The leverage ratio and liquidity in the gilt and gilt repo markets

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Abstract

Market participants argue that a significant unintended consequence of post-crisis regulatory leverage ratio requirements is a reduction in the liquidity of fixed income markets. We assess this claim in the context of the gilt (U.K. government bond) and gilt repo markets over the period 2010 to 2017. We find that gilt repo liquidity worsened during the period when U.K. leverage ratio policy was introduced, and that gilt liquidity worsened conditional on factors such as funding costs and inventory risk. We also find evidence that gilt repo liquidity has become less resilient. However, evidence from heterogeneity in dealer behavior is inconclusive regarding a causal link between leverage ratio requirements and the reduction in market liquidity.

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Market liquidity, Leverage ratio, Bank regulation, Repo, Gilt market, Market-making

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1 Introduction

Financial market commentary suggests that the liquidity of fixed income markets has deteriorated in recent years. Market participants argue that one of the key drivers of the apparent reduction in liquidity has been post-crisis regulatory reform, particularly the regulatory leverage ratio introduced as part of Basel III. Unlike the risk-weighted capital framework, the leverage ratio does not differentiate between the riskiness of assets. This means that activities with low credit and market risk, such as repo and trading in high-quality government bonds, are subject to higher capital requirements under the leverage framework than under the risk-weighted framework. To the extent it is binding, introducing a regulatory leverage ratio requirement therefore increases the cost of market-making in these low-risk products. Market participants argue that this increased cost has caused market-makers to reduce their activity, pass on higher costs to their customers, or exit markets completely. These changes in dealer behavior are reported to have resulted in reduced secondary market liquidity and higher trading costs.

The academic literature on the impact of post-crisis regulation on market liquidity has primarily focused on the Volcker Rule and fixed income markets in the United States (e.g., Bao et al., 2016; Trebbi and Xiao, 2017; Bessembinder et al., 2018; Dick-Nielsen and Rossi, 2018). To our knowledge, only Adrian et al. (2017a) have explicitly estimated the effect of the regulatory leverage ratio on liquidity (they consider the corporate bond market in the U.S.). This is despite the fact that the leverage ratio has frequently been cited as the element of post-crisis regulatory reform with the strongest impact on fixed income businesses (CGFS, 2014; ICMA, 2015; CGFS, 2016).

We contribute to the literature on the costs and benefits of financial regulation by assessing the impact of the leverage ratio on the liquidity of the gilt (U.K. government bond) and gilt repo markets. There are two reasons that these markets have the potential to be good testing grounds for the impact of the leverage ratio on liquidity. First, both markets rely heavily on dealers for intermediation, and so their liquidity is likely to be sensitive to the regulatory costs faced by dealers when making markets. Second, authorities in the U.K. implemented the leverage ratio earlier than the Basel and European Union timelines, meaning that U.K.-regulated entities may have started to adjust to new regulatory requirements earlier than their international peers.

We base our analysis on three rich proprietary datasets: the Zen dataset maintained by the U.K.'s Financial Conduct Authority (FCA), which contains transaction-level information on secondary market trading in gilts; BrokerTec data on interdealer gilt repo transactions; and regulatory data on gilt repo trading volumes collected by the Bank of England (Form RSL). We use these datasets to estimate a range of measures of market liquidity, and use principal components analysis to combine these into two liquidity indices: one for the gilt market and one for the gilt repo market.

Major U.K. banks have only been formally subject to a minimum leverage ratio requirement since January 2016, and other U.K. banks became formally subject to a minimum requirement in January 2018. But firms are likely to have started adjusting their balance sheets much earlier than 2016 in response to a series of policy announcements, supervisory expectations, and reporting requirements. The first major policy announcement was in December 2011, which we take to be the start of the adjustment period. We run three sets of regressions to investigate changes in gilt and gilt repo liquidity from 2010 to 2017, and to assess whether the leverage ratio had a causal role in these changes:

- Market-level time series regressions to assess whether average liquidity deteriorated during the period when leverage ratio policy was introduced, conditional on a wide range of control variables.

- Market-level quantile regressions to assess whether changes in the conditional distribution of liquidity during this period indicate that liquidity became less resilient.

- Dealer-level panel regressions to investigate whether heterogeneity in the liquidity provision of individual dealers provides evidence for a causal link between the leverage ratio and any reduction in liquidity.

The market-level regression results suggest that gilt market liquidity did not worsen in an unconditional sense after December 2011, but that gilt liquidity did worsen conditional on factors such as funding costs and inventory risk. This suggests that, were funding conditions to become less benign or interest rate volatility to increase, gilt liquidity could fall to lower levels than previously would have been the case. In the case of gilt repos, our measures of liquidity worsened from 2013 onwards, whether or not we control for other factors. For both markets, the timing of the reduction in liquidity we find is consistent with results from structural break tests (Andrews, 1993). Particularly sharp reductions in repo liquidity on regulatory reporting dates — when we would expect dealer behavior to be especially sensitive to regulatory constraints — potentially suggest a causal role for the leverage ratio in the reduction in repo liquidity. We do not, however, observe these reporting-date effects in the gilt market.

The market-level quantile regressions indicate that the (conditional) worsening in liquidity in both the gilt and gilt repo markets was more pronounced in times of poor liquidity. This is consistent with a reduction in the resilience of liquidity as leverage ratio policy was introduced. Specifically, the conditional 0.9 quantile of illiquidity worsened more than the conditional 0.5 quantile in both markets, although this difference is not always statistically significant. We also find that sudden reductions in liquidity ("liquidity jumps") have become more frequent in the repo market, consistent with concerns that liquidity risk has increased.

While the market-level regression results indicate that liquidity worsened during the period when leverage ratio policy was introduced, they do not provide strong evidence of a causal link between the leverage ratio and liquidity because changes in liquidity over this period might have been caused by some other omitted factor. In order to better identify a potential causal impact, we run dealer-level panel regressions that exploit two sources of heterogeneity across dealers: heterogeneity in the balance sheets of individual dealers and heterogeneity in the timing of regulatory requirements across jurisdictions. These dealer-level regressions provide only weak evidence of a causal role for regulation. Simple difference-in-differences regressions indicate that U.K. dealers with leverage ratios below 3% in December 2011 reduced their liquidity provision by more than dealers with leverage ratios above 3%. This is consistent with a causal role for the leverage ratio in the reduction in liquidity. However, this difference is not statistically significant, and other specifications provide no evidence that the leverage ratio caused the reduction in liquidity.

We do not attempt to quantify the net benefits of the regulatory leverage ratio. Even if the leverage ratio did cause a reduction in liquidity, two considerations suggest that this does not necessarily imply a reduction in social welfare. First, there might be risks associated with excessive liquidity. For example, excessive liquidity might be illusory, disappearing when most needed (Cunliffe, 2015); and excessive repo liquidity might encourage over-reliance on short-term funding (CGFS, 2017). Second, by leading to an increase in the capitalization of banks, the leverage ratio is likely to have increased their resilience to shocks. An assessment of the overall impact of the leverage ratio on financial stability and social welfare is beyond the scope of this paper.

The rest of the paper is structured as follows. In Section 2, we summarise the debate on the effects of regulation on market liquidity and the related academic literature. In Section 3, we describe the gilt and gilt repo markets from an institutional perspective, and summarise the history of the Basel and U.K. leverage ratio frameworks. In Section 4, we describe our datasets and use them to illustrate some recent trends in the gilt and gilt repo markets. In Section 5, we explain how we estimate liquidity measures for the two markets, and describe recent trends in these measures. In Section 6, we set out our empirical strategy for assessing the effects of the leverage ratio on market liquidity, and summarise the results of the market-level regressions. In Section 7, we consider the question of whether liquidity has become less resilient, through quantile regressions and estimates of the frequency of "jumps" in liquidity. In Section 8, we use heterogeneity in dealer behavior to assess whether the leverage ratio had a causal impact on liquidity. We conclude in Section 9.

2 Related literature

This paper contributes to the debate on the effects of post-crisis regulatory reform on market liquidity. Market participants argue that new regulations — particularly the leverage ratio and Net Stable Funding Ratio (NSFR) proposed as part of Basel III, and the Volcker Rule introduced as part of the Dodd-Frank Wall Street Reform and Consumer Protection Act in the U.S. — have led to a deterioration in liquidity across a range of markets (e.g., ICMA, 2015; Morgan Stanley and Oliver Wyman, 2015, 2016). In these reports, the authors argue that new prudential standards have increased costs for market-makers across a range of markets, leading to a reduction in the balance sheet capacity allocated to market-making and therefore to a reduction in the liquidity of dealer-intermediated markets. Market participants argue that the effect is not uniform across jurisdictions, which can be partly explained by differences in implementation timelines, calibration, and frequency of reporting requirements (CGFS, 2017).

Academic studies paint a more mixed picture when assessing recent trends in the liquidity of fixed income markets. Most studies have focussed on U.S. markets. Studying post-crisis liquidity in U.S. fixed income markets, Adrian et al. (2017b), Anderson and Stulz (2017), and Bessembinder et al. (2018) find mixed evidence across liquidity measures. Trebbi and Xiao (2017) test for structural breaks in the liquidity of U.S. corporate and government bonds and find no evidence that liquidity has deteriorated in recent years. Instead, the breaks appear to indicate a move towards improved liquidity. On the other hand, by focussing on dates when bonds are excluded from an investment grade index, Dick-Nielsen and Rossi (2018) find that the cost of immediacy in the U.S. corporate bond market has increased since the 2007-2009 financial crisis. Similarly, Bao et al. (2016) find that U.S. corporate bonds have suffered a larger deterioration in liquidity upon being downgraded since the introduction of the Volcker Rule. They also find that dealers subject to the Volcker Rule have reduced their provision of liquidity in this market relative to non-Volcker dealers. Choi and Huh (2017) argue that since the crisis, liquidity in the U.S. corporate bond market has increasingly been provided by non-dealers rather than dealers, and that this might help to explain the varying results across studies. The evidence also appears to be mixed in non-U.S. markets. Aquilina and Suntheim (2017) analyse the U.K. corporate bond market and conclude that it became more liquid after the financial crisis. The IMF (2015) investigates the liquidity of fixed income markets in the U.S., Europe, emerging markets, and Japan, and finds that trends in liquidity differ according to the market considered and the measure used.

