Liquidity and Dealer Activity in the UK Gilt Market During the Financial Crisis*

Evangelos Benos[†] Filip Zikes[‡]

December 22, 2014

Preliminary - please do not cite/circulate

Abstract

We use proprietary transactional data to study the determinants of liquidity in the UK government bond (gilt) market between 2008 and 2011. Our data covers all secondary market trades involving the primary dealers in the gilt market which enables us to associate liquidity conditions with dealer activity. We first document that gilt market liquidity deteriorated significantly during the crisis and this was associated with increased funding costs and aggregate market uncertainty. Nevertheless, dealers generally provided immediacy and liquidity by trading in the opposite direction of price changes. Additionally, we find that the reduction in market liquidity was associated with frictions in the inter-dealer market - as proxied by the ratio of inter-dealer to total volume - above and beyond the effect of funding costs and aggregate uncertainty. Finally, our paper also makes a methodological contribution by proposing a new measure of the effective spread which can be calculated in the absence of accurate transaction time stamps.

JEL Classification:
Keywords: gilt market, funding liquidity, market liquidity, interdealer trading

*We are grateful to Ana Fernandes of the UK's Financial Conduct Authority for helping us understand the data and to James Knight and Elisabetta Vangelista of the UK's Debt Management Office for providing useful comments and suggestions. The views expressed in this paper are those of the authors and not necessarily those of the Bank of England or any of its committees.

[†]Financial Market Infrastructure Directorate, Bank of England, Threadneedle street, London, EC2R 8AH, United Kingdom. Email: evangelos.benos@bankofengland.co.uk.

[‡]Macro-financial Analysis Division, Monetary Analysis Directorate, Bank of England, Threadneedle street, London, EC2R 8AH, United Kingdom. Email: filip.zikes@bankofengland.co.uk.

1 Introduction

Liquidity, or lack thereof, was at the heart of the 2008 financial crisis. Many large and important financial markets that were previously considered highly liquid exhibited unprecedented deterioration in market liquidity and elevated price volatility, especially after the collapse of Lehman Brothers. Examples include markets where counterparty risk or uncertainty about valuations cannot account for the persistent drops in market liquidity, such as the foreign exchange market (Mancini, Ranaldo and Wrampelmeyer 2013) and the US Treasury market (Engle, Fleming, Ghysels and Nguyen 2012, Hu, Pan and Wang, 2013). Funding costs, balance sheet constraints (Gromb and Vayanos, 2002, Brunnermeier and Pedersen, 2009) and slow-moving capital (Mitchel, Pedersen and Pulvino, 2007 and Duffie, 2010) have been proposed as likely drivers of the market liquidity dynamics during the crisis, and better understanding these dynamics remains an active area of research.

This paper contributes to the ongoing research agenda by studying the liquidity of the UK government bond (gilt) market between January 2008 and June 2011, a rich sample period covering the global financial crisis, the first round of asset purchases by the Bank of England (commonly known as quantitative easing or QE) as well as the onset of the Eurozone sovereign debt crisis. We use detailed transactional data from the secondary market for all conventional gilts outstanding at any point in time during this period to uncover the determinants of gilt liquidity in the time-series and cross-section. The unique feature of our data is that they contain all transactions involving the primary dealers in the gilt market, including the identity of the dealer, the transaction price, volume and buy/sell flag. Although many studies have analyzed previously the liquidity of corporate and government bond markets in various countries and time periods, very few of them have been able to associate liquidity with the actual activity of the very institutions who provide it. And to the best of our knowledge, none has done so in a comprehensive manner for the UK government bond market during or before the recent financial crisis.

We start by looking at the determinants of aggregate market liquidity as captured by the yield curve noise measure proposed by Hu et al (2013). We document that the UK yield curve noise increased almost five-fold during 2008, with the sharpest increase occurring in the wake of Lehman's default between October and December of 2008, similarly to the liquidity deterioration experienced by the US Treasury market. The noise then retracted during the first quarter of 2009 before rising again in the second quarter of 2009, which was a period when the Bank of England started its first round of asset purchases. We show that the noise was strongly associated with increased funding costs, consistent with the link between funding and market liquidity as formalized by Brunnermeier and Pedersen (2009).

We next focus on secondary market activity at the gilt level and examine the price impact and reversals associated with client order flow and Bank of England purchases. We find that, in general, dealers traded in the opposite direction of price changes, suggesting that they accommodated their clients' demand for liquidity and immediacy throughout the crisis period. We separately account for dealers' transactions with the Bank of England (QE) in our specification and find that they had a significant contemporaneous impact on prices but the price impact was almost completely reversed on the following day. The initial impact and the subsequent reversal were more pronounced in periods of elevated uncertainty and for gilts with longer duration. Given that QE auction dates are pre-announced, these reversals are indicative of limited ability or willingness of market participants to deploy capital to smoothen the price impact, especially at times when arbitrage capital is scarce.

Although dealers generally provided liquidity, gilt market transaction costs - as captured by the bid-ask spread and the effective spread - almost doubled during the crisis and remained elevated for a prolonged period of time. We show that the transaction costs were strongly negatively related with the fraction of inter-dealer trading even after controlling for gilt characteristics and measures of funding costs and aggregate uncertainty. This finding is consistent with the hypothesis that the inter-dealer market plays a key role in facilitating risk sharing as formalized in Ho and Stoll (1983). The underlying intuition is that the more difficult it is for dealers to manage their inventories by trading with other dealers, the higher a premium they will demand to temporarily warehouse risk. This implies a negative relationship between transaction costs and relative activity in the inter-dealer market.

Finally, our paper also makes a methodological contribution. Motivated by Jankowitsch, Nashikkar and Subrahmanyam (2011), we propose a new way of measuring the effective spread based on the distance between the transaction price and end-of-day midquote. This measure utilizes all transaction data, but it does not require the knowledge of transaction time stamps. The lack of accurate time stamps is a common feature of many transactional datasets from over-the-counter (OTC) markets and hence our metric may be useful for measuring liquidity beyond the application in this paper[1]. The key

[1]Examples of recently studied OTC transactional datasets that lack accurate time stamps include the

innovation of our approach with respect to Jankowitsch et al. (2011) is that we directly account for the effect of intraday volatility of the mid-quote process on the dispersion of transaction prices. Working in the framework of Roll (1984) we derive a simple and easily calculated correction for nonezero intraday volatility. We show that the contribution of the intraday volatility is non-negligible in our data and hence correcting for it is necessary in order to obtain an unbiased measure of the effective spread. Our approach is similar in spirit to the metric by Corwin and Schultz (2012) who use daily high and low prices to disentangle the contribution of the bid-ask bounce from the variation due to the mid-quote process, although our measure uses all transaction prices rather than just the daily high and low prices.

The rest of the paper is organized as follows. In Section 2 we briefly discuss the related literature. In Section 3 we describe the structure and recent developments in the UK gilt market and in Section 4 we describe our data. Section 5 presents our empirical results and in Section 6 we conclude with a short summary and suggestions for future work. The Appendix provides more details on the measure of effective spread that we propose in the paper.

2 Related literature

Our paper is most closely related to the literature studying the microstructure and liquidity of sovereign bond markets during periods of significant market stress. As recently highlighted by Engle et al (2012) and Pelizzon, Subrahmanyam, Tomio and Uno (2013), although there are numerous papers studying the government bond market microstructure, there are only a few studies that cover the recent episodes of market turbulence, such as the 2008 financial crisis or the more recent Eurozone crisis, along with the subsequent unconventional monetary policy interventions.

The few exceptions include Engle et al. (2012) who propose a new dynamic order book model and study the joint dynamics of liquidity and volatility in the US Treasury market between 2006 and 2010. They find that liquidity decreased dramatically during the crisis and that liquidity and volatility exhibit negative feedback. Pelizzon et al (2013) study price and liquidity discovery in the Italian government bond market during the Eurozone crisis of 2011-2012 and find that price discovery takes place in the futures market while liquidity discovery takes place in the spot market. Pelizzon, Subrahmanyam,

interest rate swap data (Chen, Fleming, Jackson, Li and Sarkar, 2011) and the credit default swap data (Chen, Fleming, Jackson, Li and Sarkar, 2012 and Benos, Wetherilt and Zikes, 2013).

Tomio and Uno (2014) study the microstructure of the Italian government bond market during the same period and document a strong relationship between sovereign risk and market liquidity as well as a positive impact on market liquidity of the European Central Bank interventions.

Our work is also related to the literature on limits to arbitrage and pricing anomalies. Gromb and Vayanos (2010) provide a survey of the theory, while Krisnamurthy (2010) discusses a range of empirical examples from the 2008 crisis. In the context of government bond markets, the most relevant paper is that by Hu et al (2013) who propose to measure market-wide liquidity in the Treasury market by yield curve noise, i.e. the deviations of bond yields from a smooth fitted curve. They show that in periods of abundant risk capital, arbitrage forces work to smooth out the yield curve, while in periods of funding illiquidity and hightened risk aversion, large deviations in prices of similar bonds may persist, consistent with the predictions of Gromb and Vayanos (2002), Brunnermeier and Pedersen (2009) and Duffie (2010), among others. Musto, Nini and Schwarz (2014) find that liquidity characteristics of individual bonds largely explain the cross section of the yield curve pricing errors and that highly levered investors tend to demand more liquid bonds during stressed times thereby exacerbating the pricing discrepancies. Fleckenstein, Longstaff and Lustig (2014) study the large and persistent mispricing between nominal and inflation-linked Treasury securities and, consistent with theory, find that the basis narrows when arbitrage capital flows into the market.

Outside the US Treasury market, Buraschi, Menguturk and Sener (2014) find evidence for significant mispricing between sovereign bonds issued in different currencies and attribute this mispricing to credit and funding frictions. Pelizzon et al (2014) document that market liquidity in the Italian government bond market was an important determinant of the cash-futures basis, and that this relationship was significantly altered by the interventions of the European Central Bank during the Eurozone crisis. Dick-Nielsen, Gyntelberg and Lund (2013) find sound empirical support for the link between market liquidity and funding liquidity in the Danish government bond market during the crisis.

Since we also examine inter-dealer activity in the gilt market, our paper is also related to a number of studies that aim to understand the role of the inter-dealer segment in OTC or hybrid markets. The seminal paper is Ho and Stoll (1983) which shows formally how the inter-dealer market can allow dealers to share inventory risk. On the empirical side, Lyons (1995) documents that an FX dealer uses the inter-dealer segment systematically in order to control her inventory while Reiss and Werner (1998) show that dealers active on the LSE trade with each other more when they have extreme and opposite inventory imbalances. Overall, the empirical literature suggests that the inter-dealer segment facilitates risk sharing among dealers in various markets.

Finally, since our sample period covers the first round of asset purchases by the Bank of England, our paper is also related to the literature examining the impact of quantitative easing on sovereign bond markets. Although the impact of QE on the term structure of interest rates is not the main topic of this paper, accounting for the presence of a large price-insensitive buyer in the market is necessary to properly measure secondary-market liquidity. D'Amico and King (2013) study the permanent and transitory effects of QE on the US Treasury yields and find that actual asset purchases by the Federal Reserve have a contemporaneous price impact, but this impact is subsequently reversed. Joyce and Tong (2012) study the impact of the UK QE purchases on days around the QE auctions and find similar results. We contribute to this stream of literature by showing that the magnitude of the price impact and reversals associated with actual gilt purchases by the Bank depends both the gilt and auction characteristics as well as on aggregate market uncertainty. Importantly, unlike the other studies, we explicitly control for the effect of non-QE market activity on gilt price changes both on the day of the QE auction and on the day after the auction.

