquidity levels.

As the spillover effect is related to bilateral linkages (i.e., the traded bond which is transmitting liquidity shock and the non-traded bond that is responding to the shock), two models with different explanatory variables were constructed. The first model focuses on the spill-over effect emanating from the trades of sovereign bonds of a particular market ("spill-over from", i.e., analyzing why the trade signal emanating from some markets is stronger, while from others—weaker. Most of the model's variables were constructed from the transactional data because this model concentrates on the sovereign bonds from which the spillover effect reverberates, i.e., from the traded bonds. The second model focuses on the strength of the spill-over effect to the bonds from another market than the traded bond ("spill-over to"). As this model is related to the sovereign bonds that are "receiving" spill-over effect, most of the variables were constructed from the limit order book data.

The first model results reveal that the strongest liquidity shock spillover effect arises from sovereign bonds that are less liquid and whose issuer is closer by distance to the country of another—non-traded—bond (Table 1). As transactions affect more severely the liquidity of the relatively less liquid and therefore more sensitive traded bonds, the spillover effect from such transactions is also stronger. This result directly relates to the Bank for International Settlements (2016a) and Pellizon et al. (2013) that risks of information leakage from illiquid securities are often much higher. Intuitively, the liquidity spillover effect is stronger when it emanates from the traded bond whose issuer is closer by distance to another sovereign bond issuer. However, other variables—number of transactions, average trade size, and residual maturity of the traded bond—has no statistically significant explanatory power (Table 1).

Table 1. Explanation of variables and results.

Variable	Description	Results
Spill-over FROM	Average monthly spill-over effect from the country of the traded bond (from which spill-over impact is measured) to non-traded bond from another country	Dependent variable
distance	The distance between the country of the traded bond and the country of another bond (in 1000 km)	−0.00028 ** (−8.55)
num_trades	The number of trades from which the spill-over effect is measured during a month	−0.018 (−1.41)
trade_size	The average trade size of bonds from which spill-over effect is measured during a month (in millions)	−0.0000195 (−0.9)
illiq_score	The average illiquidity score of bonds from which spill-over effect is measured at the time of the trade	0.0015 ** (12.02)
res_maturity	The average residual maturity of traded bonds at the time of the trade (in years)	−0.000017 (−1.68)

Note: The number in parentheses is the heteroscedasticity robust *t* value, ** indicates statistically significant variables at 5% level.

The second model results (i.e., spillover effect to another market) are quite similar to the results of the first model (Table 2). The closer the two countries are, the higher the liquidity shock spill-over effect to the bonds from another market than the traded bond. Also, the less liquid bonds are affected more severely. Nevertheless, this model reveals that the number of quoted bonds also matters: the higher the number of bonds from a particular issuer that is quoted in the particular market, the weaker is the liquidity shock spillover effect, possibly due to the dilution of the impact among different bonds. Interestingly, bonds with a higher number of limit order revisions are more affected, meaning that such bonds quickly incorporate new information transmitted by trades of bonds from another market—though this effect is significant only at the 10% significance level. This result is also confirmed by other studies that state that rapid technological changes enable dealers to quickly incorporate incoming information in the central order book. Only the residual maturity of the non-traded bond is not statistically significant, contrary to Schneider et al. (2016) (Table 2).

Table 2. Explanation of variables and results.

Variable	Description	Results
Spill-over TO	The average monthly spill-over effect to the bonds from the country of the non-traded bond (to which spill-over effect is measured)	Dependent variable
distance	The distance between the country of the traded bond and the country of another bond (in 1000 km)	−0.00038 ** (−8.51)
num_bonds	The number of bonds with standing limit orders at the time of the trade	−0.000026 ** (−4.35)
num_updates	The number of limit order revisions in the central limit order book	0.0000012 * 1.75
illiq_score	The average illiquidity score of bonds to which spill-over effect is measured at the time of trade	0.0024 ** (13.79)
res_maturity	The average residual maturity of non-traded bonds from another country than the traded-bond (in years)	−0.00003 (−0.77)

Note: The number in parentheses is the heteroscedasticity robust *t* value, ** indicates statistically significant variables at 5% level, *—at 10% level.

The main takeaway from the two-panel regression models is that it is difficult to relate particular bond-specific factors to the size of the liquidity shock spillover effect both from and to another market. Only the distance between the countries and the relative liquidity of bonds help explain the spillover effect in both models. Possibly, other

variables that are not directly related to the MTS bond market might be useful to explain these cross-country differences, e.g., the trading and quoting activity in other (including over-the-counter and futures) markets, linkages between different markets, and et cetera.