Few researchers have attempted to empirically link changes in market liquidity to the introduction of the regulatory leverage ratio. This is despite the fact that the leverage ratio has frequently been cited as the element of post-crisis regulatory reform with the strongest impact on fixed income businesses (CGFS, 2014; ICMA, 2015; CGFS, 2016). To our knowledge, only one paper reports the impact of leverage ratio policy on market liquidity. Analysing the U.S. corporate bond market, Adrian et al. (2017a) find that prior to the financial crisis, bonds traded by more levered institutions were more liquid, but that this relation reversed after new regulations were introduced, such that bonds traded by institutions with lower leverage were more liquid. Adrian et al. (2017a) argue that this is consistent with leverage regulation causing a reduction in liquidity. Other researchers have assessed the impact of the leverage ratio on the behavior of individual banks. Acosta-Smith et al. (2018) find that leverage-constrained European banks shifted towards higher risk-weighted activity following the Basel III leverage ratio announcement. Allahrakha et al. (2018) find that the introduction of the supplementary leverage ratio (SLR) in the U.S. in 2012 led affected broker-dealers to decrease their total repo borrowing but to increase their use of repo backed by more price-volatile collateral. Conversely, Bucalossi and Scalia (2016) find that leverage-constrained European banks did not reduce their repo volumes between 2013 and 2014. However, in none of these is the potential impact of this behavior on market liquidity assessed. On the theoretical side, Cimon and Garriott (2017) show that the leverage ratio and other post-crisis regulations lead market makers to intermediate fewer client trades.

Our paper is also related to the literature on the determinants of market liquidity more broadly, including the impact of balance sheet constraints and funding costs on liquidity. From a theoretical perspective, Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009) show that limited market-maker capital can impact liquidity. Brunnermeier and Pedersen (2009) show that funding liquidity is also an important determinant of market liquidity. The study closest to our research is Benos and Zikes (2018), who also consider the determinants of liquidity in the gilt market. In line with theoretical results, they show that dealer balance sheet constraints (proxied by aggregate net trading volume) and funding costs are important determinants of liquidity. However, their paper focusses on the crisis period, before new regulatory requirements were introduced.

Our paper is also related to a small recent empirical literature on the resilience of liquidity, spurred by market commentary claiming that the risk of "flash crashes" and sudden reductions in liquidity has risen. The IMF (2015) examines the effects of structural drivers and cyclical factors on the level and resilience of market liquidity. The authors conclude that changes in market structure, such as larger and more concentrated holdings of corporate bonds by mutual funds, may have increased the fragility of liquidity. They argue that accommodative monetary policy and benign cyclical conditions in recent years may be masking growing liquidity risks. Adrian et al. (2015a,b) use the frequency of sudden large increases in a composite illiquidity metric as a measure of liquidity risk. They find that jumps in illiquidity have become more frequent in the U.S. equity and Treasury markets in recent years. In contrast, there appears to be no increase in the liquidity risk of U.S. corporate bonds, a heavily dealer-intermediated market that might have been expected to be more sensitive to changes in regulation. Following a similar approach, CGFS (2016) finds an increase in the frequency of jumps in the bid-ask spreads of U.S., Japanese, and Italian government bonds in recent years.

To our knowledge, our paper is the first report of a study of liquidity in the gilt repo market. Most empirical papers on repo markets have focussed on U.S. markets (Gorton and Metrick, 2012; Copeland et al., 2014; Krishnamurthy et al., 2014) and euro markets (Mancini et al., 2016).

3 Institutional and regulatory background

In this section, we describe the gilt and gilt repo markets from an institutional perspective. We then discuss the regulatory leverage ratio.

3.1 The gilt market

Gilts are U.K. government bonds, issued by the U.K. Debt Management Office (DMO). The DMO issues gilts, typically via auctions and syndications, to financial institutions designated as primary dealers for the gilt market, known as Gilt-Edged Market Makers (GEMMs). There are currently 18 GEMMs, although there has been entry and exit among the GEMMs, such that 25 firms have been GEMMs at some point since 2008.[1]

The vast majority of secondary-market trading in gilts takes place over the counter. End-investors typically transact with GEMMs, either negotiating trades bilaterally over the phone or through electronic trading platforms. The GEMMs are required to provide secondary market liquidity by quoting continuous bid and ask prices to their customers. In return, the GEMMs are entitled to certain privileges. For example, they are the only institutions eligible to bid directly in the DMO's gilt auctions, so that other market participants wishing to bid must route their order through a GEMM.[2] GEMMs frequently trade with each other, in order to rebalance their gilt portfolios and to hedge trades with their clients. Often this takes place through interdealer brokers (IDBs), which act as intermediaries for anonymous trading between the market-makers.

The main investors in gilts are U.K.-based insurance companies and pension funds, and

[1]The current GEMMs are Barclays, BNP Paribas, Citigroup, Deutsche Bank, Goldman Sachs, HSBC, Jefferies, JP Morgan, Lloyds, Merrill Lynch, Morgan Stanley, Nomura, Royal Bank of Canada, Royal Bank of Scotland, Santander, Toronto-Dominion Bank, UBS, and Winterflood Securities. The other firms that have been GEMMs since 2008 are ABN Amro, Lehman Brothers, Commerzbank, Scotiabank, Société Générale, State Street, and Credit Suisse.

[2]See DMO (2017) for more detail on the role of GEMMs.

overseas investors such as governments, central banks, sovereign wealth funds, and asset managers. Currently, the largest single holder of gilts is the Bank of England, which since 2009 has purchased gilts through its Asset Purchase Facility (APF) in its program of quantitative easing.

3.2 The gilt repo market

A market closely related to the gilt market is the gilt repo market. Formally, a repo is a repurchase agreement: one counterparty sells a security to another counterparty for a given price, and commits to repurchase the same (or similar) security at a specified future date and for a specified price. The trade is economically equivalent to a secured loan: the underlying security acts as collateral, and the difference between the prices at which the security is sold and repurchased implies an annualised interest rate known as the repo rate. From the perspective of the cash borrower, the transaction is referred to as a repo, while from the perspective of the cash lender, it is referred to as a reverse repo. If the precise security to be exchanged is agreed when the trade is struck, the trade is referred to as a specific collateral repo. Alternatively, the counterparties may agree that any of a certain group of securities may be exchanged. In this case, the trade is referred to as a general collateral repo.

The vast majority of sterling-denominated repo involves the sale and repurchase of gilts. A wide range of market participants use the gilt repo market. Money market funds, corporates, and local authorities use the market to deposit cash securely. Meanwhile, hedge funds, asset managers, pension funds, and insurance companies borrow cash via repos to finance leveraged investment strategies. GEMMs frequently use the gilt repo market to cover short gilt positions. Banks use reverse repos to borrow gilts for their liquid asset buffers. And if a bank needed to liquidate gilts at short notice, it would most likely access the repo market, rather than sell the gilts outright in the secondary market. The gilt repo market also plays an important role in the Bank of England's monetary policy transmission and liquidity insurance operations (see Bank of England, 2015a).

Like the secondary gilt market, the gilt repo market is intermediated by a group of dealer banks, and there is significant overlap between the communities of GEMMs and repo dealers. The interdealer repo market is also intermediated by interdealer brokers, mostly using electronic broking platforms, the largest of which is BrokerTec. Almost all interdealer gilt repo trading is at overnight term, and the vast majority of interdealer gilt repo trades are centrally cleared through LCH Limited. In contrast to the dollar repo market, only a small proportion of the gilt repo market is intermediated by tri-party agents.

3.3 The leverage ratio

Following the global financial crisis, the Basel Committee on Banking Supervision (BCBS) undertook a significant program of reform to banking regulation known as Basel III. This proposed new international regulatory standards for capitalization and liquidity risk management. The revised capital standards include reforms to the risk-based capital framework that existed under previous Basel accords, and a new regulatory leverage ratio to supplement the risk-based framework.

The leverage ratio is an indicator of a firm's solvency, and is defined as Tier 1 capital divided by the exposure measure. The exposure measure includes on-balance sheet exposures, derivative exposures, securities financing transaction exposures (including repo), and certain off-balance sheet exposures. Requiring banks to maintain a minimum leverage ratio is intended to "restrict the build-up of leverage in the banking sector to avoid destabilizing deleveraging processes that can damage the broader financial system and the economy" and to "reinforce the risk-based requirements with a simple, non-risk based 'backstop' measure" (BCBS, 2014).

The BCBS first indicated that it planned to introduce a regulatory leverage ratio in a consultation document in 2009 (BCBS, 2009). In 2010, the BCBS proposed a 3% minimum leverage ratio (BCBS, 2010). At this time, the BCBS also proposed a transition path to implementation, whereby banks would be required to publically disclose their leverage ratios from January 2015 and meet a 3% minimum as part of their Pillar 1 capital requirements by January 2018. In 2014, the BCBS finalized the definition of the leverage ratio that banks would be required to disclose from 2015 and reiterated that the leverage ratio would become a Pillar 1 requirement from 2018 (BCBS, 2014).

The way in which domestic legislators and regulators have implemented the leverage ratio varies across jurisdictions: see Bank of England (2014a) for a summary. Since most GEMMs and gilt repo dealers are U.K. banks or U.K. subsidiaries of foreign banks, the leverage ratio frameworks most relevant to the functioning of the gilt and gilt repo markets have been those of the U.K. and EU.

U.K. authorities implemented the leverage ratio earlier than the Basel and EU timelines. In December 2011, the Bank of England's Financial Policy Committee (FPC) recommended that the FSA (the U.K. regulator at the time) encourage banks "to disclose their leverage ratios... not later than the beginning of 2013" (Bank of England, 2011), two years ahead of the Basel timeline for disclosure. The FSA implemented this recommendation by asking large U.K. banks to publish their leverage ratios in their 2012 annual reports and on a bi-annual basis thereafter. In June 2013, the Prudential Regulation Authority (PRA), which now regulates U.K. banks, required two large U.K. banks that did not meet a 3% leverage ratio to submit plans for how they would reach that standard (Bank of England, 2013b). Major U.K. banks have been expected to meet a 3% leverage ratio since January 2014, four years ahead of the Basel and EU implementation date of January 2018 (Bank of England, 2013a). Following a review by the FPC (Bank of England, 2014a,b), the PRA finalized the U.K. leverage ratio framework in 2015 (Bank of England, 2015c,b), stipulating a 3% minimum requirement for large U.K. banks starting in January 2016. Other U.K. banks became subject to a 3% minimum requirement from January 2018 under CRD IV. See Table 1 for a summary of this timeline.

Several large dealers in the gilt and gilt repo markets are U.K. subsidiaries of U.S. banks. This means that the U.S. leverage ratio framework might also have an impact on the functioning of these markets. A domestic leverage ratio has applied to U.S. banks since 1981, but the framework has been substantially revised and toughened in recent years (including changes to the definition of the exposure measure). The supplementary leverage ratio (SLR), proposed in June 2012 and finalized in July 2013, implements the Basel III leverage ratio in the U.S. In addition, the enhanced supplementary leverage ratio (eSLR) requires G-SIBs and insured depository institutions of G-SIBs to meet 5% and 6% minimum leverage ratios, respectively. See Allahrakha et al. (2018) for more detail on the U.S. leverage ratio framework.