3 Institutional framework and market structure

Conventional gilts are nominal fixed-coupon bonds issued by Her Majesty's Treasury (HMT) on behalf of the UK government. Even though the gilts are listed on London Stock Exchange (LSE), the vast majority of trading takes place over the counter. This involves bilateral transactions between market participants either over the phone or via some electronic trading platform (not operated by the LSE). Central to the functioning of the gilt market are the so-called Gilt-Edged Market Makers (or GEMMs). These are financial institutions that have been designated as primary dealers in the gilt market by the UK Debt Management Office (DMO), an executive agency of HMT responsible for managing the debt of the UK government.

The gilt-edged market makers are obliged to provide liquidity in the secondary gilt market by making "on demand and in all conditions, continuous and effective two-way prices"[2]. This practically means that GEMMs stand ready to make markets and respond

[2] United Kingdom Debt Management Office (2013). This obligation covers trades between the GEMM and its customers only. The GEMM is not obliged to provide quotes to other recognized GEMMs, to

to a request for quotes by their customers at all times during normal business hours. Additionally, the spread between the bid and ask prices the GEMMs are required to quote should be "reasonable", although the DMO does not provide a strict definition of what a "reasonable" spread is as the spread varies depending on the market conditions. Overall, the rationale is that by providing liquidity at all times, the GEMMs should ultimately help reduce the borrowing costs for the UK government. In practice, the GEMMs are the primary source of liquidity in the gilt market and are a party to the vast majority of transactions in gilts.

In exchange for their market making obligations, GEMMs enjoy a number of privileges such as the exclusive right to participate in gilt primary auctions run by the DMO and a non-competitive allowance of 10% of the amount of debt issued in each auction. Additionally, GEMMs have a preferred counterparty status which means that the DMO will only deal with GEMMs when operating in the secondary market. Although designated as such by the DMO, GEMMs are supervised and monitored by the UK Financial Conduct Authority (FCA) and are required to report all their secondary-market trades in gilts to the FCA.

Apart from the GEMMs, an important element of the gilt market structure are the Inter-dealer Brokers (or IDBs). These are firms that operate exclusively as intermediaries between GEMMs allowing them to complete transactions anonymously. Should a GEMM wish to trade with another GEMM, a direct communication between the two parties would reveal the parties' intentions to trade and this might compromise dealers' ability to effectively manage inventory, which may in turn adversely affect market liquidity. IDBs themselves are not allowed to take a proprietary positions and deal on a matched principle basis. In addition to the IDBs, there are also Agency Brokers operating in the gilt market who may broker trades between dealers and end-investors.

The GEMMs play a key role in the primary market for gilts as well. The DMO typically sells gilts either via outright auctions in which only the GEMMs have the right to participate, or via syndications. In a syndication, the DMO selects a group of GEMMs to manage the sale of gilt on its behalf. Unlike in the U.S. where each auction by the U.S. Treasury involves a new Treasury note or bond, the DMO may "tap" an existing issue i.e., it may sell an additional amount of a previously issued gilt. An existing gilt may be tapped multiple times over a number of years. Consequently, the on-the-run/off-the-run phenomena observed in the U.S. Treasury market and the role of age of a bond

---

Interdealer Brokers or Agency Brokers although the GEMM is not prohibited from doing so. Additionally, this obligation does not cover rump gilts which are bond issues considered too small to be liquid.

in determining its yield and liquidity (Fontaine and Garcia, 2013, and the references therein) do not play a role in the UK gilt market.

In response to the financial crisis of 2007/2008, the Bank of England introduced a programme of asset purchases financed by central bank reserves, commonly known as quantitative easing (QE). During the first round of QE between March 2009 and January 2010, which overlaps with our sample period, the Bank purchased £200 billion worth of gilts in the secondary market via reverse auctions. These purchases represented a significant fraction of issuance and seemed to have lowered gilt yields (Joyce and Tong, 2012). At the same time, new issuance of gilts by HMT continued at a relatively fast pace amid the recession following the financial crisis. Figure 1 shows the cumulative amount of debt issued by HMT, the cumulative amount of QE purchases and the difference of the two, i.e. the free float. One can see that the free float remained relatively stable during the QE period as QE purchases reduced stocks by almost as much as HMT increased them.

4 Data and summary statistics

The main source of our data is the ZEN database maintained by the UK Financial Conduct Authority (FCA). ZEN contains reports for all secondary-market trades in gilts where at least one party is an FCA-regulated entity. Given that all GEMMs are UK domiciled and hence FCA-regulated institutions, our data fully covers the trading activity of these institutions.

Each transaction report contains information on the transaction date and time, gilt ISIN, execution price, size of the transaction, buyer/seller flag and an agency/principle capacity flag. The most important feature of the reports is that they contain the identity of the party submitting the report and frequently, but not always, the identity of their counterparty. However, since all FCA-regulated firms have to report their transactions, a trade between FCA-regulated firms would be reported separately by each firm and hence we can match these reports based on transaction characteristics. This way, we can match all reports pertaining to (1) direct interdealer trades, (2) all legs of interdealer trades brokered by interdealer brokers and (3) dealer-client trades involving FCA-regulated end-investors. Dealer-client trades involving non-FCA-regulated end-investors would only be reported once, by the GEMM, and we would not always know the GEMM's counterparty.

We match our transactional data with publicly available information on total issuance, maturity and coupons, obtained from the DMO, as well as end-of-day closing prices, closing bid-ask quotes and bond durations, obtained from Bloomberg. We use the Bank of England's proprietary data on QE auctions to adjust the total amount outstanding of each gilt by the Bank's purchases and construct the total privately-held amount of each gilt (free float). We also use daily values for a number of other variables: we obtain the 5-year UK sovereign CDS spread from Markit, the 3-month sterling LIBOR rate from Datastream, daily values of the 3-month sterling general collateral repo rate from the Bank of England and finally daily values of the FTSE 100 implied volatility index (VFTSE) from Bloomberg.

Our sample covers the period between January 2008 and June 2011 and consists of 883 business days. There were 43 different conventional gilts traded at some point in time during this period, including both gilts issued prior to the beginning of the sample period as well as gilts issued during the sample period. The number of primary dealers varies as some firms lose their GEMM status (e.g. Lehman Brothers due to bankruptcy in 2008 and Commerzbank AG due to resignation in 2009) while new firms acquire it between 2008 and 2011 (e.g. Nomura in March 2009 and Toronto Dominion in April 2010). In total, there were 24 different GEMMs during the sample period.

Table 1 reports summary statistics for the gilts in our sample. For every six-month period, starting in June and December, we group the outstanding gilts into four residual-maturity buckets and calculate for each bucket the number of gilts outstanding together with cross-sectional statistics for coupon, issuance and percentage of issuance held by the Bank of England through its QE programme. The table shows that the number of gilts outstanding as well as the average issuance increased over time across all maturities. The average coupon decreased during the sample period, mainly for shorter maturity gilts, reflecting the cuts in Bank rate (i.e. the Bank of England's main policy rate) and the fact that the DMO issues new gilts with market value close to par. The asset purchases by the Bank removed on average between 25% and 45% of the issuance depending on the residual maturity bucket and particular point in time, though the cross-sectional maxima show that at times as much as 57% of the amount outstanding of a gilt was held by the Bank. Note that the cross sectional statistics vary over time not only because of the Bank's purchases, which were spread over 10 months, or because the gilts transition between the maturity buckets, but also because the DMO tapped some of the outstanding gilts and thus increased the issuance of these gilts.

We next report summary statistics for market activity during our sample period. We measure all activity variables in par value terms throughout. Figure 2 shows that the monthly traded volume fluctuated between 200 and 400 billion. These numbers are large - they equal around 3-6 times the monthly traded volume of the shares listed on the London Stock Exchange during the same period. The traded volume is increasing over time, partly reflecting the increasing stock of gilts in issue, as shown in Figure 1. However, the traded volume did not fully keep up with the rising issuance. As the bottom panel of Figure 2 shows, the monthly turnover actually decreased from 0.8 in January 2008 to 0.4 in June 2011. This implies that while in January 2008 the entire stock of gilts outstanding changed hands at the rate of around 10 times per year, in June 2011 it was only around 5 times per year. Similar drops in turnover are also observed in the US Treasury market during this period[3].

Table 2 shows summary statistics of market activity in the cross section of gilts. We group gilts into the four residual maturity buckets as before and report statistics for the monthly trading volume, the percentage of inter-dealer volume and the aggregate net secondary-market dealer volume, separately for each half-year and bucket. The statistics are calculated using all gilt-month observations within each half-year and bucket. The reported numbers suggest that there is considerable variation in the trading activity across the gilts in our sample. There are gilts whose monthly turnover equals a multiple of their amount outstanding, while others trade fairly thinly. The proportion of inter-dealer trading, reported in the middle set of columns of the table also varies significantly in the cross section and over time taking values anywhere between 0% and almost 75%. Interestingly, the proportion of inter-dealer trading is substantially lower around the peak of the crisis between 2008-H1 and 2009-H2 across all maturity buckets. In the last set of columns we report statistics on net dealer volume, which is the total amount of gilts bought less the total amount sold collectively by all dealers. These statistics show that the dealers as a group tend to maintain relatively flat positions in gilts, as the average net position changes are relatively small compared to the traded volumes and amounts outstanding. However, it is important to reiterate that the net dealer volume reported here only includes secondary market trading activity, thereby leaving out primary market transactions.

5 Aggregate market liquidity and its determinants

We start by examining aggregate gilt market liquidity and its determinants during our sample period. Following Hu et al (2013), we use the yield curve noise to measure aggregate liquidity. The idea underlying the noise measure is that in normal times,

[3]SIFMA, http://www.sifma.org/research/statistics.aspx.

when arbitrage capital is abundant, arbitrage forces will smooth out the yield curve and keep pricing errors (noise) small. When funding conditions tighten and risk aversion rises, however, the ability and willingness of market participants to keep bond prices aligned declines, and consequently the yield curve noise increases. The existence of arbitrage opportunities due to funding illiquidity is not the only source of variation in the noise measure. Widening bid-ask spreads can also contribute to the widening of the noise measure even if the law of one price holds when accounting for transactions costs. The noise measure therefore captures funding and market liquidity in a bond market and serves as a good metric for gauging overall liquidity conditions.