6. Conclusions

In our research, we tried identifying the liquidity spill-over effect. We wanted to reveal how different trades can influence sovereign bonds' prices and how this effect differs for the traded (direct impact) and non-traded (spill-over effect) bonds. Our event studies of spill-over effects of trades were carried out with minute frequency bond data from mid-2011 until the end-2017 for the six largest euro area markets. We determined that the outcome was permanent as the average price does not reverse even 15 min after the trade's execution. We would also like to point out that the change of other bonds' prices from the same country as the traded bond was smaller than the traded bond price change. However, the prices of other (non-traded) bonds change much more before the trade was executed than the price of the traded bond. The latter results mean that the change of bond prices entered the endogenous investors' decision process of selecting particular bonds that had been traded. Finally, we can conclude that the liquidity spill-over effect was relatively small. In the next step, we try to analyze maturity buckets. The liquidity of bonds from the same country and residual maturity closer to the traded "bonds" maturity was affected most detrimentally. Both components of illiquidity score—quoted quantities and bid-ask spreads—were more severely affected for the bonds with similar residual maturity as the traded bond.

The other interesting fact that we want to point is that the liquidity spill-over to non-traded bonds varies notably during time. The spill-over effect on the first minute after the trade was most robust during turbulent times and was almost negligible during calm market periods. We want to stress that the liquidity of bonds with closer residual maturity to the traded bonds' maturity was affected most significantly during the whole analyzed period. Such a tendency could be explained by the tight relationship between the spill-over effect and the market risk tolerance.

Because the trade size of sovereign bonds can also be used to explain the differences in magnitudes of the liquidity spillover effect, we included that factor. We have noticed that the smallest value transactions have almost no liquidity spillover effect, while the largest transactions lead to a considerable detrimental effect. So because of that, investors split the orders across more extended periods to avoid liquidity shocks.

Issuing country is also a significant factor for liquidity spill-over effects. We determined that the spill-over is relatively small in sovereign bond markets from Germany, France, and Italy. At the same time, it is much more noticeable in smaller countries—Belgium, the Netherlands, and Spain.

Finally, in our study, we tried to investigate the liquidity spill-over effects from one market to another. We revealed that the liquidity shock spill-overs are most robust for the bonds from the same issuing country as the traded bond rather than on the bonds from other countries. Regarding the strength of bilateral spill-over effects among different markets, the panel regression model results revealed that few liquid bonds and bonds whose issuer is closer by distance to the country of the traded bond has a more substantial reactive spillover effect. Such bonds are also affected more by the trades executed in another market. Also, the higher the number of bonds (mostly if they are less actively quoted) that are being listed in the particular market, the weaker is the liquidity spillover effect.

Results of this research should be of particular interest to the sovereign bond traders, analysts, market supervisors who actively monitor the dynamics of bond markets and try to understand the underlying reasons for market movements and liquidity dry-ups. Market liquidity can quickly evaporate after trades are executed even in another market. Market participants should pay increasing attention to the cross-country effects and have a pre-emptive strategy to cope with the spillover shocks. Otherwise, increasing liquidity

premium might reduce the efficiency of the trading strategies and negatively affect trading returns.

References

Albagli, Elias, Luis Ceballos, Sebastian Claro and Damian Romero. 2017. Channels of US Monetary Policy Spillovers into International Bond Markets. *Working Papers Central Bank of Chile* 771: 1–29. doi:10.2139/ssrn.2684921.

Amihud, Yakov. 2002. Illiquidity and Stock Returns: Cross-section and Time-series Effects. *Journal of Financial Markets* 5: 31–56.

Andrulytė, Ieva, and Linas Jurkšas. 2015. The Scale of Insider Trading at the Nasdaq OMX Vilnius Exchange. *Monetary Studies* 17–19: 5–23.

Bank for International Settlements. 2016a. *Electronic Trading in Fixed Income Markets. Report of Bank for International Settlements*. Basel: Bank for International Settlements, pp. 1–44.

Bank for International Settlements. 2016b. *Fixed Income Market Liquidity*. CGFS Papers No. 55. Basel: Bank for International Settlements, pp. 1–35.

Barth, Daniel, and Jay Kahn. 2020. *Basis Trades and Treasury Market Illiquidity, Briefs 20-01*. Washington: Office of Financial Research, US Department of the Treasury.

Bein, Murad A. 2017. Time-Varying Co-Movement and Volatility Transmission between the Oil Price and Stock Markets in the Baltics and Four European Countries. *Inzinerine Ekonomika-Engineering Economics* 28: 482–93. doi:10.5755/j01.ee.28.5.17383.