The leverage ratio exposure measure does not seek to differentiate between the riskiness of different assets. Taken in isolation, activities that receive low risk-weights under the risk-based framework (such as market-making in the gilt and gilt repo markets) are therefore more capital intensive under the leverage framework than under the risk-based framework. If binding, the introduction of a regulatory leverage ratio therefore increases the capital requirements associated with these business lines. On the basis that equity is more expensive than debt for banks,[3] participants in these and related markets have argued that a higher marginal cost of market-making is causing market-makers to reduce their activity, charge higher margins, or exit certain markets completely (CGFS, 2014; SLRC, 2014; ICMA, 2015; DMO, 2016). Indeed, two recent GEMM resignations — by Credit Suisse in 2015 and Société Générale in 2016 — have been attributed to the increased capital cost of market-making in gilts (Reuters, 2016). In aggregate, these changes in dealer behavior are reported to have resulted in reduced secondary market liquidity in both the gilt and gilt repo markets.

4 Data and summary statistics

We use three proprietary datasets: the "Zen" dataset maintained by the U.K. Financial Conduct Authority (FCA), which contains transaction-level information on secondary market trading in gilts; transaction-level data from the BrokerTec platform for interdealer gilt repos;

[3]This claim is questioned by, for example, Miles et al. (2013).

and regulatory data on gilt repo activity collected by the Bank of England (Form RSL). In this section, we discuss the three key proprietary datasets before setting out some descriptive summary statistics for the gilt and gilt repo markets.

4.1 Zen dataset

Our analysis of the secondary market for gilts is based on the Zen dataset maintained by the FCA.[4] This dataset has also been used by Aquilina and Suntheim (2017) and Benos and Zikes (2018).

The Zen dataset includes transaction reports for all secondary market trades in gilts where at least one counterparty is an EEA firm. Since GEMMs are EEA entities, the dataset covers the entire gilt market-making business of dealers. Each transaction report includes the date, time, quantity, price, International Securities Identification Number (ISIN), a buyer/seller flag, trading capacity information, the identity of the reporting firm, and in most cases, the identity of their counterparty. The counterparty identifier field allows us to match reports in cases where both counterparties report the trade. We clean the data by dropping trades that are implausibly large or small, or that have prices far from the end-of-day prices recorded by Bloomberg. The dataset covers the period from January 2008 to December 2017, with a total of 2,527 business days. After cleaning and matching trade reports, our final dataset has around 9.4 million unique trades.

4.2 BrokerTec

We obtain transaction-level data on the interdealer gilt repo market from BrokerTec (owned by NEX Group), which is the largest electronic platform for interdealer gilt repos. For each transaction, we observe the date, time, quantity, repo rate, and collateral. The collateral information allows us to classify trades as general collateral or specific collateral. The dataset is anonymized.

[4] Trades prior to August 2011 are recorded in a similar database called Sabre II.

We estimate that the BrokerTec data cover the majority of the interdealer gilt repo market. And comparisons with the Form RSL data (discussed below) suggest that the BrokerTec data cover around 40% of the total gilt repo market (by value). We use data for the January 2006 to December 2017 period, consisting of 3,032 business days. The dataset consists of around 2.3 million trades.

4.3 Form RSL

Between February 1996 and May 2018, participants in the gilt repo market reported quarterly summary statistics of their activity to the Bank of England through Form RSL. Reporting was voluntary, but as of 2017 around 35 institutions chose to report, including most of the major dealer banks. Firms reported their turnover and number of transactions (summing over the quarter and aggregating across counterparties), as well as the cash value of their outstanding positions. In this paper, we focus on total repo turnover (value of cash borrowed, summed across all maturities), because repo borrowing increases the leverage exposure measure.

4.4 Summary statistics

Figure 1 shows the nominal value of gilts outstanding. The stock of gilts in issue has grown substantially since the financial crisis, from around £400 billion in 2008 to nearly £1.5 trillion by the end of 2017. Since 2009, the Bank of England has purchased a stock of £435 billion of gilts through its Asset Purchases Facility (APF) by market value. Since the pace of gilt issuance by the DMO was generally faster than the pace of asset purchases by the Bank of England, the nominal "free float" — total outstanding gilts minus government holdings, APF holdings, and other Bank of England holdings — more than doubled between 2008 and 2017.

Gilt trading volumes did not keep pace with the growth of gilts in issue over this period. Figure 2 shows annual gilt trading volumes and turnover ratios, which measure trading volume relative to gilts outstanding and free float. Trading volumes increased between 2008 and 2017. But given the large increases in the stock of gilts outstanding and free float, turnover ratios fell over this period. The ratio of trading volume to free float fell from 8.4 in 2013 to 5.8 in 2016, before increasing to 6.6 in 2017. Figure 3 shows the number of trades per year and the average trade size. Both increased after the financial crisis. The average trade size has remained stable since 2013, while the number of trades increased in 2017.

Figure 4 shows aggregate annual repo borrowing in the gilt repo market since 1997, broken down by maturity. The market tripled in size between 1997 and the financial crisis. It continued to grow after the financial crisis, which Jackson and Sim (2013) argue reflected a substitution from unsecured borrowing to secured borrowing, driven by heightened sensitivity to credit risk and new liquidity regulations. Repo volumes then fell sharply between 2012 and 2016, a trend that market participants primarily attributed to the regulatory leverage ratio (SLRC, 2014; ICMA, 2015). The average size of a gilt repo trade also fell substantially over this period (Figure 5), from £74 million in 2009 to £42 million in 2016, potentially indicating reduced liquidity. However, gilt repo activity increased markedly in 2017. Market participants argued that this partly reflected more efficient balance sheet allocation from a regulatory perspective (Money Markets Committee, 2017).

Figures 4 and 5, which are based on the Form RSL data, refer to the gilt repo market as a whole. But similar trends are also evident in the interdealer market, as recorded by BrokerTec. Figure 6 shows a significant fall in interdealer gilt repo volumes between 2012 and 2015, followed by a substantial increase in 2017. Since the financial crisis, there has been a very large reduction in repo trades of longer maturity. By 2012, more than 99% of interdealer gilt repo trading by value was at overnight maturity. The average trade size in the interdealer gilt repo market also fell sharply during the post-crisis period, from around £50 million in 2009 to less than half of this amount in 2015, before partially recovering in 2017 (Figure 7).

5 Measures of market liquidity

There are three concepts of liquidity in the literature: monetary liquidity, which relates to the ease of converting monetary assets into goods and services; funding liquidity, which relates to the ability of market participants to obtain funding; and market liquidity, which relates to the ease with which an asset can be traded (ECB, 2012; IMF, 2015). This paper is principally concerned with market liquidity. But market liquidity itself has multiple facets, and no one metric is likely to measure it perfectly. We therefore construct several measures of market liquidity that have frequently been used in the literature.

5.1 Gilt liquidity measures

For the gilt market, we compute four measures of market liquidity. The first three are constructed using transaction-level information from the Zen dataset, at the level of individual bonds. We then take the median across bonds to form a market-level measure. The fourth (yield curve noise) is estimated using end-of-day yields from Bloomberg, and is calculated at the level of the market rather than individual bonds. All the measures are computed at daily frequency, with higher values indicating lower liquidity.

1. *Amihud measure*: Amihud (2002) measures liquidity as the ratio of absolute return to trading volume. This measure is intended to indicate the price impact of trades. Following Dick-Nielsen et al. (2012), we estimate price impact at the level of individual trades, and then average over the trade-level values each day to obtain a measure at daily frequency. More precisely, for a given gilt and a given day t, we define $r_{i,t}$ to be the return and $Q_{i,t}$ to be the trade size (in £ million) of the ith trade, and define N_t to be the number of trades. The Amihud measure at the gilt level is the daily average

of the absolute returns divided by the corresponding trade sizes:[5]

$$Amihud_t = \frac{1}{N_t - 1} \sum_{i=2}^{N_t} \frac{|r_{i,t}|}{Q_{i,t}}.$$

2. *Roll measure:* Roll (1984) shows that under certain assumptions, the percentage bid-ask spread is equal to two times the square root of the negative first-order serial covariance of returns. The intuition is that the transaction price will tend to bounce between the bid price and ask price so that returns on consecutive trades are negatively correlated, and that this negative correlation will be larger if the bid-ask spread is wider. For a given gilt and a given day t, we define $r_{i,t}$ to be the return on the ith trade. We define the Roll measure at the gilt level as:

$$Roll_t = 2\sqrt{\max\{0, -\text{cov}(r_{i,t}, r_{i-1,t})\}}.$$

3. *Round-trip cost (RTC):* As an additional measure of the bid-ask spread, we estimate the round-trip cost of trading a bond, following Goldstein et al. (2007). We search for instances in which a given dealer buys a gilt from a client, and then the same dealer sells the same gilt to another client on the same day (or alternatively, instances in which a given dealer sells a gilt to a client, and then buys the same gilt from another client on the same day); and we find the dealer's return on this pair of transactions. For a given gilt and a given day, we then take the average of these returns.

4. *Yield curve noise:* Following Hu et al. (2013), our final measure of liquidity for the gilt market is based on the differences between observed bond yields and the fitted yields from a smoothed yield curve. The intuition is that these differences indicate deviations from fundamental values. The noise measure is computed as the root-mean-squared difference between end-of-day actual and fitted yields on bonds with maturity between

[5] In line with Bessembinder et al. (2009), we exclude trades smaller than £100,000 because these can have a disproportionate effect on the Amihud measure.

one and ten years. For fitted yields, we use the Bank of England's fitted nominal gilt curve, which is based on the Anderson and Sleath (2001) variable roughness penalty (VRP) approach. On day t, suppose that there are N_t conventional gilts with residual maturity between one and ten years. We define y_t^i to be the actual end-of-day yield of gilt i, and $y^i(\mathbf{b}_t)$ to be the fitted yield of gilt i based on the model parameters $\mathbf{b}_t$ estimated for day t. Then the noise measure is defined as:

$$Noise_t = \sqrt{\frac{1}{N_t}\sum_{i=1}^{N_t}\left[y_t^i - y^i(\mathbf{b}_t)\right]^2}.$$

Our estimated liquidity measures for the gilt market are shown in Figure 8, with higher values indicating worse liquidity. We combine the information from these measures by extracting the first principal component, which is shown in Figure 11.[6] Annual averages of the four measures are shown in Table 2, along with the factor loadings of the first principal component. The four measures are strongly correlated, with the first principal component explaining 71% of the sample variance. All four measures increased sharply during the financial crisis of 2007-2009, before drifting back down over late 2009 and 2010. Most of the measures were again elevated over 2011-2012, during the European sovereign debt crisis. The measures exhibited substantial volatility between 2014 and 2017.

5.2 Repo liquidity measures

We construct three liquidity measures for the interdealer gilt repo market, in each case using the transaction-level BrokerTec data. We construct these separately for general collateral trades and specific collateral trades, at daily frequency. All measures are constructed using overnight trades only (over 99% of the trades in the sample are overnight). The specific collateral measures are constructed at the level of the underlying security, and we take the

[6]Before computing the first principal component, we standardize the measures to have mean zero and standard deviation equal to one.

median across securities to form a market-level measure.