Constructing the noise measure requires a smooth model of the yield curve. Following Hu et al. (2013) and Malkhozov, Mueller, Vedolin and Venter (2014), we employ the well-known Svensson model for the instantaneous forward curve (Svensson, 1994):

$$f(m, \boldsymbol{b}) = \beta_0 + \beta_1 \exp\left(\frac{-m}{\tau_1}\right) + \beta_2 \frac{-m}{\tau_1} \exp\left(\frac{-m}{\tau_1}\right) + \beta_3 \frac{-m}{\tau_2} \exp\left(\frac{-m}{\tau_2}\right) \tag{1}$$

where $\boldsymbol{b} = (\beta_0, \beta_1, \beta_2, \beta_3, \tau_1, \tau_2)$.[4] As in Hu et al. (2013), we use conventional gilts with residual maturity between 1 and 10 years to fit the Svensson model. However, we do not use Sterling treasury bills in the estimation because they are known to be illiquid. While the Bank of England use repo rates to anchor the short end of the yield curve (Anderson and Sleath, 2001), we avoid doing so in order not to plague our noise measure by microstructure effects in the repo market. Letting N_t denote the number of gilts with residual maturity between 1 and 10 year at time t, we estimate the parameters of the Svensson model by minimizing the duration-weighted sum of squared pricing errors:

$$\boldsymbol{b}_t = \arg\min \sum_{i=1}^{N_t} \left[(P^i(\boldsymbol{b}) - P_t^i) \times \frac{1}{D_t^i} \right]^2 \tag{2}$$

where P_t^i denotes the market observed price of gilt i, $P^i(\boldsymbol{b})$ is the model-implied price of gilt i given parameters $\boldsymbol{b}$ and D_t^i denotes the MacCauley duration of gilt i at time t. Given the fitted yield curve, the noise measure is defined as:

$$Noise_t = \sqrt{\frac{1}{N_t} \sum_{i=1}^{N_t} [y_t^i - y^i(\boldsymbol{b}_t)]^2} \tag{3}$$

[4]For robustness, we also experimented with cubic splines with and without smoothness penalty (Fisher, Nychka and Zervos 1995). The results reported later in this section are qualitatively similar across the different yield curve models and are available upon request.

where y_t^i is the market observed yield of gilt i and $y^i(\boldsymbol{b}_t)$ is the model-implied yield of gilt i obtained from the zero-coupon yield curve corresponding to the instantaneous forward curve $f(m, \boldsymbol{b}_t)$.

Figure 3 shows the evolution of the noise measure during our sample period, together with the LIBOR-Repo spread and the UK CDS spread for comparison. Similarly to the the noise derived from the U.S. Treasury market by Hu et al. (2013), we see that the U.K. noise measure tends to be elevated during periods of market turbulence, such as the demise of Bear Stearns in March 2008, the aftermath of Lehman Brothers' default in September 2008 and the Eurozone sovereign crisis of 2011. Additionally, we observe that although the noise started dropping significantly during the first quarter of 2009, the downward trend was temporarily interrupted during the first few months of the QE purchases by the Bank of England, which were initiated in March 2009.

More importantly though, Figure 3 reveals a high degree of co-movement between the Noise measure, the Libor spread and the UK 5-year CDS spread. Although not perfectly synchronized, all three variables increase substantially during the financial crisis from the Fall of 2008 and up until the end of 2009. Given that the three variables are respectively a measure of liquidity, a proxy for the cost of funding and a proxy for gilt inventory risk, this degree of co-movement is consistent with the link between market and funding liquidity: dealers' funding constraints in combination with increased inventory risk reduce dealers' ability to either engage in or facilitate arbitrage trades.

To formally investigate how the yield curve noise relates to contemporaneous and lagged variables measuring funding and market conditions, we estimate the following time-series specification:

$$\begin{aligned} \Delta Noise_t &= \alpha + \boldsymbol{\beta}_0' \Delta \mathbf{marketvars}_t + \boldsymbol{\beta}_1' \Delta \mathbf{marketvars}_{t-1} \\ &\quad + \boldsymbol{\gamma}_0' \Delta \mathbf{giltvars}_t + \boldsymbol{\gamma}_1' \Delta \mathbf{giltvars}_{t-1} \\ &\quad + \delta_0 netdvlm_t + \delta_1 netdvlm_{t-1} + \epsilon_t \end{aligned} \tag{4}$$

where **marketvars** is a vector of market variables capturing funding costs and uncertainty, **giltvars** is a vector of aggregate gilt market characteristics and *netdvlm* is the aggregate net dealer volume. The net dealer volume is used as a proxy for changes in dealer inventories. The hypothesis is that as dealers' inventories increase, dealers become less able to take on additional inventory and their intermediation capacity declines. Thus, we would expect a positive relationship between contemporaneous and lagged net dealer volume on one had and market-wide illiquidity (noise) on the other.

In terms of the market variables, we include the LIBOR-Repo spread as a measure of dealers' and other market participants' funding costs, the UK CDS spread as a measure of inventory risk, the UK implied equity volatility (VFTSE index) as a measure of uncertainty and the 3-month sterling general collateral (GC) repo rate as a measure of the cost of secured borrowing. Our gilt market characteristics include the aggregate value of gilts outstanding (issuance) and the associated free float defined as the issuance less the purchases of gilts by the Bank of England through quantitative easing. We include these variables in order to control for supply shocks that might correlate with the aggregate liquidity measure. To proxy for the easiness with which gilts can be obtained to establish short positions outside the repo market, we use the total amount of gilts available through securities lending.[5]

The estimation results are reported in Table 3. All regressions are estimated using monthly data to reduce the contribution of high-frequency noise but we sample the data weekly to improve estimation efficiency. To account for the overlap in the data, we use Newey-West standard errors throughout. We find that the LIBOR-Repo spread is positively related with noise and the effect is statistically significant in all specifications, especially for the first lag. The LIBOR-Repo spread alone explains almost 30% of the variation in the noise (column 1). This is consistent with the theory of Brunnermeier and Pedersen (2009) which links funding and market liquidity and is qualitatively similar to the empirical findings of Dick-Nielsen et al (2013) and Pelizzon et al (2013) for the Danish and Italian government bond markets, respectively.

The implied volatility index and the UK CDS spread are also both positively related with noise (columns 3 and 4), consistent with the theoretical prediction that higher uncertainty and default risk lead to lower liquidity. The GC repo rate correlates negatively with noise and the effect is more pronounced for the first lag (column 2). This finding is similar to Hu et al. (2013) for the US Treasury market. Low repo rates may be indicative of high demand for gilts in the repo market (reverse repo) which may be in turn be associated with increased search frictions and hence lower liquidity.

Consistent with dealers' inventory constraints negatively impacting market liquidity, we find that net dealer volume correlates positively with the noise measure, but the effect is statistically insignificant (column 9). This may be because our net dealer volume variable is only a noisy proxy for the actual changes in dealers' inventories, as we do not observe primary market activity.

Turning to the supply shocks measured by changes in either aggregate issuance or

[5] We obtained this data from Markit.

the free float, we find that these are insignificantly correlated with the noise individually (columns 6 and 7), but the (partial) correlation turns negative in the regression that includes the funding cost and uncertainty variables. The amount of gilts available for lending is significantly negatively related with noise (column 8). This is consistent with the intuition that the more gilts are available for loan the lower the search costs and the easier it is for market participants to eliminate any mispricings across the yield curve. However, the effect becomes statistically insignificant in the multivariate regressions reported in columns 11-13.

Overall, the findings of this section suggest that funding costs and uncertainty were some of the key drivers of the observed deterioration of liquidity in the UK gilt market during the crisis. We next exploit the granularity of our data to associate market liquidity with dealer activity at the gilt level.

6 Market liquidity and dealer activity at the gilt level

In this section we study the relationship between gilt market liquidity and dealer activity at the gilt level. This allows us to also examine if the relationship between dealer activity, funding costs, aggregate uncertainty and liquidity depends on gilt characteristics such as duration and free float.

6.1 Dealer net volume and trade direction

We first examine if dealers on average provided or consumed liquidity over our sample period. We do this by looking at whether dealers traded in the same or the opposite direction of daily price changes.[6] For this purpose, we estimate the following panel specification:

$$\begin{aligned}\Delta \log P_{it} = \alpha + & (\alpha_0 + \boldsymbol{\beta}_0' \mathbf{giltvars}_{it} + \gamma_0 VFTSE_t) netdealervlm_{it} \\ & + (\alpha_1 + \boldsymbol{\beta}_1' \mathbf{giltvars}_{it-1} + \gamma_1 VFTSE_{t-1}) netdealervlm_{it-1} \\ & + (\delta_0 + \boldsymbol{\kappa}_0' \mathbf{QEgiltvars}_i + \lambda_0 VFTSE_t) QEdealervlm_{it} \\ & + (\delta_1 + \boldsymbol{\kappa}_1' \mathbf{QEgiltvars}_{it-1} + \lambda_1 VFTSE_{t-1}) QEtdealervlm_{it-1} + v_i + u_{it}\end{aligned} \tag{5}$$

[6]In order to explain the divergence in the CDS-bond bais during the crisis, Choi and Shachar (2013) do a similar study of dealer activity in the US corporate bond market. They find that dealers generally traded in the opposite direction of price changes.

where the change in the (log) price of each bond is regressed on the contemporaneous and lagged aggregate net dealer volume and its interactions with bond-specific variables, as well as the implied volatility index. We do this separately for non-QE and QE volumes in order to capture any differences between these two types of transactions. In regression (5), **giltvars** is the vector of bond-specific variables and includes the bond duration and the amount outstanding of each issue, net of the cumulative QE purchases. **QEgiltvars** contains two additional variables associated with QE auctions: the dispersion of the winning bids and the fraction of accepted bids. The dispersion of the winning bids is calculated as in Song and Zhu (2014) and essentially measures the heterogeneity of private valuations and information of auction participants. The fraction of allocated bids captures excess supply of gilts by the dealers in an auction. We also interact dealer non-QE and QE volumes with the FTSE 100 volatility index to see if and how the relationship between net dealer volume and price changes varies with uncertainty.

Table 4 reports the estimation results. In columns (1) and (2) we run regressions of log price changes on net dealer volumes and QE volumes respectively along with their lags. The negative coefficients of the contemporaneous (and lagged) non-QE flows suggest that, in general, dealers traded in the opposite direction of price changes during our sample period. This means that dealers "leaned against the wind" by responding to their clients' demand for liquidity and immediacy. Since net dealer flow equals minus the client order flow, the negative coefficient on the lagged flow variable in specification (1) suggests that client flow has a permanent price impact. This finding is consistent with client order flow being informed and is similar to the results obtained by Dick-Nielsen et al (2013) who study the Danish government bond market.[7] Turning to the QE purchases, we find that they had a significant contemporaneous price impact that is almost completely reversed the following day. The strong reversals imply that QE purchases made the gilt market temporarily one-sided, which created price pressure despite the fact that the QE auctions were pre-announced. Similar findings were obtained by D'Amico and King (2013) for the first round of QE purchases by the Federal Reserve, although they do not control in their regression for the secondary market activity on QE auction days. We do so in column (3) and find that the results do not change when we include in the model both

[7] Although it has been established that order flow imbalances account for a significant proportion of the daily variation in bond prices (Brandt and Kovajecz, 2004), it is still unclear whether this is primarily due to client or to dealer order flow. For instance, Valseth (2012) finds that inter-dealer order flow is more informative than dealer-to-client order flow in the Norwegian market, whereas Dick-Nielsen et al (2013) find the opposite in the Danish market. Since our transaction reports do not identify the party initiating the trade, we cannot shed more light on this issue here.

the non-QE and QE net dealer volumes.

In columns (4) and (5) we interact the dealer activity variables with aggregate uncertainty (proxied by the implied volatility index) and gilt-specific variables, respectively. In column (6) we include all variables in the regression. The results show that the price impact of (client) order flow is only marginally larger in states of higher uncertainty with the effect being somewhat stronger for the QE purchases. Bond characteristics also matter, with bonds of higher duration experiencing larger price impact and subsequent reversal associated with QE purchases. The price impact of QE is also higher for bonds with a higher fraction of allocated bids. This is perhaps not surprising as a higher allocation is indicative of lower supply during QE auctions, which ceteris paribus implies a larger price impact. The coefficients associated with the offer dispersion interaction term have the expected sign, but they are only marginally significant.

Overall, throughout our sample period dealers were generally trading in the opposite direction to price changes meaning that they fulfilled their role as primary liquidity providers in the gilt market. However, gilt market liquidity did deteriorate during the financial crisis after all as we saw in the previous section, and this deterioration persisted well into 2009. To explain these developments and given the importance of the inter-dealer segment in facilitating risk-sharing in OTC markets, we next examine the relationship between liquidity and inter-dealer activity. To do that, we first need to define our gilt-specific liquidity metrics.