Blasi, Leonardo. 2016. Liquidity risk and market shock: An event study on emerging market corporate bonds. *FMA Conferences Proceedings* 1–44.

Bowman, David, Juan M. Londono, and Horacio Sapriza. 2015. US Unconventional Monetary Policy and Transmission to Emerging Market Economies. *Journal of International Money and Finance* 55: 27–59.

Brière, Marie, Ariane Chapelle, and Ariane Szafarz. 2012. No contagion, only globalization and flight to quality. *Journal of International Money and Finance* 31: 1729–44.

Broto, Carmen, and Matias Lamas. 2020. *Is Market Liquidity Less Resilient after the Financial Crisis? Evidence for US Treasuries. Economic Modelling*. Amsterdam: Elsevier, vol. 93, pp. 217–29.

Brunnermeier, Markus K., and Lasse Heje Pedersen. 2008. Market Liquidity and Funding Liquidity. *The Review of Financial Studies* 22: 221–38. doi:10.1093/rfs/hhn098.

Calice, Giovanni, Jing Chen, and Julian Williams. 2013. Liquidity Spillovers in Sovereign Bond and CDS Markets: An Analysis of the Eurozone Sovereign Debt Crisis. *Journal of Economic Behavior and Organization* 85: 122–43. doi:10.1016/j.jebo.2011.10.013.

Chordia, Tarun, Asani, Sarkar, and Avanidhar, Subrahmanyam. 2007. Liquidity Spill-overs and Cross-Autocorrelations. *Federal Reserve Bank of New York Staff Reports* 303: 1–43.

Cifuentes, Rodrigo, Gianluigi Ferrucci, and Hyun Song Shin. 2005. Liquidity Risk and Contagion. *Journal of the European Economic Association* 3: 556–66. Available online: http://www.jstor.org/stable/40004998 (accessed on 4 March 2021).

Claeys, Peter, and Borek, Vašíček. 2014. Measuring Bilateral Spillover and Testing Contagion on Sovereign Bond Markets in Europe. *Journal of Banking and Finance* 46: 151–65.

Clancy, Daragh, Peter G. Dunne, and Pasquale Filiani. 2019. *Liquidity and Tail-Risk Interdependencies in the Euro Area Sovereign Bond Market*. Research Technical Papers 11/RT/19. Dublin: Central Bank of Ireland.

Darbha, Madhucchand, and Alfonso Dufour. 2015. Euro Area Government Bond Market Liquidity. *SSRN Electronic Journal* 1–45. doi:10.2139/ssrn.2470944.

Diaz, Antonio, and Ana Escribano. 2017. Liquidity measures throughout the lifetime of the U.S. Treasury bond. *Journal of Financial Markets* 33: 42–74. doi:10.1016/j.finmar.2017.01.002.

Diebold, Francis, and Kamil Yilmaz. 2009. Measuring Financial Asset Return and Volatility Spillovers, with Application to Global Equity Markets. *Economic Journal* 119: 158–71. doi:10.1111/j.1468-0297.2008.02208.x.

Dufour, Alfonso, and Minh Nguyen. 2011. Permanent Trading Impacts and Bond Yields. *The European Journal of Finance* 18: 841–64. doi:10.2139/ssrn.1427087.

Dungey, Mardi, Renee Fry, Brenda González-Hermosillo, and Vance Martin. 2006. Contagion in international bond markets during the Russian and the LTCM crises. *Journal of Financial Stability* 2: 1–27.

Dunne, Peter, Harald Hau, and Michael Moore. 2015. Dealer Intermediation between Markets. *Journal of the European Economic Association* 13: 770–804. doi:10.1111/jeea.12118.

ECB (European Central Bank). 2017. *Debt Securities Statistics*. Frankfurt am Main: European Central Bank.

European System of Financial Supervision. 2016. Market liquidity and market-making. *Report by European System of Financial Supervision* 53: 1–25. doi: 10.2849/098493.

Fassas, Athanasios, and Costas Siriopoulos. 2019. Intraday price discovery and volatility spill-overs in an emerging market. *International Review of Economics & Finance* 59: 333–46.

Fleming, Michael 2003. Measuring Treasury Market Liquidity. *Economic Policy Review* 9: 1–57. doi:10.2139/ssrn.276289.

Galliani, Clara, Giovanni Petrella, and Andrea Resti. 2014. The liquidity of corporate and government bonds: Drivers and sensitivity to different market conditions. *Joint Research Centre Technical Reports* 1: 38. doi:10.2788/70146.

Gkillas, Konstantinos, Rangan Gupta, and Christian Pierdzioch. 2020. Forecasting realized oil-price volatility: The role of financial stress and asymmetric loss. *Journal of International Money and Finance* 104: 102137.