1. *Amihud:* As for gilts, we construct an Amihud measure of repo liquidity, which is intended to measure the impact on the repo rate of a £1 million trade. For a given underlying security and a given day t, we define $R_{i,t}$ to be the repo rate and $Q_{i,t,}$ to be the trade size (in £ million) of the ith trade, and define N_t to be the number of trades. The Amihud measure for repo is then the daily average of absolute changes in repo rates divided by the corresponding trades sizes:

$$Amihud_t = \frac{1}{N_t - 1} \sum_{i=2}^{N_t} \frac{|R_{i,t} - R_{i-1,t}|}{Q_{i,t}}.$$

2. *Roll:* Using the same notation, the Roll measure that we calculate for gilt repo is defined as:

$$Roll_t = 2\sqrt{\max\left\{0, -\text{cov}\left(R_{i,t} - R_{i-1,t}, R_{i-1,t} - R_{i-2,t}\right)\right\}}.$$

3. *Effective spread:* As an alternative measure of the bid-ask spread, and following Hong and Warga (2000), we calculate the effective bid-ask spread. This is defined as the difference between the volume-weighted average repo rates on cash-borrower-initiated and cash-lender-initiated trades.

Our estimated liquidity measures for the gilt repo market are shown in Figures 9 and 10 and in Table 3, again with higher values indicating worse liquidity. The first principal component is shown in Figure 11. As for gilts, the repo liquidity measures are strongly correlated. The first principal component explains 60% of the variance of the three measures for general collateral, 70% of the variance of the three measures for specific collateral, and 53% of the variance when we pool the six measures. The measures indicate that repo liquidity worsened during the early stages of the financial crisis in 2007, before deteriorating dramatically with the collapse of Lehman Brothers in September 2008. This is in line with the findings of

Gorton and Metrick (2012) for the U.S. repo market.

All of the measures indicate a worsening in gilt repo liquidity over the post-crisis period. We can use Table 3 to compare recent levels of liquidity to pre-crisis levels. All six measures indicate that liquidity was worse on average in 2017 than in 2006, although in most cases the difference is modest. However, it is important to emphasise that these measures only use data from the interdealer market, which is almost entirely overnight and centrally cleared. These characteristics mean that the interdealer market is likely to be the part where most netting can occur under leverage ratio rules, making this segment the least affected by leverage ratio requirements. As such, to the extent that this reduction in liquidity was caused by the leverage ratio, it is likely to represent a lower bound for any deterioration in gilt repo liquidity more broadly.

6 Market-level analysis

We seek to test the hypothesis that the introduction of leverage ratio policy in the U.K. caused a reduction in the liquidity of the gilt and gilt repo markets. Our empirical analysis proceeds in three steps:

- First, we estimate market-level time series regressions, to assess how the liquidity of the gilt and gilt repo markets changed during the period when U.K. leverage ratio policy was introduced, conditional on other factors. By identifying changes in liquidity on key reporting dates, when dealers' behavior is likely to be most sensitive to regulatory requirements, these regressions also provide preliminary evidence on whether there was a causal link between the leverage ratio and liquidity.

- Second, we estimate market-level time series quantile regressions. While the first set of regressions provides information about the conditional mean of liquidity, the quantile regressions indicate how other parts of the conditional distribution changed during this period, providing insights into the resilience of liquidity.

- Third, we estimate dealer-level panel regressions, which use heterogeneity in dealer behavior to identify any causal relationship between the leverage ratio and changes in liquidity.

In this section, we discuss the market-level time series regressions. The quantile regressions and panel regressions are discussed in Sections 7 and 8, respectively.

6.1 Market-level regression specifications

The primary role of our market-level regressions is to investigate how the liquidity of the gilt and gilt repo markets changed during the period when U.K. leverage ratio policy was introduced. Major U.K. banks have only been formally subject to a minimum leverage ratio requirement from January 2016, and other U.K. banks became formally subject to a minimum requirement in January 2018. But firms are likely to have started to adjust their balance sheets much earlier than this in response to a series of policy announcements, supervisory expectations, and reporting requirements (see Subsection 3.3 and Table 1 for more detail). The first of these announcements was in December 2011, so we assume that the adjustment process began in 2012 or later. We therefore include indicator variables for the years 2012, 2013, 2014, 2015, 2016, and 2017 in order to estimate whether the conditional mean of liquidity shifted during this period. We also employ structural break tests as a complement to this regression analysis.

While the indicator variables provide information on whether there was a change in liquidity during the period when banks were adjusting to meet leverage ratio requirements, they cannot establish causality, because any change in liquidity might have been caused by variables omitted from the regressions. To provide preliminary evidence on causality, we additionally include indicator variables for quarter-ends from 2012 and month-ends from 2014. Large U.K. banks started to disclose quarter-end leverage ratios in 2012 (following the FPC's December 2011 recommendation), and all PRA-regulated firms started to report leverage ratios based on month-end balance sheets in 2014 (when EU-level reporting requirements, COREP, came into force). Dealers' behavior is likely to have been particularly sensitive to leverage ratio policy on these dates. If the leverage ratio did cause a change in liquidity, we therefore expect this to be particularly pronounced at month-ends and quarter-ends. We consider the question of causality more formally in Section 8.

By providing information on the determinants of liquidity more broadly, these regressions also allow us to test several other hypotheses concerning, for example: the impact of market structure on liquidity; the impact of predictable events, such as Bank of England QE purchases and DMO gilt auctions, on liquidity; and the relation between funding liquidity and market liquidity.

We run separate regressions for gilts and gilt repos. The regressions are at daily frequency, for the period January 2010 to December 2017 (to exclude the impact of the financial crisis), and take the following form:

$$\begin{aligned} Liquidity_t &= \beta_0 + \beta_1 YearIndicators_t + \beta_2 PeriodEndIndicators_t \\ &\quad + \beta_3 LiquidityOtherMarket_{t-1} \\ &\quad + \beta_4 FundingCosts_{t-1} + \beta_5 Sentiment_{t-1} + \beta_6 InventoryRisk_{t-1} \\ &\quad + \beta_7 EuroCrisis_{t-1} + \beta_8 MarketStructure_{t-1} + \beta_9 GiltMarketEvents_t \\ &\quad + \beta_{10} OtherControls_t + \varepsilon_t, \end{aligned} \tag{1}$$

where:

- $Liquidity_t$ is the first principal component of the liquidity measures discussed in Section 5. These are shown in Figure 11. Higher values of this variable indicate worse liquidity. $Liquidity_t$ is normalized such that its standard deviation over the regression sample period is equal to one.

- $YearIndicators_t$ consists of six indicator variables, indicating each of the six years (2012 to 2017) following the first major U.K. policy announcement on leverage ratio regulation (December 2011).

- $PeriodEndIndicators_t$ consists of four indicator variables for month-ends and quarter-ends: a variable equal to one on the last day of the month and zero otherwise; a variable equal to one on the last day of the month if the date is after January 1, 2014 and zero otherwise; a variable equal to one on the last day of the quarter and zero otherwise; and a variable equal to one on the last day of the quarter if the date is after January 1, 2012 and zero otherwise. The coefficients on these variables can be interpreted additively: for example, on quarter-ends after 2014, all four of the variables are equal to one.

- $LiquidityOtherMarket_t$ is the liquidity measure from the other market. That is, in the gilt regressions, this variable is the first principal component of the repo liquidity measures, while in the repo regressions, it is the first principal component of the gilt liquidity measures.

- $FundingCosts_t$ consists of variables related to dealer funding costs, specifically the 3-month Libor-OIS spread (unsecured funding), and the spread between the 3-month general collateral repo rate and the OIS rate (secured funding).

- $Sentiment_t$ is a set of variables indicating general financial market sentiment: the VIX (the implied volatility of the S&P 500), the percentage change in the FTSE 100, and the change in the 10-year gilt yield.

- $InventoryRisk_t$ consists of variables that affect the riskiness of a gilt portfolio: the implied volatility of the 10-year sterling interest rate, and the change in the U.K. sovereign CDS premium.

- $EuroCrisis_t$ consists of two variables to control for the potential impact of the European sovereign debt crisis on liquidity: the change in the euro Libor-OIS spread, and the change in the spread of the 10-year Italian sovereign bond yield over the 10-year German bund yield.

- $MarketStructure_t$ is a set of variables related to the structure of the market: the change in the share of gilts held by insurance companies and pension funds (ICPFs); the change in the market value of the free float (total outstanding gilts minus government holdings, APF holdings, and other Bank of England holdings); and, for the gilt regressions, the ratio of interdealer trading volume to total trading volume.

- $GiltMarketEvents_t$ consists of indicator variables for the dates of Bank of England APF (quantitative easing) purchases and the dates of DMO gilt auctions.

- $OtherControls_t$ consists of additional control variables, specifically several lags of the dependent variable (the number of lags is chosen using the Bayesian information criterion), and fixed effects for each quarter-end.[7]

Summary statistics for the variables used in these regressions are provided in Table 4. All potentially endogenous explanatory variables are lagged by one day. For each of gilt and gilt repos, we run two main regressions: the first includes only $YearIndicators_t$, $PeriodEndIndicators_t$, and $OtherControls_t$; and the second includes the full set of control variables.

6.2 Market-level regression results

The results are presented in Tables 5 and 6 for gilts and gilt repos, respectively. In the last row of each table, we show the results of a Wald test for the hypothesis that the year indicator variables are jointly equal to zero.

We consider first the results for gilt liquidity. Column (1) of Table 5 shows that when we do not control for factors such as funding costs and inventory risk, there is no evidence that gilt market liquidity became systematically worse during the period when U.K. leverge ratio policy was introduced. The 2012, 2015, and 2016 indicators are positive and significant,

[7]The quarter-end fixed effects are constrained to sum to zero. This means that the quarter-end indicator variables in $PeriodEndIndicators_t$ measure the average impact of quarter-ends on liquidity, while the quarter-end fixed effects pick up the individual deviations around this average. The purpose of the quarter-end fixed effects is to prevent the very large spikes in the liquidity measures that occur on some quarter-ends from impacting the coefficients on the year indicator variables.

indicating that liquidity in these years was worse than in the "control" years (2010 and 2011). However, the 2014 and 2017 indicators are negative and significant, indicating that liquidity was on average better during these years relative to 2010 and 2011. This is consistent with a visual inspection of Figure 8, which shows no clear trend in gilt liquidity over the post-crisis period. However, as shown in column (2), once we control for a wider range of influences on liquidity, we find that the conditional liquidity of the gilt market was significantly worse throughout 2012-2017 relative to 2010 and 2011. Each of the year indicators is positive, statistically significant and economically significant (recall that the units of the dependent variable are standard deviations). In column (3), we show that including only the Libor-OIS spread, interest rate implied volatility, and the gilt interdealer ratio is sufficient to obtain positive and significant coefficients on each of the year indicators.