6.2 Bond-specific liquidity measures

To measure individual gilt liquidity we use two different metrics. The first is the quoted bid-ask spread normalized by the mid-quote. Thus, for gilt j and day t our quoted proportional bid-ask spread metric equals:

$$BA_{jt} = \frac{Ask_{jt} - Bid_{jt}}{Mid_{jt}} \times 100 \tag{6}$$

where $Mid_{jt} = \frac{Ask_{jt}+Bid_{jt}}{2}$.

The second liquidity metric utilizes our transactional data and measures the proportional effective spread. As our transactions data do not contain reliable time stamps, we cannot construct intraday returns and measure the effective spread by using the first-order serial covariance as is common in the literature (Roll, 1984). Instead, inspired by the dispersion metric developed by Jankowitsch et al (2011), we base our measure on the average distance between the transaction price and the end-of-day midquote, which does not require the knowledge of time stamps:

$$\hat{d}_{jt} = \sqrt{\frac{1}{n_{jt}} \sum_{i=1}^{n_{jt}} (p_{ij,t} - m_{jt})^2}, \tag{7}$$

where $p_{ij,t}$ is the logarithmic price associated with transaction i in gilt j on day t and m_{jt} is the logarithmic end-of-day mid-quote and n_{jt} is the number of transactions in gilt j on day t. It is easy to see that this metric suffers from an important drawback: centering each transaction price by the end-of-day mid-quote, rather than the mid-quote prevailing at the time of the transaction, introduces an upward bias due to intraday volatility of the mid-quote. To obtain an accurate measure of the effective spread, it is therefore necessary to remove the contribution of the intraday volatility to the dispersion metric $\hat{d}_{jt}$. In the Appendix, we show that in the simple model of Roll (1984), where the logarithmic intraday mid-quote follows random walk and market orders arrive independently over time, the proportional effective spread can be approximated by:

$$ES_{jt} = \sqrt{\max\left\{\frac{1}{2}(3\tilde{d}_{jt}^2 - \hat{d}_{jt}^2), 0\right\}}, \tag{8}$$

where $\tilde{d}_{jt} = \sqrt{\frac{1}{n_{jt}-1} \sum_{i=1}^{n_{jt}} (p_{ij,t} - \bar{p}_{jt})^2}$ and $\bar{p}_{jt} = \frac{1}{n_{jt}} \sum_{i=1}^{n_{jt}} p_{i,j,t}$. The idea underlying this estimator is that $\hat{d}_{jt}$ and $\tilde{d}_{jt}$ both depend on the effective spread and intraday volatility in expectation, but the latter metric is less sensitive to intraday volatility than the former. This gives us two equations in two unknowns and solving these equations for the effective spread in the Roll (1984) model leads to (8). The censoring of the statistic at zero ensures that the estimator remains non-negative.

To reduce the noise associated with the daily liquidity metrics, we construct calendar-month metrics by averaging the daily observations within each calendar month. Figure 4 plots these two metrics over our sample period. Both metrics are clearly elevated during the crisis although the effective spread starts from a higher level and also drops sooner, by the end of 2009. Both of these plots suggest that the cost of trading in the gilt market almost doubled during the crisis. Comparing the average bid-ask and effect spreads, we see that the latter is typically about twice as high as the former.

6.3 Liquidity and inter-dealer activity

As we saw earlier, gilt market liquidity deteriorated during the crisis and execution costs increased substantially despite the fact that dealers generally kept providing liquidity in the market. Given that the reduction in liquidity was associated with increased funding costs, one may conjecture that dealers were unable or unwilling to deviate from their desired inventories to the extent demanded by their clients. However, since we do not observe dealer inventories, we cannot verify this directly. Instead, in this section we provide indirect evidence that dealer balance sheet constraints may have contributed to the deterioration of liquidity by looking at the activity in the inter-dealer segment of the gilt market.

The microstructure literature suggests that the inter-dealer segment is used by dealers to share risk in OTC markets.[8] We therefore hypothesize that the reduced activity in the inter-dealer segment during the crisis (as evidenced in Table 2) may have been associated with a deterioration in liquidity above and beyond what would be expected given individual dealers' funding costs and balance sheet constraints. The reason is that reduced inter-dealer activity would ceteris paribus imply that dealers end up with riskier inventories since they would be less able to share risk with each other. Consider, for example, a dealer whose client wants to sell to him a large quantity of long-term gilts. In the presence of an inter-dealer market, the dealer could accommodate the client's order knowing that he can subsequently off-load some of these gilts in the inter-dealer market to reduce his inventory risk. A less active inter-dealer market might force the dealer to charge his client a wider spread as compensation for the increased inventory risk.

To examine the relationship between inter-dealer activity and liquidity, we estimate, for each bond i and month t of our sample, the following panel specification:

$$Illiqmetric_{it} = \alpha + \beta interd_{it} + \boldsymbol{\gamma}'\mathbf{marketvars}_{it} + \boldsymbol{\delta}'\mathbf{marketvars}_{t-1} + v_i + u_{it} \quad (9)$$

where *Illiqmetric* is any of the two bond-specific (il)liquidity metrics defined in equations (6) and (8). These variables are monthly averages of their daily values. *interd*, the main variable of interest, is the fraction of dealer-to-dealer volume over total dealer volume (dealer-to-dealer plus dealer-to-client). If a reduction of inter-dealer trading means that dealers are less able to share risks, then we would expect the coefficient β to be negative and significant. **giltvars** is a vector of two gilt characteristics used previously in our

[8] See for example Ho and Stoll (1983) for a theoretical model and Lyons (1995) and Reiss and Werner (1998) for empirical evidence in the FX and stock markets respectively.

specifications: the duration and the gilt free float. The duration is a proxy for inventory risk (since longer duration bonds are more sensitive to interest rate fluctuations) while the free float measures the size of the market.

The next set of controls, **marketvars**, is a vector of market variables. We use their end-of-month values and they enter the specification with a lag so as to ensure that they are pre-determined with respect to the dependent variables which are averaged over the entire month. These variables include the 3-month Libor spread (difference between the 3-month Libor and the 3-month repo rate), the FTSE 100 volatility index, the 3-month repo rate, the yield spread between 10-year and 1-year gilts and the CDS spread on 5-year UK sovereign CDS contracts. These variables are intended to control for other potential determinants of liquidity. The Libor spread captures funding costs: the more constrained the dealers are, the less willing they will be to make markets and the more illiquid the gilts will be (Brunnermeier and Pedersen 2009). The FTSE 100 volatility index is used as a metric of overall market uncertainty. It is intended to capture the effect of dealers' risk aversion on their market making activity: for a given inventory size and riskiness, dealers' willingness to provide liquidity should also depend on their degree of (time-varying) risk aversion. Similarly, the term spread is intended to capture investors' expectations about future economic conditions. The next control variable is the repo rate which captures the cost of secured borrowing and lending. Since gilts are frequently used as collateral in repo transactions, it is not a-priori clear how the repo rate might be related to gilt market liquidity. On the one hand, ff dealers need to borrow gilts in the repo market to cover short positions, then a higher repo rate would mean that it is less costly for dealers to borrow gilts (and lend cash in the process). On the other hand, if dealers need to use the repo market to fund their positions in gilts, then higher repo rate implies higher cost of funding gilt inventories. Finally, we use the 5-year CDS spread on the UK sovereign to captures default risk. Elevated CDS spread should be associated with higher bid-ask and effective spreads as dealers seek additional compensation for bearing increased default risk associated with their inventories of gilts.

Table 5 shows summary statistics for the variables used in the regression. These statistics highlight both the temporal and cross-sectional variability of our sample. The effective and bid-ask spreads range from 0.02% and 0.01% to 0.55% and 0.27% respectively while the fraction of inter-dealer trading ranges from 0 to 73%. Duration ranges from a few days (for newly issued gilts) to more than 20 years while the free float ranges anywhere between £2.57 billion to almost £28 billion.

We estimate model (9) allowing for bond-specific fixed effects. One potential concern about our specification is that the degree of inter-dealer trading is endogenous to market liquidity: if trading costs are higher, dealers may be more reluctant to initiate trades with other dealers and may instead choose to manage their inventory by trading passively with their clients.[9] For this reason, we also report results of a fixed effects specification where we instrument inter-dealer trading using lagged values of this variable. Table 6 shows the results of these estimations. The coefficients on the share of inter-dealer trading (*interd*) are negative and significant for both measures of illiquidity and across specifications. This suggests that conditional on bond-specific and aggregate control variables, a lower fraction of inter-dealer trading is associated with a deterioration of liquidity in the gilt market as predicted by the risk-sharing argument of Ho and Stoll (1983). The control variables also have the expected signs: The Libor spread, the volatility index, the repo rate, the term spread and the CDS spread are all positively related to the illiquidity metrics. This suggests that dealer funding costs, risk aversion and inventory risk all matter to for gilt market liquidity. The importance of inventory risk is also evident in the positive and statistically significant coefficient on gilt duration, while the free float is only marginally significant.

Overall however, the key result here is that the degree of inter-dealer trading matters above and beyond these other potential determinants of illiquidity. This is consistent with the hypothesis that dealers use the inter-dealer market to share and shift risk and to the extent that they are less able to do so, they will demand a premium in the form of higher spreads for the additional risk that they are forced to bear. If, in turn, the inter-dealer market slows down because of dealers' funding constraints, this suggests that the impact of funding constraints on market liquidity may be amplified in the presence of a two-tiered market that features an inter-dealer segment.

7 Summary and conclusion

This paper studies the liquidity of the UK government bond market during the financial crisis and relates it to the activity of primary dealers. To this end, it utilizes transactional data from the secondary gilt market which explicitly identify the dealer-executed trades.

We first document a deterioration of market liquidity after the collapse of Lehman Brothers which persisted well into 2009. This liquidity deterioration is captured by a number of metrics such as the degree of gilt mispricing along the yield curve, the

[9] The assumption here is that it is the clients who typically initiate trades with dealers and thus bear the transaction cost.

quoted bid-ask spread as well as the effective spread. Furthermore, it is associated with increases in funding costs, consistent with the link between funding and market liquidity as formalized by Brunnermeier and Pedersen (2009). We document that dealers traded in the opposite direction of price changes throughout our sample period implying that they generally fulfilled their role as primary liquidity providers in the gilt market. While the dealers accommodated the demand for gilts by the Bank of England in its QE operations, the QE purchases were associated with significant contemporaneous price impact and subsequent reversal.

Given that dealers "leaned against the wind", what caused the prolonged liquidity dry up? We conjecture that owing to increased funding costs, dealers were not able to use their balance sheets to the full extent required by their clients. Additionally, we find that frictions in the inter-dealer market inhibited dealers' ability to share risk and manage their inventories, which in turn translated into a higher cost of trading above and beyond what can be explained by funding costs and aggregate uncertainty. In calculating trading costs, we make a methodological contribution by proposing a new measure of effective spread that can be calculated from transactions prices without the knowledge of transaction time stamps.

Our work suggests several avenues for future research. First, it would be interesting to examine in more detail the behavior of dealers in the QE reverse auctions and to relate their behavior to the outcomes of these auctions. Second, although we document that inter-dealer activity seems to be associated with gilt market liquidity in our sample, it is remains unclear what the determinants of inter-dealer activity are and how the frictions in the inter-dealer market affect liquidity. Finally, it would be interesting to compare our measure of effective spread with that of Corwin and Schulz (2012), both in theory and in applications to OTC markets.