Glosten, Lawrence, and Paul Milgrom. 1985. Bid, ask and transaction prices in a specialist market with heterogeneously informed traders. *Journal of Financial Economics* 14: 71–100.

Goyenko, Ruslan, Y. Craig, W. Holden, and Charles A. Trzcinka. 2009. Do Liquidity Measures Measure Liquidity? *Journal of Financial Economics* 92: 153–81.

Gupta, Chandra P., Sanjay Sehgal, and Sahaj Wadhwa. 2018. Agricultural Commodity Trading: Is it Destabilizing Spot Markets? *Vikalpa: The Journal for Decision Makers* 43: 47–57.

Han, Jianlei, and Zheyao Pan. 2017. On the relation between liquidity and the futures-cash basis: Evidence from a natural experiment. *Journal of Financial Markets* 36: 115–31. doi:10.1016/j.finmar.2016.12.002.

He, Feng, Baiao Liu-Chen, Xiangtong Meng, Xiong Xiong, and Wei Zhang. 2020. Price discovery and spill-over dynamics in the Chinese stock index futures market: A natural experiment on trading volume restriction. *Quantitative Finance, Taylor & Francis Journals* 20: 2067–83.

Holden, Craig W., Stacey Jacobsen, and Avanidhar Subrahmanyam. 2014. The Empirical Analysis of Liquidity. *Foundations and Trends in Finance* 8: 263–365. doi:10.2139/ssrn.2402215.

Honkanen, Pekka, and Daniel Schmidt. 2017. *Price and Liquidity Spill-Overs during Fire Sale Episodes*. HEC Research Papers Series 1214. Paris: HEC.

International Monetary Fund. 2015. *Market Liquidity—Resilient or Fleeting?* Global Financial Stability Report. Washington, DC: International Monetary Fund, vol. 49, p. 82.

Jiang, Ying, Neil Kellard, and Xiaoquan Liu. 2020. *Night Trading And Market Quality: Evidence From Chinese And US Precious Metal Futures Markets, Journal of Futures Markets*. Hoboken: John Wiley & Sons, Ltd., vol. 40, pp. 1486–507.

Jurkšas, Linas, Daniel Kapp, Ken Nyholm, and Julian Von Landesberger. 2018. Euro area sovereign bond market liquidity since the start of the PSPP. *ECB Economic Bulletin*. Forthcoming. doi:10.2866/275.

Kandil, Magda. 2018. *Growth in Oil- and Non-Oil-Producing Countries*. 1 Ivory Square, Plantation Wharf, SW11 3UE. London: World Economics, vol. 19, pp. 75–134.

Kurosaki, Tetsuo, Yusuke Kumano, Kota Okabe, and Teppei Nagano. 2015. *Liquidity in JGB Markets: An Evaluation from Transaction Data*. Bank of Japan Working Paper Series. Tokyo: Bank of Japan, vol. E2, pp. 1–38.

Kyle, Albert S. 1985. Continuous Auctions and Insider Trading. *Econommetrica* 53: 1315–36.

Levisauskaite, Kristina, Vilija Alekneviciene, and Eglė Alekneviciute. 2015. Hierarchical Structures of the Relationships Between Government Bond Markets in the EU Countries. *Transformations in Business & Economics* 14: 158–72.

Lin, Hai, Junbo Wang, and Chunchi Wu. 2013. Liquidity Risk and Momentum Spill-over from Stocks to Bonds. *The Journal of Fixed Income* 23: 5–42. doi:10.3905/jfi.2013.23.1.005.

Macchiati, Valentina, Giuseppe Brandi, Giulio Cimini, Guido Caldarelli, Daniela Paolotti, and Tiziana Di Matteo. 2020. Systemic liquidity contagion in the European interbank market. *Journal of Economic Interaction and Coordination.* 32p.

Mahanti Sriketan, Amrut Nashikkar, Marti Subrahmanyam, George Chacko, and Gaurav Mallik. 2008. Latent liquidity: A new measure of liquidity, with an application to corporate bonds. *Journal of Financial Economics* 88: 272–98. doi:10.1016/j.jfineco.

Moshirian, Fariborz, Xiaolin Qian, Claudia Koon, Ghee Wee, and Bohui Zhang. 2017. The determinants and pricing of liquidity commonality around the world. *Journal of Financial Markets* 33: 22–41. doi:10.1016/j.finmar.2017.02.004.

MTS (Mercato dei Titoli di Stato). 2017. MTS Markets Overview. Presentation at World Bank. Available online: http://pubdocs.worldbank.org/en/265741493316237603/Angelo-Proni-WB-Apr-2017.pdf (accessed on 8 March 2021).