Surprisingly, the month-end indicator variable for the period 2014-2017 and the quarter-end indicator variable for the period 2012-2017 have negative coefficients. This indicates that liquidity on month-ends and quarter-ends *improved* relative to average liquidity as leverage ratio requirements were introduced. This casts doubt on a causal connection between the leverage ratio and the conditional deterioration in gilt liquidity.

Turning to the other variables, we observe a strong association between funding costs (measured by the Libor-OIS spread and the GC repo-OIS spread) and gilt liquidity. This indicates that funding liquidity supports market liquidity, in line with the prediction of Brunnermeier and Pedersen (2009). Meanwhile, increases in inventory risk (measured by interest rate implied volatility) are associated with reductions in liquidity. We find that a larger interdealer market is associated with an improvement in liquidity. This is consistent with the hypothesis that a larger interdealer market improves dealers' ability to manage their inventories and share risk, and therefore makes dealers more willing to provide liquidity to their clients. This result is in line with the findings of Benos and Zikes (2018), but contrasts with Anderson and Liu (2018), who find that a higher interdealer ratio is associated with tighter dealer risk constraints. We also find that worse liquidity in the interdealer gilt repo market is associated with worse liquidity in the gilt market. Finally, we observe that gilt market liquidity improves on days when the DMO issues gilts.

We next consider the results for repo liquidity. Both columns of Table 6 indicate that repo liquidity worsened significantly from 2013 to 2017. This result holds whether or not we control for other potential determinants of liquidity, and is consistent with Figure 11.[8]

The estimated coefficients on the indicator variables for month-ends over 2014-2017 and quarter-ends over 2012-2017 are positive and statistically significant. This indicates that the deterioration in repo liquidity was particularly pronounced on regulatory reporting dates. This provides indicative evidence of a causal connection between the leverage ratio and the reduction in repo liquidity, and reflects the results in Munyan (2015) for the U.S. tri-party repo market. None of the control variables in the repo regressions are statistically significant, suggesting that repo liquidity is less sensitive to changes in funding costs, inventory risk, and market structure than gilt liquidity.

For both markets, the timing of the reduction in liquidity shown by the regressions is consistent with results from structural break tests. We re-estimate the regressions with the full set of controls but without the year indicators, and test for a single unknown breakpoint in the intercept using the supremum Wald test of Andrews (1993). For gilts we detect a structural break in January 2012, while for repos we detect a structural break in October 2015.

In summary, the market-level regression results suggest that liquidity did worsen in both markets during the period when U.K. leverage ratio policy was introduced. For gilts, this result only holds when we control for other factors, while for gilt repos, the result also holds unconditionally. Changes in liquidity on regulatory reporting dates also provide preliminary evidence of a causal connection between the leverage ratio and the deterioration in repo liquidity, although not for gilt liquidity. We find that gilt liquidity is sensitive to several

[8]We find similar results when we run the regressions separately for general collateral and specific collateral liquidity measures (available upon request). In most cases, the estimated coefficients on the year indicators are larger for general collateral and smaller for specific collateral.

other variables, including funding costs, inventory risk, market structure, and repo liquidity. On the other hand, repo liquidity appears to be relatively insensitive to changes in market conditions.

7 Liquidity resilience

Policymakers and market participants have expressed concern that the risk of sudden reductions in liquidity has increased in recent years, with several well-publicised bouts of volatility cited as evidence (see, for example, Shafik, 2015 and CGFS, 2016). We therefore consider the question of whether liquidity became less resilient as banks adjusted to the leverage ratio. We address this question in two ways. First, we estimate quantile regressions, which allow us to compare changes in liquidity at different parts of the conditional distribution. Second, we plot the frequency of sudden "jumps" in liquidity.

Tables 7 and 8 show the results from quantile regressions of equation (1) for the gilt and repo markets, respectively.[9] In each case, column (1) shows the results from the median regression and column (2) shows the results from the the 0.9 quantile regression. The results for the 0.9 quantile indicate the impact of the regressors on liquidity in times of poor conditional liquidity. Column (3) shows the differences between the estimated coefficients from the two regressions.

For both gilts and gilt repos, the results for the conditional median regressions (column (1)) are broadly similar to the conditional mean regression results shown in Tables 5 and 6. And in both cases, the results in column (3) show that the estimated coefficient on almost all of the year indicator variables is larger at the 0.9 quantile than at the median. This indicates that the (conditional) worsening in liquidity over this period was more pronounced at times of poor liquidity than at times of normal liquidity, consistent with a reduction in the resilience of liquidity. For gilts, the difference is statistically significant only for the

[9]In the quantile regressions we do not include quarter-end fixed effects, because quantile regressions are robust to outliers.

2015 and 2016 indicators, and the Wald test results indicate that the differences are jointly insignificant (column (3), last row). For repos, the difference is statistically significant only for the 2017 indicator, but the Wald test results indicate that the differences are jointly significant. We also note that, in the repo market, the 2012-2017 quarter-end effects are substantially larger at the 0.9 quantile than at the median.

Further evidence that repo liquidity became less resilient is provided by considering the frequency of jumps in liquidity. Following an approach similar to Adrian et al. (2015a,b), we define a jump to be a one-day increase in the first principal component of liquidity of at least one standard deviation.[10] Figure 12 shows annual sums of the number of jumps in liquidity in the two markets. In both markets, jumps were most frequent during the financial crisis. There is no clear trend in the frequency of jumps in gilt liquidity during the post-crisis period. But jumps became more frequent in the repo market over 2013-2017, indicating an increase in the risk that liquidity suddenly evaporates.

8 Dealer-level analysis

The market-level regression results indicate that liquidity in both the gilt and gilt repo markets worsened during the period when U.K. leverage ratio policy was introduced, once we control for factors such as changes in funding costs and inventory risk. And the quantile regression results indicate that this worsening in liquidity was more pronounced in times of poor liquidity, consistent with a reduction in the resilience of liquidity. However, these regression results do not provide strong evidence of a causal link between the leverage ratio and liquidity because the changes in liquidity over this period might have been caused by some other omitted factor. In order to better identify a potential causal impact, we run dealer-level panel regressions that exploit two sources of heterogeneity across dealers: heterogeneity in the balance sheets of individual dealers, and heterogeneity in the timing of

[10] We use the standard deviation of the level of the first principal component across 2008-2017 for gilts and 2006-2017 for gilt repos.

regulatory requirements across jurisdictions.

A significant challenge to this analysis is that we lack a clear treatment date. Policies were developed gradually, and banks were given lengthy periods of time (typically years) to adjust ahead of full implementation, making it difficult to establish when a given bank would have started its adjustment process. Therefore, as discussed in more detail below, we consider several different specifications and treatment dates. In some specifications, all banks are assumed to start the adjustment process at the same time. In others, the treatment date differs across banks. For this second set of regressions, we partition the sample of dealers into three groups: large U.K. banks ($LargeUK$), U.K. subsidiaries of U.S. banks ($SubsidiaryUS$), and other U.K. entities ($OtherUK$). The $OtherUK$ group includes both smaller U.K. banks and U.K. subsidiaries of foreign (non-U.S.) banks. The sizes and market shares of these three groups are shown in Table 9. We exclude a small number of dealers that are U.K. branches of foreign banks because we do not have consistent balance sheet data for these entities. We also exclude any banks that are inactive over either the full pre-treatment period or the full post-treatment period. For example, we exclude GEMMs that exited the market before the treatment date. This ensures that all banks in the sample are active both before and after the treatment date.

The treatment dates that we focus on are the following (see Subsection 3.3 and Table 1 for further detail):

- **December 2011:** The FPC recommended that the FSA encourage U.K. banks to disclose their leverage ratios. The FSA implemented this by asking banks in the $LargeUK$ group to publish their leverage ratios in their 2012 annual reports and on a bi-annual basis thereafter.

- **June 2012:** Regulators in the U.S. proposed a supplementary leverage ratio for large U.S. banks, including the parent companies of the banks in the $SubsidiaryUS$ group. Allahrakha et al. (2018) find that this announcement caused affected broker-dealers to decrease their total repo borrowing.

- **January 2014:** PRA-regulated banks started to report regulatory leverage ratios through COREP on the basis of month-end balance sheets. This was the first time that banks in the $OtherUK$ group were required to report regulatory leverage ratios.

- **January 2016:** Banks in the $LargeUK$ group became formally subject to a minimum leverage ratio requirement.

8.1 Dealer-level regression specifications

We consider several different specifications for the dealer-level regressions. Each takes the following general form:

$$\begin{aligned} LiquidityProvision_{i,t} &= \alpha_i + \lambda_t + Treatment_{i,t} \\ &\quad + \beta_1 CountryControls_{i,t} + \beta_2 DealerControls_{i,t} + \varepsilon_{i,t}, \end{aligned} \tag{2}$$

where:

- $LiquidityProvision_{i,t}$ is a measure of the liquidity provided by dealer i in quarter t. We measure liquidity provision in the gilt market in two ways: first, round-trip cost at the dealer level, which is a measure of the average bid-ask spread that the dealer charges its clients on gilt trades;[11] and second, the log of the dealer's trading volume with clients. For the gilt repo market, we measure liquidity provision as the log of the dealer's total repo borrowing (we do not observe transaction-level repo data for individual dealers).

- $Treatment_{i,t}$ is a function that differs across specifications, as defined below.

- $CountryControls_{i,t}$ is a vector of control variables for the country where dealer i has

[11] We do not consider the other two transaction-based liquidity measures (Amihud and Roll) to be meaningful at the individual dealer level.

its main headquarters, specifically the GDP growth rate and the equity index growth rate.

- $DealerControls_{i,t}$ is a vector of control variables at the dealer level: the first lag of liquidity provision; the log of total assets; return on assets; the share of assets that are recorded as being in the trading book; the share of assets that are cash or government bonds; and the risk-weighted capital ratio.

- α_i and λ_t are dealer and time fixed effects, respectively. The dealer fixed effects control for all time-invariant heterogeneity at the dealer level. The time fixed effects control for factors that might have impacted the liquidity provision of all dealers in a similar way, such as the implementation of quantitative easing.

The samples consist of 16 GEMMs and 19 repo dealers. The regressions are at quarterly frequency, because the dealer-level control variables and the RSL data are available only at quarterly frequency. Standard errors are double-clustered at the dealer and time level using the implementation in Correia (2017).

We estimate four versions of equation (2), which differ according to the definition of $Treatment_{i,t}$. Each of these exploits variation in dealers' leverage ratios at the time of key policy announcements and/or differences in the timing of leverage ratio implementation across jurisdictions.