References

Aït-Sahalia, Y. and J. Jacod, 2014, *High-Frequency Financial Econometrics*, Princeton University Press.

Anderson, N. and J. Sleath, 2001, New estimates of the UK real and nominal yield curves, Bank of England Working Paper no. 126.

Benos, E., Wetherilt, A. and F. Zikes, 2013, The structure and dynamics of the UK credit default swap market, Financial Stability Paper No. 25, Bank of England.

Brunnermeier, M. K. and L. H. Pedersen, 2009, Market Liquidity and Funding Liquidity, *Review of Financial Studies*, **22**, 2201-2238.

Buraschi, A., Menguturk, M. and Sener, E., 2014, The Geography of Risk Capital, *Review of Financial Studies*, forthcoming.

Chen, K., Fleming, M., Jackson, J., Li, A. and A. Sarkar, 2011, An Analysis of CDS Transactions: Implications for Public Reporting, Staff Report No. 517, Federal Reserve Bank of New York.

Chen, K., Fleming, M., Jackson, J., Li, A. and A. Sarkar, 2012, An Analysis of OTC Interest Rate Derivatives Transactions: Implications for Public Reporting, Staff Report No. 557, Federal Reserve Bank of New York.

Corwin, S. and P. Schultz, 2012, A Simple Way to Estimate Bid-Ask Spreads from Daily High and Low Prices, *Journal of Finance*, **67**(2), 719–759.

D'Amico, S. and T.B. King, 2013, Flow and stock effects of large-scale treasury purchases: Evidence on the importance of local supply, *Journal of Financial Economics*, **108**, 425–448.

Dick-Nielsen, J., Gyntelberg, J. and J. Lund, 2013, From Funding Liquidity To Market Liquidity: Evidence from Danish Bond Markets, Working paper, Copenhagen Business School.

Dick-Nielsen, J. and M. Rossi, 2013, Arbitrage crashes: Slow-moving capital or market segmentation?, Working paper, Copenhagen Business School.

Duffie, D. 2010, Asset Price Dynamics With Slow-moving Capital, *Journal of Finance*, **65**, 1238-1268.

Engle, R., Fleming, M., Ghysels, E. and G. Nguyen, 2012, Liquidity, Volatility, and Flights to Safety in the U.S. Treasury Market: Evidence from a New Class of Dynamic Order Book Models, Staff Report No. 590, Federal Reserve Bank of New York.

Fisher, M., Nychka, D. and D. Zervos, 1995, Fitting the term structure of interest rates with smoothing splines, Finance and Economics Discussion Series, Board of Governors of the Federal Reserve System.

Fleckenstein, M., Longstaff, F.A. and H. Lustig, 2014, The TIPS-Treasury Bond Puzzle, *Journal of Finance*, **69**(5), 2151-2197.

Fleming, M., 2003, Measuring Treasury Market Liquidity. Federal Reserve Bank of New York Economic Policy Review.

Fleming, M. and J.V. Rosenberg, 2008, How Do Treasury Dealers Manage Their Positions?, Staff Report No. 299, Federal Reserve Bank of New York.

Fontaine, J.S. and R. Garcia, 2012, Bond Liquidity Premia, *Review of Financial Studies*, **25**(4), 1207–1254.

Gromb D. and Vayanos D., 2002, Equilibrium and Welfare in Markets with Constrained Arbitrageurs, *Journal of Financial Economics* 66, 361-407

Ho, T. and Stoll, H., 1983, The dynamics of dealer markets under competition, *Journal of Finance*, **38**, 1053–1074.

Hu, G.X., Pan, J. and J. Wang, 2013, Noise as Information for Illiquidity, *Journal of Finance*, **68**(6), 2341–2382.

Huang, R.D., Cai, J. and X. Wang, 2002, Information-Based Trading in the Treasury Note Interdealer Broker Market, *Journal of Financial Intermediation*, **11**, 269–296.

Jankowitsch, R., Nashikkar, A. and M.G. Subrahmanyam, 2011, Price Dispersion in OTC Markets: A New Measure of Liquidity, *Journal of Banking and Finance*, **35**, 343–357.

Joyce, M. and M. Tong, 2012, QE and the gilt market: a disaggregated analysis, *Economic Journal*, **122**(564), 348-384.

Krishnamurthy, A., 2010, How Debt Markets Have Malfunctioned in the Crisis, *Journal of Economic Perspectives*, **24**(1), 3–28.

Lyons R, 1995, Tests of microstructural hypotheses in the foreign exchange market, *Journal of Financial Economics* 39, 321–351.

Li, H., Wang, J., Wu, C. and Y. He, 2009, Are Liquidity and Information Risks Priced in the Treasury Bond Market?, *Journal of Finance*, **64**(1), 467–503.

Mahanti, S., Nashikkar, A., Subrahmanyam, M.G., Chacko, G. and G. Mallik, 2008, Latent liquidity: A new measure of liquidity, with an application to corporate bonds, *Journal of Financial Economics*, **88**, 272–298.

Malkhozov, A., Mueller, P., Vedolin, A. and G. Venter, 2014, Funding Liquidity CAPM: International Evidence, Working paper, London School of Economics.

Mancini, L., Ranaldo, A. and J. Wrampelmeyer, 2013, Liquidity in the Foreign Exchange Market: Measurement, Commonality, and Risk Premiums, *Journal of Finance*, **68**, 1805-1841.

Mitchel, M., Pedersen, L.H. and T. Pulvino, 2007, Slow moving capital, *American Economic Review*, **97**(2), 215-220.

Musto, D., Nini, G. and K. Schwarz, 2014, Notes on Bonds: Liquidity at all Costs in the Great Recession, Working paper, University of Pennsylvania.

Naik, N.Y. and P.K. Yadav, 2003, Risk Management with Derivatives by Dealers and Market Quality in Government Bond Markets, *Journal of Finance*, **58**(5), 1873–1904.

Pelizzon, L., Subrahmanyam, M.G., Tomio, D. and J. Uno, 2013, The Microstructure of the European Sovereign Bond Market: A Study of the Euro-zone Crisis, Working paper, New York University.

Pelizzon, L., Subrahmanyam, M.G., Tomio, D. and J. Uno, 2014, Limits to Arbitrage in Sovereign Bond Markets: A Study of Price and Liquidity Discovery in a High Frequency Quote Driven Market, Working paper, New York University.

Reiss C. and Werner I., 1998, Does Risk Sharing Motivate Interdealer Trading?, *Journal of Finance* 53, 1657–1703

Roll, R., 1984, A Simple Implicit Measure of Effective Bid-Ask Spread in an Efficient Market, *Journal of Finance*, **39**, 1127–1140.

Song, Z and H. Zhu, 2014, QE Auctions of Treasury Bonds, Finance and Economics Discussion Series, Federal Reserve Board.

Svensson, L., 1994, Estimating and Interpreting Forward Interest Rates: Sweden 1992-1994, Working paper, National Bureau of Economic Research.

United Kingdom Debt Management Office, 2013, GEMM Guidebook: A guide to the roles of the DMO and Primary Dealers in the UK government bond market, January

Vayanos, D. and J. Wang, 2012, Market Liquidity - Theory and Empirical Evidence, NBER Working Paper No. 18251.

Appendix

In this appendix, we derive the measure of effective spread introduced in Section 4. Suppose that we divide the day into n subintervals of equal length and suppose that a transaction arrives at the beginning of each of these subintervals. We assume that the associated logarithmic transactions prices, p_i, $i = 1, ..., n$, are related to the logarithmic efficient price, m_i, by

$$p_i = m_i + \frac{s}{2} q_i, \quad i = 1, ..., n, \tag{10}$$

where s is the proportional effective spread and q_i is a binary variable indicating whether the i-th transaction is buyer-initiated $(+1)$ or seller-initiated (-1). Since we cannot construct intraday returns, we cannot use the first-order autocovariance to estimate s as is standard in the microstructure literature following Roll (1984). Nor can we use the various realized measures recently developed in the financial econometrics literature (Ait-Sahalia and Jacod, 2014, Ch. 7) to estimate σ in the presence of microstructure noise (induced by q). We can nonetheless construct statistics that use all transactions prices but do not require the knowledge of time stamps.

As discussed in the introduction, the efficient price may be observable at some point during the trading day. Here we assume for simplicity that m is observed at the end of the day, i.e. at the end of the last subinterval n, and denote it by m_{n+1}. To estimate the effective spread s we follow Jankowitsch et al (2011) and consider the statistic:

$$\hat{d^2} = \sum_{i=1}^{n} (p_i - m_{n+1})^2 w_i. \tag{11}$$

where w_i, $i = 1, ..., n$ are some weights satisfying $\sum_{i=1}^{n} w_i = 1$. Jankowitsch et al. (2011) take $w_i = V_i / \sum_{i=1}^{n} V_i$, where V_i is the volume associated with transactions i. This measure implicitly assumes that the intraday volatility σ of the efficient price is small, so that substituting m_{n+1} for the unobserved m_i entails only a minor distortion when estimating s. Here we do not make this assumption.

If the efficient price is not observable at all, we can consider instead of $\hat{d^2}$ the statistic

$$\tilde{d^2} = \frac{n}{n-1} \sum_{i=1}^{n} (p_i - \bar{p})^2 w_i, \tag{12}$$

where $\bar{p} = \sum_{t=1}^{n} p_i w_i$ is the mean transaction price. As will become clear shortly, this statistic has similar properties to the one in equation (11) and is superior for estimating

s even when m_{n+1} is observable to the econometrician.

To get an idea about the properties of these estimators, we assume that the logarithmic efficient price m follows random walk:

$$m_{i+1} = m_i + \epsilon_{i+1}, \quad i = 0, ..., n, \tag{13}$$

If we further assume that q_i is uncorrelated with m_j for all i, j and take $w_i = 1/n$, it is straightforward to show that

$$\mathrm{E}(\hat{d}^2 | m_{n+1}) = s^2 + \frac{\sigma^2}{2}\left(\frac{n+1}{n}\right). \tag{14}$$

Similarly, for $\tilde{d}^2$ we get

$$\mathrm{E}(\tilde{d}^2) = s^2 + \frac{\sigma^2}{6}\left(\frac{n+1}{n}\right). \tag{15}$$

Note that $\mathrm{E}(\tilde{d}^2|m_{n+1}) = \mathrm{E}(\tilde{d}^2)$ so there is no gain from conditioning on m_{n+1}. We see that both statistics are affected by the volatility of the intraday price and hence are biased estimators of the squared proportional spread s^2. Clearly, the bias of the latter statistic, $\tilde{d}^2$, is three times smaller than that of the original statistic proposed by Jankowitsch et al. (2011). Moreover, the difference between the two statistics can be used to construct an unbiased estimator of s^2:

$$\hat{s}^2 = \frac{1}{2}(3\tilde{d}^2 - \hat{d}^2). \tag{16}$$

By construction we have $\mathrm{E}(\hat{s}^2) = s^2$. It is easy to see that the estimator is not guaranteed to be non-negative. To deal with the (occasional) negativity of the estimator, we follow Corwin and Schultz (2012) and censor the estimator at zero. The final estimator of the proportional effective spread is thus:

$$ES = \sqrt{\max\left\{\frac{1}{2}(3\tilde{d}^2 - \hat{d}^2), 0\right\}}. \tag{17}$$

Our estimator of the proportional spread is based on the key observation that, in expectation, $\hat{d}^2$ is larger than $\tilde{d}^2$ due to intraday volatility. To see if that is the case in our data, we report in Table 7 some descriptive statistics for these metrics. The statistics are pooled over gilts and are calculated for daily metrics as well as for calendar-month metrics, which are obtained by averaging the daily metrics within each calendar month.