O'Sullivan, Conal, and Vassilios G. Papavassiliou. 2019. *Measuring and Analyzing Liquidity and Volatility Dynamics in the Euro-Area Government Bond Market*. Open Access publications 10197/9299, Research Repository. Dublin: University College Dublin.

Papadamou, Stephanos, Costas Siriopoulos, and Nikolaos A. Kyriazis. 2020. A Survey of Empirical Findings on Unconventional Central Bank Policies. *Journal of Economic Studies*. Available online: https://www.researchgate.net/profile/Costas_Siriopoulos2/publication/340512691_A_survey_of_empirical_findings_on_unconventional_central_bank_policies/links/5f1ae98245851515ef44f106/A-survey-of-empirical-findings-on-unconventional-central-bank-policies.pdf (accessed on 8 March 2021).

Pellizon, Loriana, Marti G. Subrahmanyam, Davide Tomio, and Jun Uno. 2013. The Microstructure of the European Sovereign Bond Market: A Study of the Euro-zone Crisis. *SSRN Electronic Journal* 1–51. doi:10.2139/ssrn.2242918.

Rappoport, David, and Tugkan Tuzun. 2020. *Arbitrage and Liquidity: Evidence from a Panel of Exchange Traded Funds*. Finance and Economics Discussion Series 2020-097. Washington, DC: Board of Governors of the Federal Reserve System (U.S.).

Righi, Marcelo Brutti, and Kelmara Mendes Vieira. 2014. Liquidity Spill-over in International Stock Markets through Distinct Time Scales. *PLoS ONE* 9: e86134. doi:10.1371/journal.pone.0086134.

Rigobon, Roberto. 2019. Contagion, Spillover, and Interdependence. *Economía* 19: 69–100.

Rindi, Barbara, and Ingrid M. Werner. 2017. *U.S. Tick Size Pilot.* Working Paper Series 2017–18. Columbus: Ohio State University, Charles A. Dice Center for Research in Financial Economics.

Roll, Richard. 1985. A Simple Implicit Measure of the Effective Bid-Ask Spread in an Efficient Market. *The Journal of Finance* 39: 1127–39. doi:10.2307/2327617.

Sarr, Abdourahmane, and Tonny Lybek. 2002. *Measuring Liquidity in Financial Markets*. IMF Working Paper Series. Washington, DC: International Monetary Fund (IMF), vol. 232, pp. 1–64.

Schneider, Michael, Fabrizio Lillo, and Loriana Pellizon. 2016. Modelling illiquidity spill-overs with Hawkes processes: An application to the sovereign bond market. *Quantitative Finance* 1–11. doi:10.1080/14697688.2017.1403155.

Shaikh, Imlak. 2018. 'Investors' fear and stock returns: Evidence from National Stock Exchange of India. *Inzinerine Ekonomika-Engineering Economics* 29: 4–12. doi:10.5755/j01.ee.29.1.14966.

Sheng, Xin, Janusz Brzeszczyński, and Boulis M. Ibrahim. 2017. *International Stock Return Co-Movements and Trading Activity, Finance Research Letters*. Amsterdam: Elsevier, ssvol. 23, pp. 12–18.

Smimou, Kamal, and Wajih Khallouli. 2017. On the intensity of liquidity spill-overs in the Eurozone. *International Review of Financial Analysis* 48: 388–405. doi:10.1016/j.irfa.2015.03.009.

Stock, James H., and Mark W. Watson. 2011. *Introduction to Econometrics*, 3rd ed. Boston: Pearson Addison-Wesley, chp. 10.

Tang, Dragon, Yongjun, and Hong Yan. 2008. *Liquidity and Credit Default Swap Spreads*. Bank of Canada Working Paper Series. Ottawa: Bank of Canada, pp. 1–42. doi:10.2139/ssrn.1008325.

Tsuchida, Naoshi, Toshiaki Watanabe, and Toshinao Yoshiba. 2016. *The Intraday Market Liquidity of Japanese Government Bond Futures.* Monetary and Economic Studies. Tokyo: Bank of Japan, pp. 67–96.

White, Michael, Paloma Taltavull de La Paz, and Jens Lunde. 2018. *The Role of Liquidity in the Transmission of Volatility Across Housing Markets, ERES eres2018_142*. Kaiserslautern: European Real Estate Society (ERES).

Zhu, Lili, and Jiawen Yang. 2008. The Role of Psychic Distance in Contagion: A Gravity Model for Contagious Financial Crises. *Journal of Behavioral Finance* 9: 209–23. doi:10.1080/15427560802539466.