In the first version of equation (2), we define $Treatment_{i,t}$ as:

$$Treatment_{i,t} = \delta Dec2011\_Constrained_{i,t}, \tag{3}$$

where:

$$Dec2011\_Constrained_{i,t} = \begin{cases} 1 & \text{if } LR_{i,s} < 3\% \text{ and } t > s, \\ 0 & \text{otherwise,} \end{cases}$$

for $s =$ December 2011. This results in a simple difference-in-differences specification, where the treatment (control) group is the set of dealers whose leverage ratios were below (above) 3% in December 2011. December 2011 was the first major U.K. policy announcement regarding the leverage ratio, when the FPC recommended that U.K. banks be encouraged to disclose their leverage ratios from 2013. While this recommendation was only applied to large U.K. banks, it might have also affected the behavior of other banks by signaling that U.K. authorities would be front-running the Basel and EU timelines. This definition of $Treatment_{i,t}$ is our preferred version, because using a treatment date early in the policy-making process reduces the possibility that the date falls after banks started adjusting their balance sheets. This choice of date is also supported by our market-level analysis, which indicates that there was a structural break in conditional gilt liquidity in January 2012. The rationale for this definition of $Treatment_{i,t}$ is that banks whose leverage ratios were below 3% (the regulatory minimum proposed by the BCBS) at the start of the adjustment process would, over the following years, have needed to adjust their balance sheets by more than banks with leverage ratios above 3%. If the leverage ratio had a causal impact on liquidity, we would therefore expect this to have occurred mainly through the liquidity provision of banks in the treatment group ("constrained" banks). This regression specification is similar to those used in ESRB (2016) and Acosta-Smith et al. (2018).

In the second version of the regression, we define $Treatment_{i,t}$ as:

$$Treatment_{i,t} = -\delta Dec2011\_PTLR_{i,t}, \tag{4}$$

where:

$$Dec2011\_PTLR_{i,t} = \begin{cases} LR_{i,s} & \text{if } t > s, \\ 0 & \text{otherwise,} \end{cases}$$

for $s =$ December 2011. The variable $Dec2011\_PTLR$ is equal to the bank's December 2011 leverage ratio if the date is after December 2011 and zero otherwise (PTLR stands for "pre-treatment leverage ratio"). Again this results in a difference-in-differences specification, but in this case the treatment variable is continuous rather than binary. We include this version because a bank's adjustment to the regulatory leverage ratio may have depended on how far it was from the proposed minimum. In addition, banks typically maintain buffers over regulatory minima, meaning that even banks with leverage ratios above 3% in December 2011 may have attempted to increase their leverage ratios further. This regression specification is broadly similar to those used in Allahrakha et al. (2018).

In the third version, we allow the treatment date to differ across banks. We define $Treatment_{i,t}$ as:

$$Treatment_{i,t} = \delta_1 Treated_{i,t} - \delta_2 PTLR_{i,t}, \tag{5}$$

where:

$$Treated_{i,t} = \begin{cases} 1 & \text{if } t > s_i, \\ 0 & \text{otherwise,} \end{cases}$$

and

$$PTLR_{i,t} = \begin{cases} LR_{i,s_i} - \overline{LR_{i,s_i}} & \text{if } t > s_i, \\ 0 & \text{otherwise,} \end{cases}$$

where:

$$s_i = \begin{cases} \text{December 2011} & \text{if } i \in LargeUK, \\ \text{June 2012} & \text{if } i \in SubsidiaryUS, \\ \text{January 2014} & \text{if } i \in OtherUK, \end{cases}$$

and $\overline{LR_{i,s_i}}$ is the average leverage ratio across banks in the same group as i ($LargeUK$, $SubsidiaryUS$ or $OtherUK$) at date s_i. In words, $Treated$ is an indicator variable equal to one for a given bank after its treatment date (s_i) and zero otherwise. δ_1 therefore measures the average post-treatment change in the liquidity provision of treated banks, relative to banks not yet treated. And $PTLR$ is the bank's leverage ratio at the time of treatment, minus the mean leverage ratio across all banks in its group. δ_2 therefore identifies how changes in the liquidity provision of treated banks are associated with deviations from the within-group average leverage ratio at the time of treatment.

In the fourth version, we define $Treatment_{i,t}$ as:

$$Treatment_{i,t} = \delta Jan2016\_Treated_{i,t}, \tag{6}$$

where:

$$Jan2016\_Treated_{i,t} = \begin{cases} 1 & \text{if } i \in LargeUK \text{ and } t > \text{January 2016}, \\ 0 & \text{otherwise.} \end{cases}$$

This results in a simple difference-in-differences regression, where the treatment group is the set of large U.K. banks that became subject to a formal minimum regulatory leverage ratio requirement in January 2016.

Each of the variables used in $Treatment_{i,t}$ is defined such that, for the regressions with gilt volumes or repo volumes as the dependent variable, a *negative* coefficient suggests that the leverage ratio led to reduced liquidity provision (because treated banks, or those with lower leverage ratios, reduced volumes relative to other banks); while for the regressions with round-trip cost as the dependent variable, a *positive* coefficient suggests that the leverage ratio led to reduced liquidity provision (because treated banks, or those with lower leverage ratios, increased their bid-ask spreads relative to other banks).

The first three versions of $Treatment_{i,t}$ relate to the adjustment period during which leverage ratio requirements were announced but before they became formally binding. For these regressions, we use the 2008:Q1 - 2015:Q4 sample period, which ends just before the leverage ratio requirement for large U.K. banks became binding. The fourth version of $Treatment_{i,t}$ relates to the formal introduction of a minimum leverage ratio requirement for large U.K. banks. For these regressions, we use the 2014:Q1 - 2017:Q4 sample period, which includes two years of data either side of the treatment date. These choices of sample period ensure that banks are not treated multiple times within a single regression.

The definition of dealers' leverage ratios differs across specifications due to data availability. For most dealers in the sample, Basel-consistent leverage ratios are unavailable in December 2011. So for the first and second regression specifications, we use the simple leverage ratio (Tier 1 capital divided by total assets), calculated from regulatory data at the individual entity level. Acosta-Smith et al. (2018) show that the simple leverage is highly correlated with the Basel regulatory definition. For the third specification, we are able to use regulatory leverage ratios. For $LargeUK$ banks, we use Basel-consistent leverage ratios at the group level, as reported in their Quantitative Impact Study (QIS) submissions for 2011:Q4. For banks in the $OtherUK$ group, we use regulatory leverage ratios at the U.K.-group level reported through COREP for 2014:Q1. For the $SubsidiaryUS$ group, we use the Basel-consistent leverage ratio estimates computed by Allahrakha et al. (2018). These are based on Form Y-9C filings for 2012:Q2 and are calculated at the BHC level.

8.2 Dealer-level regression results

The regression results are shown in Table 10 for gilts and Table 11 for repos.

We first consider the results for the first version of $Treatment_{i,t}$. Columns (1) and (6) of Table 10 and column (1) of Table 11 show the results when we include dealer and time fixed effects but no other control variables. The results for this simple difference-in-differences specification are also represented graphically in Figures 13, 14, and 15. The figures show the evolution of dealer-level liquidity provision between 2009 and 2015, distinguishing between banks with leverage ratios above and below 3% as of December 2011. For all measures of liquidity provision, the sign of the estimated effect is consistent with a causal role for the leverage ratio in the reduction in liquidity: relative to the control group, dealers with leverage ratios below 3% increased their average bid-ask spreads on gilt transactions by around 0.9 bps, reduced their gilt trading volumes with clients by around 14%, and reduced their repo borrowing by around 65%. However, in each case the estimated coefficient is statistically insignificant.

Columns (2) and (7) of Table 10 and column (2) of Table 11 again show results for the first definition of $Treatment_{i,t}$, but also include additional country-level and dealer-level controls. In each case, the added control variables lead to a reduction in the estimated effect, and in the case of dealer-to-client gilt volumes, the effect changes sign. The estimated coefficients remain statistically insignificant.

The results for the second version of $Treatment_{i,t}$ are shown in columns (3) and (8) of Table 10 and column (3) of Table 11. The results for the third version of $Treatment_{i,t}$ are shown in columns (4) and (9) of Table 10 and column (4) of Table 11. Finally, the results for the fourth version of $Treatment_{i,t}$ are shown in columns (5) and (10) of Table 10 and column (5) of Table 11. If the leverage ratio caused the reduction in liquidity, we would expect to see positive coefficients in the regressions with gilt round-trip cost as the dependent variable, and negative coefficients in the regressions with gilt volumes or repo volumes as the dependent variable. But these patterns are not observed: the signs of the estimated coefficients vary across specifications (some are consistent with a causal role for the leverage ratio, while others are not), and few of the estimated coefficients are statistically significant.

In summary, the dealer-level analysis does not provide convincing evidence of a causal link between the leverage ratio and the reduction in gilt and repo liquidity. Dealers with leverage ratios below 3% at the time of the first U.K. leverage ratio policy announcement did reduce their liquidity provision relative to the control group over the adjustment period. But this result is not statistically significant, and is robust neither to the inclusion of control variables nor to alternative regression specifications.

9 Conclusion

In this paper, we assess the impact of the leverage ratio — a key component of the Basel III package of post-crisis regulatory reform — on the liquidity of the gilt and gilt repo markets in the U.K.

High-level trends in these markets are indicative of reductions in liquidity during the period when U.K. leverage ratio policy was introduced. Over 2012-2016, we find that there were falls in gilt turnover ratios, gilt repo trading volumes, and the average gilt repo trade size. These patterns are consistent with market participants reducing their activity and breaking up trades in response to higher costs. But they are not definitive evidence of reduced liquidity because they might reflect other trends, such as structural changes in the investor base.