It is clear from the Table that $\hat{d}^2$ is on average significantly higher than $\tilde{d}^2$: the mean $\hat{d}^2$ is more than twice as high as the mean $\tilde{d}^2$. Moreover, $\hat{d}^2$ exceeds $\tilde{d}^2$ on more than 99.9% gilt-days and gilt-months. The uncensored estimator of the squared effective spread, $\hat{s}^2$, does get occasionally negative, in around 16% of the gilt-days in our sample, but as expected, averaging over calendar months significantly reduces the variability of the estimator and consequently the occurrence of negative estimates. We find negative $\hat{s}^2$ in only around 5% of the gilt-months in our sample.

Table 1: Summary statistics for the UK gilts in our sample. For every six-month period starting at the end of December and June of each year, we group the gilts into buckets based on their residual maturity. We then calculate for each maturity bucket the number of gilts outstanding, the average coupon, the average amount issued and the percentage of issuance purchased through QE, together with the corresponding minima, maxima and standard deviations. The sample period is January 2, 2008 to June 31, 2011.

		# Bonds				Coupon (%)				Issuance (£bn)				QE (% of issuance)			
		(0,5)	[5,10)	[10,20)	[20,50)	(0,5)	[5,10)	[10,20)	[20,50)	(0,5)	[5,10)	[10,20)	[20,50)	(0,5)	[5,10)	[10,20)	[20,50)
2008-6	mean	9	7	4	8	5.42	6.21	5.50	4.63	11.5	11.2	15.1	14.2	0.0	0.0	0.0	0.0
	min					4.00	4.00	4.25	4.25	5.4	6.7	11.2	9.1	0.0	0.0	0.0	0.0
	max					9.00	8.75	8.00	6.00	17.1	14.2	18.3	18.0	0.0	0.0	0.0	0.0
	stdev					1.43	1.80	1.47	0.56	4.5	3.1	2.7	2.5	0.0	0.0	0.0	0.0
2008-12	mean	11	6	5	9	5.45	5.92	5.30	4.58	14.2	15.7	14.8	16.0	0.0	0.0	0.0	0.0
	min					3.25	4.00	4.25	4.25	6.1	9.1	5.8	7.3	0.0	0.0	0.0	0.0
	max					9.00	8.75	8.00	6.00	24.4	20.4	20.6	20.3	0.0	0.0	0.0	0.0
	stdev					1.65	1.78	1.37	0.54	6.3	4.7	5.3	3.5	0.0	0.0	0.0	0.0
2009-6	mean	11	7	6	10	5.30	5.71	5.33	4.40	16.2	19.9	17.6	16.7	0.0	30.0	32.5	4.8
	min					2.25	4.00	4.00	4.25	6.7	10.0	9.8	4.5	0.0	13.4	14.2	0.0
	max					9.00	8.75	8.00	4.75	26.9	26.3	22.7	22.8	0.0	52.2	49.7	28.3
	stdev					1.85	1.72	1.35	0.20	6.7	6.3	4.3	6.0	0.0	11.8	14.6	9.8
2009-12	mean	11	8	6	11	5.23	5.19	5.33	4.36	19.8	18.9	20.2	17.1	9.5	30.6	44.6	19.8
	min					2.25	2.75	4.00	4.00	6.7	10.0	16.9	7.0	0.0	0.9	29.3	6.1
	max					9.00	8.75	8.00	4.75	29.3	26.3	22.7	24.6	43.3	55.0	57.3	34.3
	stdev					1.85	1.96	1.35	0.22	8.5	6.8	2.1	5.5	13.9	17.5	9.5	9.1
2010-6	mean	11	8	6	12	5.05	5.44	5.17	4.35	21.2	23.3	18.6	17.7	9.6	33.0	34.6	18.3
	min					2.25	3.75	3.75	4.00	6.7	10.0	3.8	8.0	0.0	8.1	0.0	0.0
	max					9.00	8.75	8.00	4.75	33.8	31.4	23.9	25.6	39.2	48.5	51.0	34.8
	stdev					1.98	1.75	1.47	0.22	9.6	7.7	6.9	4.7	13.5	12.0	17.0	10.1
2010-12	mean	11	9	5	12	4.91	4.94	5.45	4.35	24.4	20.6	22.5	19.1	12.8	24.0	39.7	17.3
	min					2.25	2.00	4.00	4.00	7.3	8.2	17.9	11.5	0.0	0.0	31.5	0.0
	max					9.00	8.75	8.00	4.75	36.6	31.4	25.1	25.6	39.1	48.5	49.7	34.8
	stdev					1.94	2.01	1.45	0.22	9.5	8.7	2.5	4.0	14.8	16.7	6.5	9.7
2011-6	mean	12	7	7	11	4.98	4.93	5.11	4.32	23.9	24.8	21.6	20.2	14.9	24.7	31.8	15.3
	min					2.00	3.75	3.75	4.00	7.3	10.5	10.2	16.4	0.0	0.0	0.0	0.0
	max					9.00	8.75	8.00	4.75	36.6	31.4	27.6	25.6	43.0	48.5	49.7	34.8
	stdev					2.22	1.62	1.37	0.19	10.3	6.3	5.4	3.0	16.2	15.0	14.8	9.2

Table 2: Summary statistics for UK gilt trading activity in our sample. For each half-year and residual maturity bucket (as of the beginning of each half-year), we calculate the average monthly traded volume, the average proportion of inter-dealer volume, and the average monthly aggregate net dealer volume, together with the corresponding minima, maxima and standard deviations on a month-gilt basis.

		Volume (£million)				Inter-dealer volume (%)				Net dealer volume (£million)			
		(0,5)	[5,10)	[10,20)	[20,50)	(0,5)	[5,10)	[10,20)	[20,50)	(0,5)	[5,10)	[10,20)	[20,50)
2008-H1	mean	8837.2	5875.5	12811.2	5877.9	20.4	24.6	24.8	22.6	73.6	-51.7	-193.1	-134.7
	min	536.4	783.9	2748.6	1755.1	3.2	3.4	12.5	11.1	-1612.2	-1576.2	-2219.9	-1485.6
	max	23723.9	28227.7	50294.9	16867.0	37.8	56.4	42.8	48.5	1766.7	1607.8	1997.6	1306.0
	stdev	6249.0	4650.9	14317.1	3449.5	7.7	11.0	8.4	9.4	599.0	515.4	841.0	537.8
2008-H2	mean	7095.2	8350.0	5643.6	5094.7	23.5	26.0	23.9	23.8	-186.6	332.1	146.4	-60.7
	min	261.9	464.4	2427.9	1388.5	3.6	7.6	10.4	5.3	-2768.9	-844.1	-977.9	-2498.4
	max	20369.1	53261.6	10086.2	17041.4	48.7	52.3	58.9	48.9	1212.4	10964.3	2342.2	783.4
	stdev	5667.1	12299.1	1783.0	3225.6	10.6	11.1	11.3	10.8	753.8	1709.1	707.4	536.3
2009-H1	mean	6542.0	10060.5	7213.1	5274.6	23.3	29.6	27.6	19.6	-14.3	476.1	263.9	212.9
	min	175.4	553.6	1456.7	1087.9	0.5	0.1	12.6	1.0	-2752.7	-3439.6	-1972.7	-686.0
	max	40059.1	37466.7	56939.6	14302.5	49.2	60.1	54.6	46.3	1766.6	3104.8	1631.8	2272.9
	stdev	6791.4	10011.3	9220.0	3552.2	10.1	13.2	11.4	11.7	743.1	1295.4	703.3	533.4
2009-H2	mean	5944.3	11461.5	5621.4	3931.1	27.1	28.5	24.3	23.7	-13.1	209.9	43.4	254.1
	min	353.5	188.6	554.3	1187.0	0.6	2.2	1.1	4.4	-1478.7	-1263.7	-2279.5	-883.0
	max	22280.3	69243.1	15256.5	16249.2	48.0	56.5	50.6	62.2	1411.6	2574.8	1413.7	1643.3
	stdev	5120.0	17453.0	4277.0	3179.3	12.0	13.6	10.8	13.6	559.9	660.8	737.7	470.3
2010-H1	mean	6111.1	11716.9	6536.2	3986.0	30.3	30.3	30.5	27.4	-48.0	-153.4	-114.8	-55.7
	min	151.7	185.2	1065.5	1065.8	1.0	5.2	11.3	5.4	-1756.7	-2218.7	-5181.4	-1849.7
	max	16516.3	59343.0	50146.4	19056.3	51.8	61.4	58.8	62.3	2035.6	1875.0	1161.2	1585.6
	stdev	4468.5	14494.6	9043.1	3830.6	13.1	14.6	9.1	11.8	743.8	748.2	921.4	417.6
2010-H2	mean	4962.1	11076.1	5745.3	4128.1	36.6	33.4	31.3	30.6	-71.4	-75.9	-38.1	-123.7
	min	272.9	234.7	1284.7	1348.3	10.8	0.0	19.0	7.4	-2153.3	-1910.9	-1989.7	-4773.4
	max	17990.5	73284.0	21007.2	18578.3	67.3	66.1	61.7	73.2	1103.6	1423.3	1186.9	1592.7
	stdev	4043.4	16696.3	4680.0	4068.9	11.8	14.7	7.3	13.1	614.1	561.1	574.1	718.9
2011-H1	mean	6844.6	15068.9	5927.4	5334.8	29.6	33.2	28.5	36.1	37.7	-253.3	-0.6	-42.5
	min	91.6	258.3	1258.4	983.4	0.7	8.0	13.4	5.6	-2649.1	-4404.0	-2100.6	-2043.9
	max	19932.9	70060.6	17093.5	24506.0	59.8	67.8	37.4	70.4	2718.1	1844.2	2059.3	1823.7
	stdev	5173.6	17311.8	4375.1	4763.8	14.5	14.8	5.7	11.4	832.6	1075.2	798.1	450.6

Table 3: Time-series OLS regressions of aggregate gilt market illiquidity($Noise$). We report estimation results of model (4) of the Noise illiquidity measure on contemporaneous and lagged net dealer volume and controls. $Noise$ is defined in equation (3). *issued* is the total amount outstanding of all gilts (in £millions). *freefloat* is total amount of gilts outstanding (in £millions) adjusted for the Bank of England stock of gilt purchases; *lendable* is the total amount of gilts (in £millions) available for borrowing. *reporate* (in %) is the 3-month cost of secured lending; *liborspread* (in %) is the difference between the 3-month Libor and the 3-month repo rate; *VFTSE* is the FTSE 100 volatility index and *ukcds* is the spread (in bps) on the UK sovereign 5-year CDS contract. The sample period is January 2, 2008 to June 31, 2011. All regressions are run in first differences using monthly overlapping data sampled weekly. Newey-West t-statistics are given in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
$const$	0.006	−0.205	0.013	−0.032	−0.116	0.009	−0.080	−0.123	0.179	0.038	0.478	0.106	0.442
	(0.04)	(−1.33)	(0.07)	(−0.19)	(−0.88)	(0.04)	(−0.47)	(−0.79)	(0.92)	(0.18)	(2.78)	(0.80)	(2.61)
$liborspread_t$	0.703				1.674						1.051	1.459	1.186
	(0.66)				(3.26)						(2.39)	(3.58)	(3.01)
$liborspread_{t-1}$	2.768				3.452						3.112	3.438	2.953
	(6.99)				(4.84)						(6.31)	(6.51)	(6.53)
$repo_t$		−1.113			1.390						0.656	0.978	0.383
		(−1.60)			(2.39)						(1.24)	(1.70)	(0.76)
$repo_{t-1}$		−0.772			−2.769						−2.585	−2.764	−2.793
		(−1.22)			(−4.12)						(−5.01)	(−4.97)	(−5.87)
$VFTSE_t$			0.012		0.013						0.006	0.009	0.011
			(0.30)		(0.65)						(0.37)	(0.58)	(0.77)
$VFTSE_{t-1}$			0.063		−0.006						0.002	−0.005	0.002
			(2.73)		(−0.43)						(0.14)	(−0.41)	(0.18)
$UKCDS_t$				0.016	0.003						0.020	0.018	0.013
				(1.12)	(0.26)						(2.13)	(2.14)	(1.25)
$UKCDS_{t-1}$				0.006	−0.023						−0.018	−0.016	−0.019
				(0.52)	(−2.12)						(−1.93)	(−1.64)	(−2.01)
$outstanding_t$						0.006			−0.063		−0.022		−0.085
						(0.31)			(−1.44)		(−3.69)		(−2.08)
$outstanding_{t-1}$						−0.007			0.036		−0.035		0.033
						(−0.35)			(0.90)		(−2.75)		(0.78)
$freefloat_t$							0.013		0.050			−0.015	0.060
							(0.74)		(1.33)			(−2.25)	(1.48)
$freefloat_{t-1}$							−0.002		−0.054			−0.029	−0.071
							(−0.11)		(−1.25)			(−2.40)	(−1.71)
$lendable_t$								−0.027	−0.027		−0.001	−0.006	−0.001
								(−2.51)	(−2.94)		(−0.22)	(−0.78)	(−0.09)
$lendable_{t-1}$								−0.025	−0.034		−0.000	−0.002	−0.002
								(−2.47)	(−3.10)		(−0.03)	(−0.25)	(−0.25)
$netdealervlm_t$										0.001	0.039	0.010	0.030
										(0.03)	(1.60)	(0.38)	(1.38)
$netdealervlm_{t-1}$										0.053	0.030	−0.009	0.009
										(1.04)	(1.20)	(−0.31)	(0.39)
Adj. R^2	0.274	0.161	0.094	0.032	0.441	-0.003	0.008	0.176	0.203	0.013	0.517	0.497	0.529
N	175	175	175	175	175	175	175	175	175	175	175	175	175

Table 4: Dealer net volume and trade direction. This table shows the estimation results of model (5). *netdealvlm* is the aggregate dealer buy volume minus the dealer sell volume, excluding trades associated with QE. *QEdealervlm* is dealer QE (sell) volume. *duration* is the bond duration in years; *freefloat* is total amount of debt outstanding for each bond (in £billions) adjusted for the Bank of England stock of bond purchases; *allocation* is the fraction of dealer bidding offers filled in the QE auctions; *Qdisp* is the dispersion of dealer winning bids in QE auctions; *VFTSE* is the FTSE 100 volatility index The sample period is January 2, 2008 to June 31, 2011. Robust t-statistics are in parentheses. *, ** and *** denotes significance at 10%, 5% and 1% respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
$netdealervlm_t$	-0.0925	–	-0.1089	0.4148	0.9414**	1.6853**
	(-0.94)	–	(-1.04)	(1.17)	(2.24)	(2.29)
$netdealervlm_{t-1}$	-0.2787***	–	-0.2468***	-0.1074	-0.1991	-0.0153
	(-3.00)	–	(-2.79)	(-0.39)	(-0.65)	(-0.03)
$netdealervlm_t \times duration_t$	–	–	–	–	-0.0439	-0.0481
	–	–	–	–	(-1.42)	(-1.54)
$netdealervlm_{t-1} \times duration_{t-1}$	–	–	–	–	-0.0192	-0.0205
	–	–	–	–	(-0.65)	(-0.68)
$netdealervlm_t \times freefloat_t$	–	–	–	–	-0.0472**	-0.0523**
	–	–	–	–	(-2.27)	(-2.46)
$netdealervlm_{t-1} \times freefloat_{t-1}$	–	–	–	–	0.0063	0.0051
	–	–	–	–	(0.42)	(0.34)
$netdealervlm_t \times VFTSE_t$	–	–	–	-0.0213	–	-0.0257
	–	–	–	(-1.43)	–	(-1.64)
$netdealervlm_{t-1} \times VFTSE_{t-1}$	–	–	–	-0.0056	–	-0.0063
	–	–	–	(-0.48)	–	(-0.53)
$QEdealervlm_t$	–	-0.8379**	-0.8726**	1.3847	2.7000**	5.2887***
	–	(-2.24)	(-2.27)	(1.07)	(2.09)	(2.91)
$QEdealervlm_{t-1}$	–	1.3914***	1.3394***	-0.1014	-0.8502	-2.5437
	–	(5.50)	(5.37)	(-0.06)	(-0.60)	(-1.34)
$QEdealervlm_t \times freefloat_t$	–	–	–	–	0.0053	0.0133
	–	–	–	–	(0.15)	(0.34)
$QEdealervlm_{t-1} \times freefloat_{t-1}$	–	–	–	–	0.0285	0.0219
	–	–	–	–	(0.57)	(0.48)
$QEdealervlm_t \times duration_t$	–	–	–	–	-0.2299**	-0.2488***
	–	–	–	–	(-2.48)	(-2.79)
$QEdealervlm_{t-1} \times duration_{t-1}$	–	–	–	–	0.1918**	0.2044***
	–	–	–	–	(2.66)	(2.85)
$QEdealervlm_t \times allocation_t$	–	–	–	–	-2.8270***	-2.9210***
	–	–	–	–	(-2.92)	(-2.94)
$QEdealervlm_{t-1} \times allocation_{t-1}$	–	–	–	–	0.1195	0.2180
	–	–	–	–	(0.10)	(0.19)
$QEdealervlm_t \times Qdisp_t$	–	–	–	–	-2.5583	-2.0252
	–	–	–	–	(-1.35)	(-1.08)
$QEdealervlm_{t-1} \times Qdisp_{t-1}$	–	–	–	–	2.2394**	1.8597*
	–	–	–	–	(2.25)	(2.01)
$QEdealervlm_t \times VFTSE_t$	–	–	–	-0.0821*	–	-0.0913*
	–	–	–	(-1.77)	–	(-1.99)
$QEdealervlm_{t-1} \times VFTSE_{t-1}$	–	–	–	0.0517	–	0.0588
	–	–	–	(0.95)	–	(1.30)
cons	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
	(774.64)	(5.21)	(4.82)	(4.75)	(4.53)	(4.58)
N	29,474	29,474	29,474	29,474	29,474	29,474

Table 5: Summary statistics of the variables used in the empirical specification (9). The illiquidity metrics are defined in equations (6) and (8). *interd* is the fraction of inter-dealer trading in each bond-month; *freefloat* is total amount of debt outstanding for each bond (in £billions) adjusted for the Bank of England stock of bond purchases; *duration* is the bond duration in years; *liborspread* is the difference between the 3-month Libor and the 3-month repo rate (in %); *VFTSE* is the FTSE 100 volatility index; *reporate* is the 3-month cost of secured lending (in %); *termspread* is the difference in yield between the 10-year and 1-year UK government bonds (in %); and *ukcds* is the spread (in bps) on the UK sovereign 5-year CDS contract.

N = 1402	*Mean*	*Std. Dev.*	*Min*	*Max*
bid-ask spread (%)	0.08	0.05	0.01	0.27
effective spread (%)	0.13	0.07	0.02	0.55
interd	0.28	0.13	0.00	0.73
duration (years)	8.68	6.08	0.02	21.93
freefloat (£billion)	15.21	5.75	2.57	27.76
reporate (%)	1.48	1.76	0.43	5.22
liborspread (%)	0.49	0.51	0.07	2.28
termspread(%)	2.34	1.08	−0.18	3.43
VFTSE	25.04	8.41	15.05	54.15
UKCDS (bps)	64.14	29.76	8.62	145.30

Table 6: Liquidity and inter-dealer trading. Panel regressions of the two liquidity metrics on the fraction of inter-dealer trading and controls. The panel is over ISINs (bonds) and months. The dependent variables are the bond-specific liquidity metrics defined in equations (6) and (8). *interd* is the percent of inter-dealer trading in each bond-month; *freefloat* is total amount of debt outstanding for each bond (in £billions) adjusted for the Bank of England stock of bond purchases; *duration* is the bond duration in years; *liborspread* is the difference between the 3-month Libor and the 3-month repo rate (in %); *VFTSE* is the FTSE 100 volatility index; *reporate* is the 3-month cost of secured lending; *termspread* is the difference in yield between the 10-year and 1-year UK government bonds (in %) and *ukcds* is the spread (in bps) on the UK sovereign 5-year CDS contract. Robust t-statistics are in parentheses. *, ** and *** denotes significance at 10%, 5% and 1% respectively.

	bid-ask spread	effective spread	bid-ask spread	effective spread	bid-ask spread	effective spread	bid-ask spread	effective spread	bid-ask spread	effective spread
$interd_{it}$	−0.0687***	−0.1225***	−0.0460***	−0.0743***	−0.0667***	−0.1008***	−0.0435**	−0.0721***	−0.1038***	−0.1189***
	(-3.60)	(-5.02)	(-3.17)	(-3.24)	(-3.16)	(-4.27)	(-2.65)	(-3.22)	(-7.00)	(-5.00)
$freefloat_{it}$	–	–	–	–	0.0012*	0.0019**	−0.0014	0.0036	0.0045*	0.0081*
	–	–	–	–	(1.81)	(2.17)	(-0.31)	(0.51)	(1.65)	(1.86)
$duration_{it}$	–	–	–	–	0.0108***	0.0334***	0.0066**	0.0238***	0.0073***	0.0244***
	–	–	–	–	(3.97)	(8.61)	(2.15)	(4.90)	(4.13)	(8.61)
$liborspread_{t-1}$	–	–	0.0103***	0.0102***	–	–	0.0113***	0.0124***	0.0097***	0.0111**
	–	–	(3.56)	(2.89)	–	–	(3.85)	(3.37)	(3.11)	(2.23)
$VFTSE_{t-1}$	–	–	0.0006***	0.0014***	–	–	0.0004***	0.0007**	0.0004*	0.0007**
	–	–	(6.18)	(5.92)	–	–	(2.88)	(2.44)	(1.93)	(2.29)
$reporate_{t-1}$	–	–	0.0110***	0.0095***	–	–	0.0090***	0.0037	0.0080***	0.0028
	–	–	(5.23)	(4.44)	–	–	(3.30)	(1.58)	(4.53)	(0.99)
$termspread_{t-1}$	–	–	0.0188***	0.0085**	–	–	0.0179***	0.0060*	0.0166***	0.0050
	–	–	(7.54)	(2.23)	–	–	(6.64)	(1.89)	(7.08)	(1.34)
$UKCDS_{t-1}$	–	–	0.0002***	0.0003***	–	–	0.0002***	0.0003***	0.0002***	0.0003***
	–	–	(4.38)	(3.66)	–	–	(3.78)	(2.92)	(4.51)	(4.20)
cons	0.0958***	0.1651***	−0.0049	0.0551***	−0.0159	−0.1596***	−0.0505**	−0.1245***	−0.0408**	−0.1170***
	(18.09)	(24.35)	(-0.44)	(3.95)	(-0.56)	(-3.58)	(-2.12)	(-2.85)	(-2.35)	(-4.21)
R^2	0.06	0.08	0.35	0.31	0.10	0.22	0.36	0.34	0.32	0.33
N	1402	1402	1359	1359	1402	1402	1359	1359	1359	1359
Specification	FE	FE	FE	FE	FE	FE	FE	FE	IV	IV

Table 7: Descriptive statistics for the dispersion metrics $\hat{d}^2$ and $\tilde{d}^2$. We report results for daily metrics ("daily") and for calendar-month averages of daily metrics ("monthly"), pooled across gilts (i.e. for gilt-days or gilt-months). The bottom rows of the table report the percentage of gilt-days/gilt-months where the statistics $(\hat{d}^2 - \tilde{d}^2)$ and $(3\tilde{d}^2 - \hat{d}^2)$ are negative.

	daily		monthly	
	$\hat{d}^2$	$\tilde{d}^2$	$\hat{d}^2$	$\tilde{d}^2$
no. obs.	24,110	24,110	1,402	1,402
mean	0.985	0.441	0.987	0.445
std. dev.	2.682	0.930	1.282	0.532
skewness	15.28	7.649	3.097	2.555
kurtosis	440.6	95.85	16.91	11.97
negative $(\hat{d}^2 - \tilde{d}^2)$	0.004%		0.071%	
negative $(3\tilde{d}^2 - \hat{d}^2)$	16.28%		4.921%	

Figure 1: Total issuance, free float and the stock of QE purchases in face-value terms (£billion) for the gilts in our sample. The sample period is January 2, 2008 to June 31, 2011.