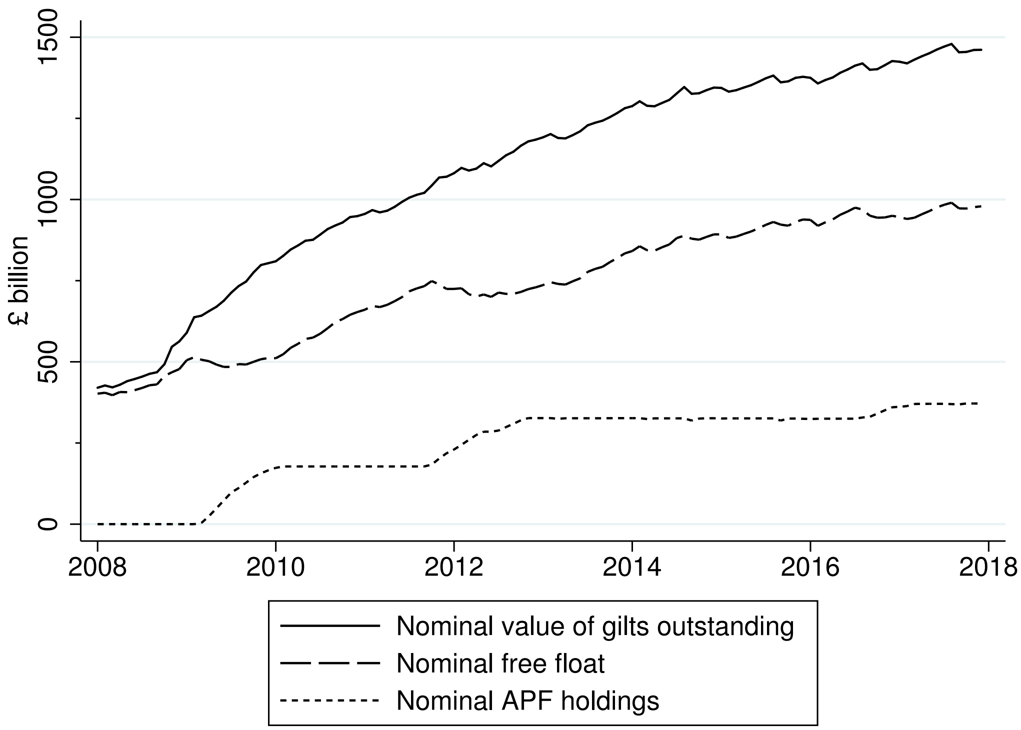
We therefore compute several more direct measures of liquidity from transaction-level data, and use principal components analysis to combine these into two liquidity indices: one for the gilt market and one for the gilt repo market. Time series regressions using these liquidity indices suggest that gilt repo liquidity indeed worsened during the period when leverage ratio policy was introduced, and that gilt liquidity worsened conditional on factors such as funding costs and inventory risk. This suggests that, were funding conditions to become less benign or interest rate volatility to increase, gilt liquidity could fall to lower levels than previously would have been the case. For both markets, the timing of the reduction in liquidity shown in the regression results is consistent with results from structural break tests.

We also find evidence that the resilience of liquidity deteriorated during the period when leverage ratio policy was introduced, particularly in the gilt repo market. First, quantile regression results suggest that the conditional reduction in liquidity has been larger in times of poor liquidity than in times of median liquidity, although this difference is not always statistically significant. Second, the frequency of sudden reductions ("jumps") in gilt repo liquidity has increased, although we do not observe this trend in the gilt market.

While the market-level analysis indicates that liquidity in these markets reduced, and potentially became less resilient, during the period when U.K. leverage ratio policy was introduced, evidence on whether the regulatory leverage ratio *caused* these changes is inconclusive. In the gilt repo market, the market-level regression results show that the deterioration in liquidity has been particularly pronounced on regulatory reporting dates, when we would expect dealer behavior to be especially sensitive to regulatory constraints [and consistent with the results in Munyan (2015) for the U.S. tri-party repo market]. This provides preliminary evidence of a causal role for the leverage ratio in the reduction in repo liquidity. Such a pattern is not, however, observed in the gilt market. We also use heterogeneity in dealer-level liquidity provision to identify any causal role for the leverage ratio. The evidence here is again inconclusive. In both the gilt and gilt repo markets, dealers with leverage ratios below 3% at the time of the first U.K. leverage ratio policy announcement in 2011 did reduce their liquidity provision relative to control dealers, consistent with a causal role for the leverage ratio. But this result is not statistically significant, and is robust neither to the inclusion of control variables nor to alternative regression specifications.

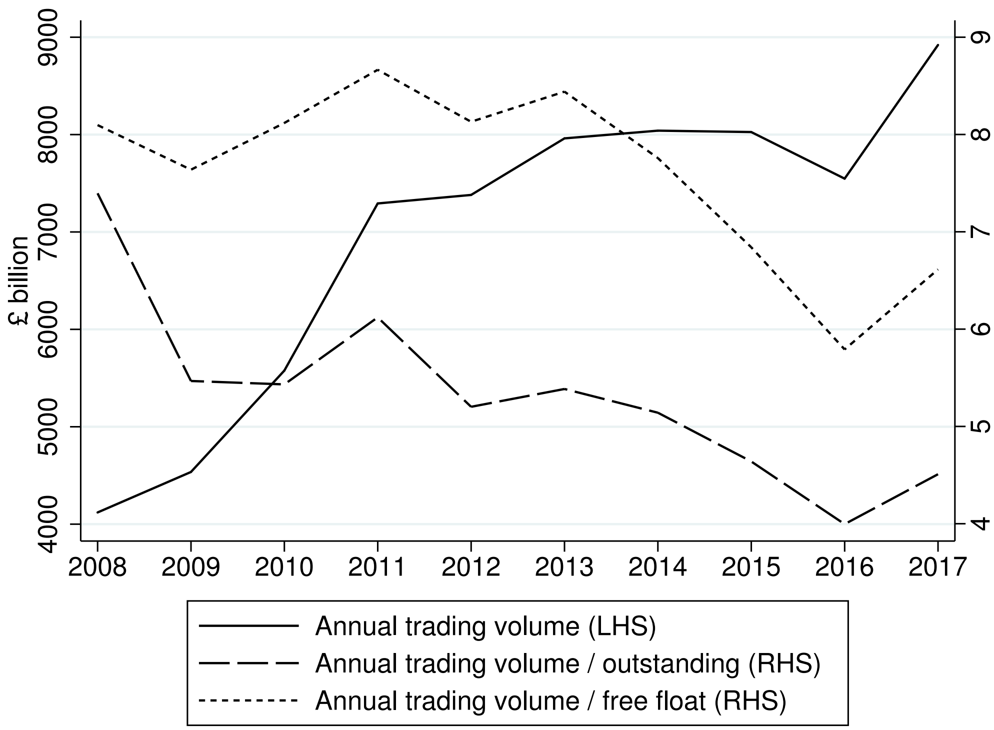
In summary, while a reduction in market liquidity appears to have occurred alongside the introduction of leverage ratio regulation in the U.K., the evidence on a causal connection is inconclusive. We do not attempt to quantify the benefits of the leverage ratio. By leading to an increase in the capitalization of banks, the leverage ratio is likely to have increased their resilience to shocks. Assessing the overall impact of the leverage ratio on financial stability and welfare is beyond the scope of this paper, but is likely to be an important area for future research.

Figure 1: Nominal value of gilts outstanding



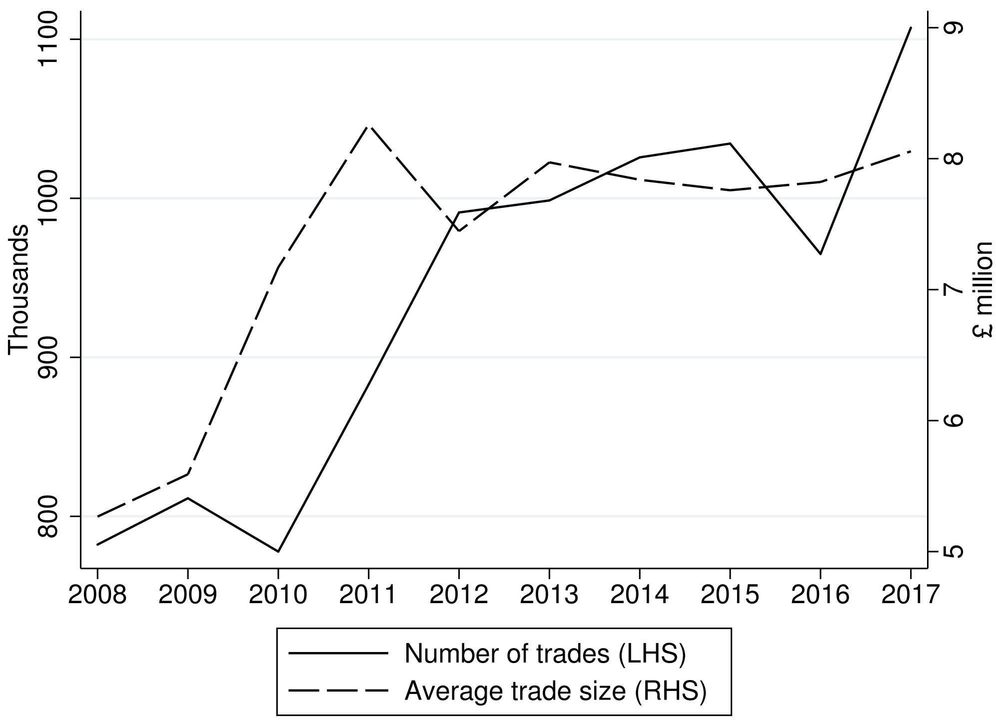
Notes: The solid line shows the nominal value of gilts outstanding. The dotted line shows the nominal value of gilts held by the Asset Purchase Facility (APF) under the Bank of England's quantitative easing (QE) program. The dashed line shows the nominal free float, defined as the value of gilts outstanding minus government holdings, APF holdings and other Bank of England holdings. Monthly averages.
Sources: U.K. Debt Management Office, Bank of England.

Figure 2: Gilt trading volume and turnover ratios



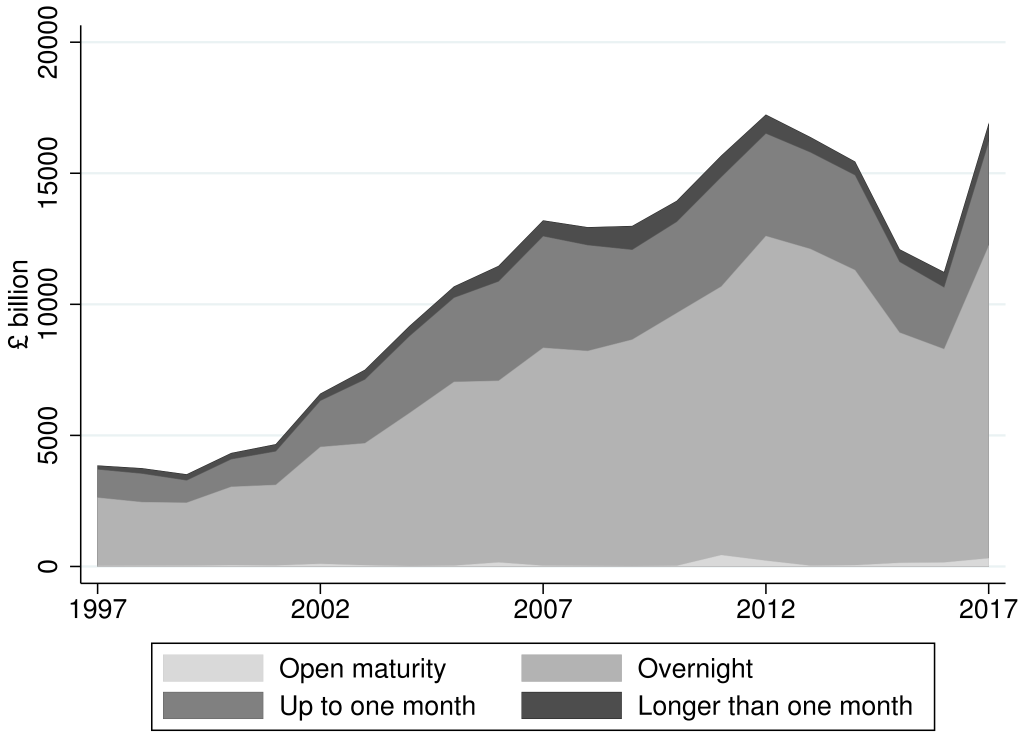
Notes: The solid line shows the annual sum of gilt trading volumes (market value). The dashed and dotted lines show annual gilt trading volume divided by the market value of gilts outstanding and the market value of free float, respectively, to give annual turnover ratios. Annual frequency.
Sources: Zen dataset, U.K. Debt Management Office, Bank of England.