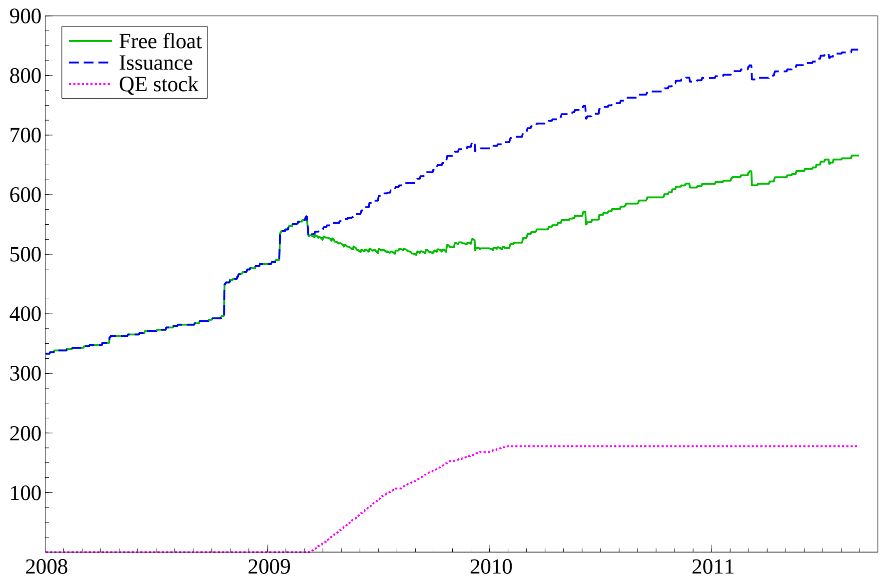

Figure 2: Trading activity. The top panels shows the total monthly volume and monthly inter-dealer volumes (£billion, face value). The bottom panel shows the total monthly volume divided by the amount of gilts outstanding (monthly turnover). The sample period is January 2, 2008 to June 31, 2011.

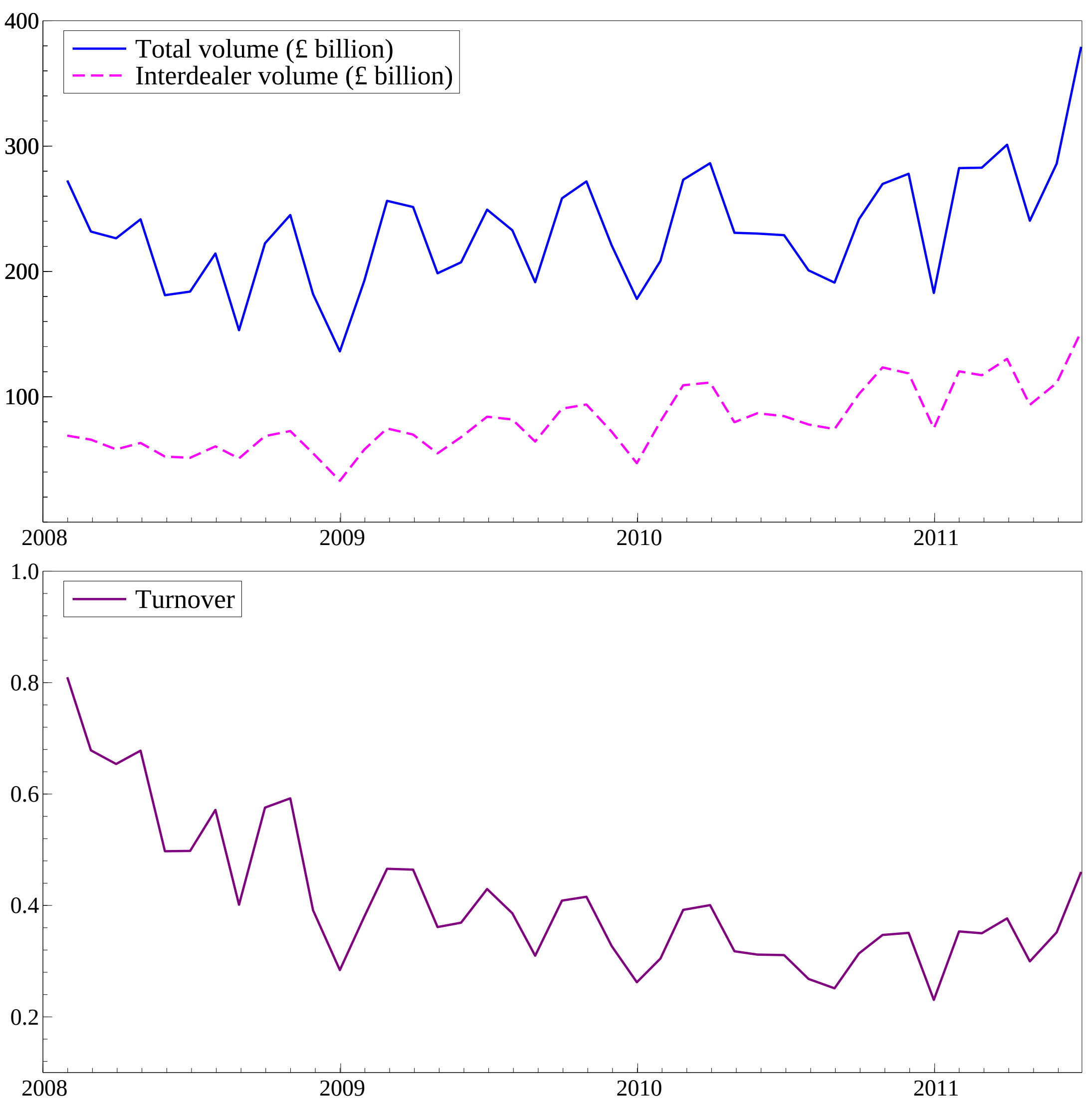

Figure 3: Noise (bps, top panel), LIBOR-Repo spread (%, middle panel) and the UK 5-year CDS spread (bps, bottom panel). The Noise measure is defined in equation (3). The sample period is January 2, 2008 to June 31, 2011.

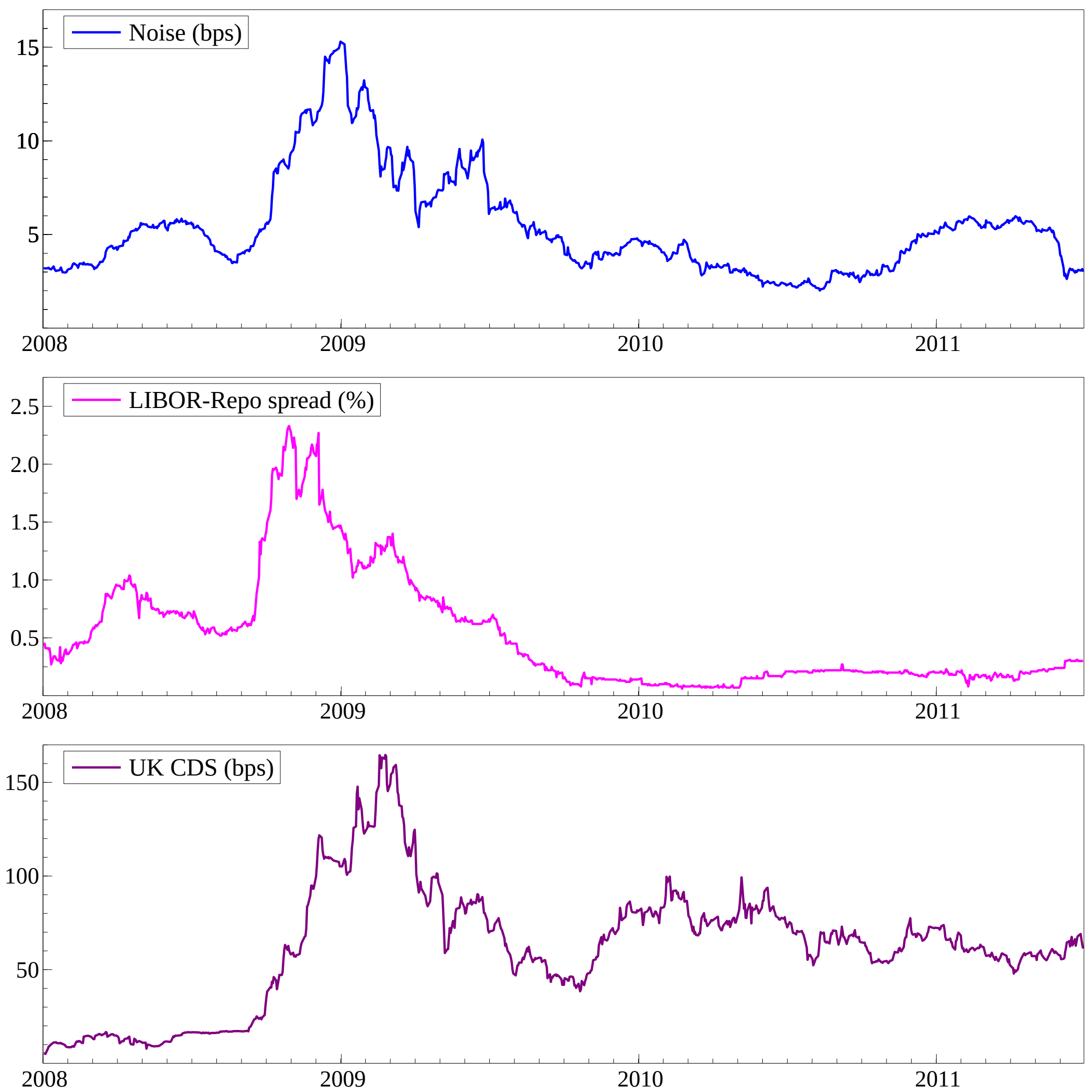

Figure 4: Average bid-ask spread and dispersion for the gilts in our sample. The gilt-specific versions of these variables are defined in equations (6) and (7) respectively. The sample period is January 2, 2008 to June 31, 2011.