Figure 3: Number of gilt trades and average trade size



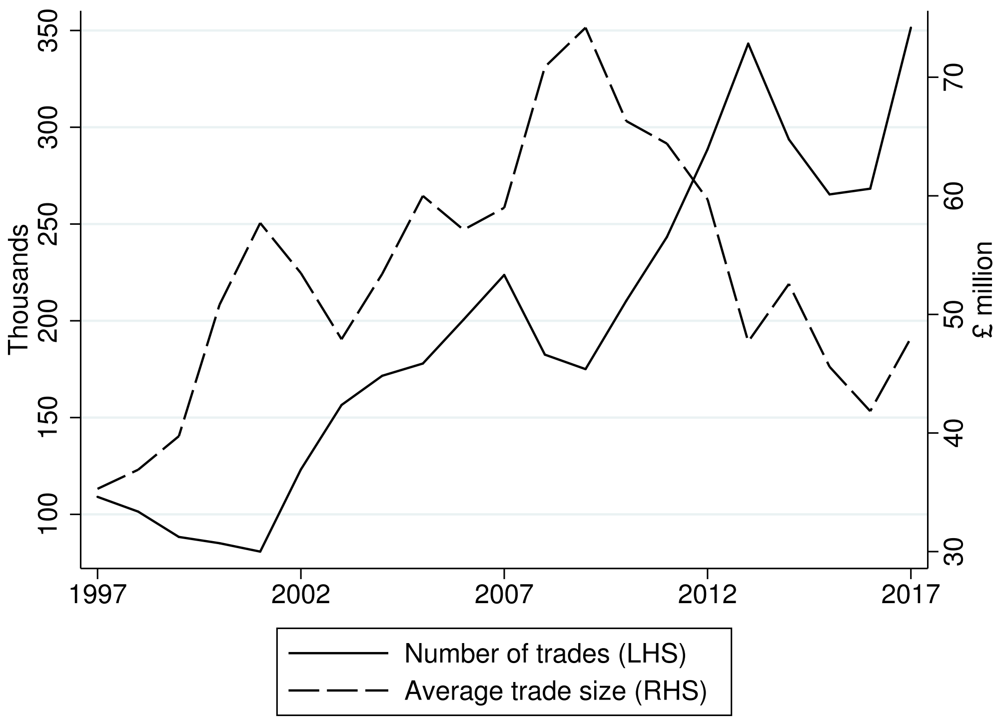
Notes: The solid line shows the total number of gilt trades per year. The dashed line shows the market value of the average trade. Annual frequency.
Source: Zen dataset.

Figure 4: Gilt repo trading volume



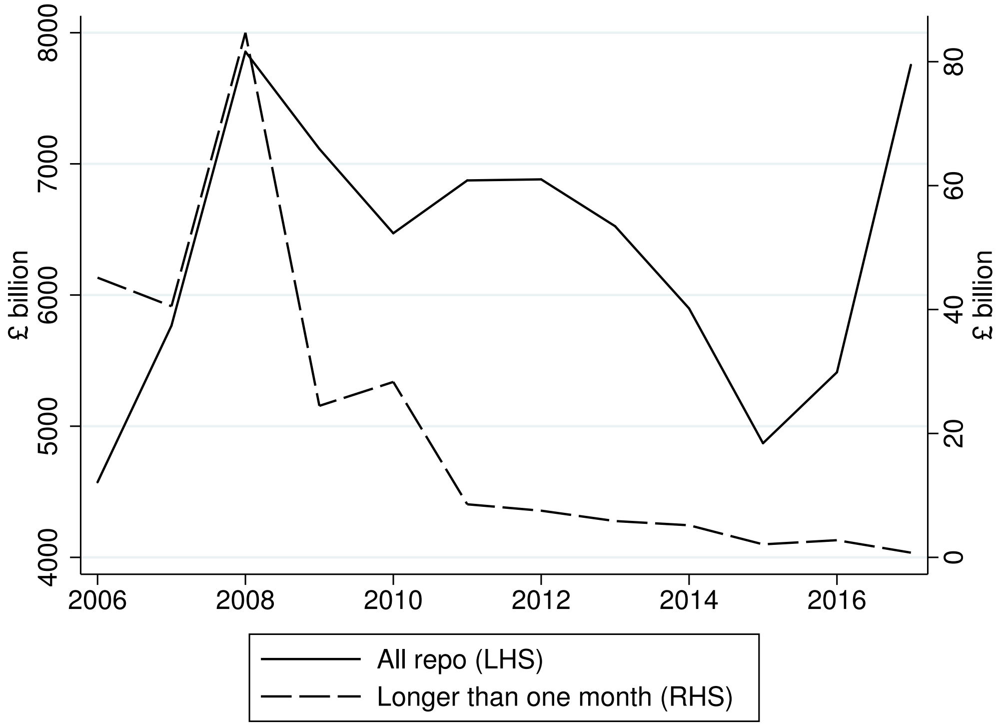
Notes: The chart shows the annual sum of gilt repo trading volumes, by maturity at trade date. Annual frequency.
Source: Form RSL.

Figure 5: Number of gilt repo trades and average trade size



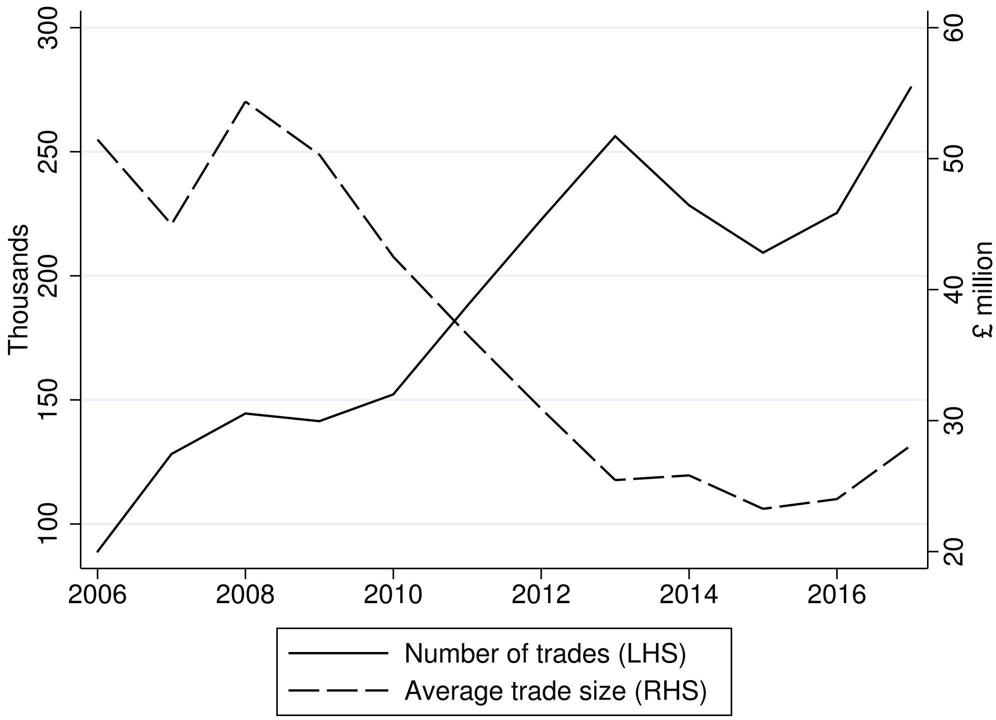
Notes: The solid line shows the total number of gilt repo trades per year. The dashed line shows the value of the average trade. Annual frequency.
Source: Form RSL.

Figure 6: Interdealer gilt repo trading volume



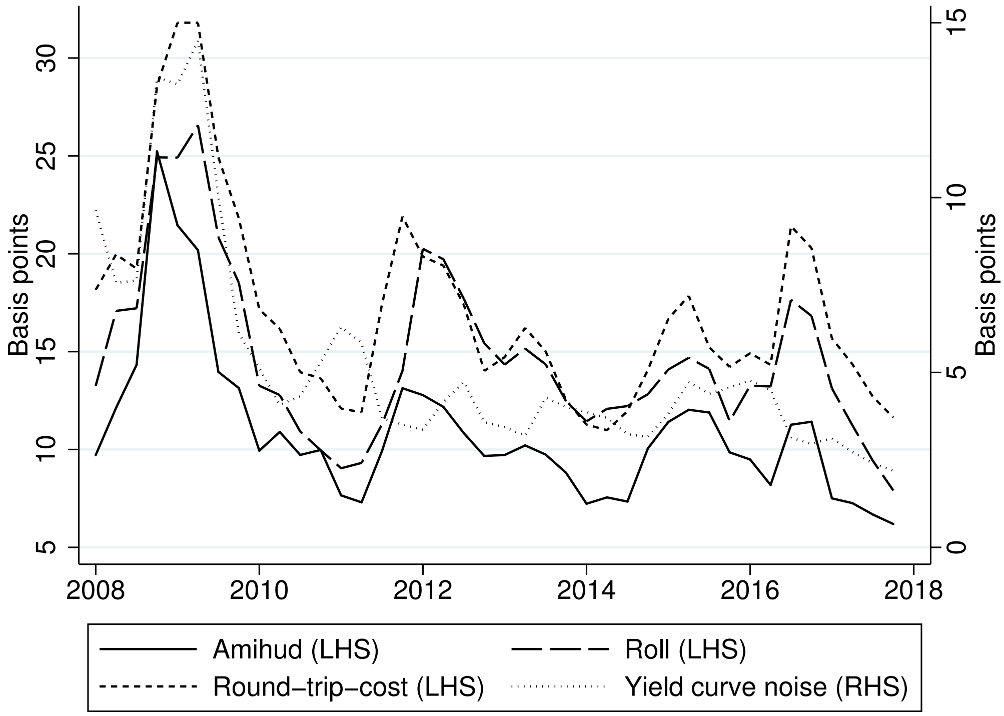
Notes: The chart shows the annual sum of gilt repo trading volumes transacted through BrokerTec. Annual frequency.
Source: BrokerTec.

Figure 7: Number of interdealer gilt repo trades and average trade size



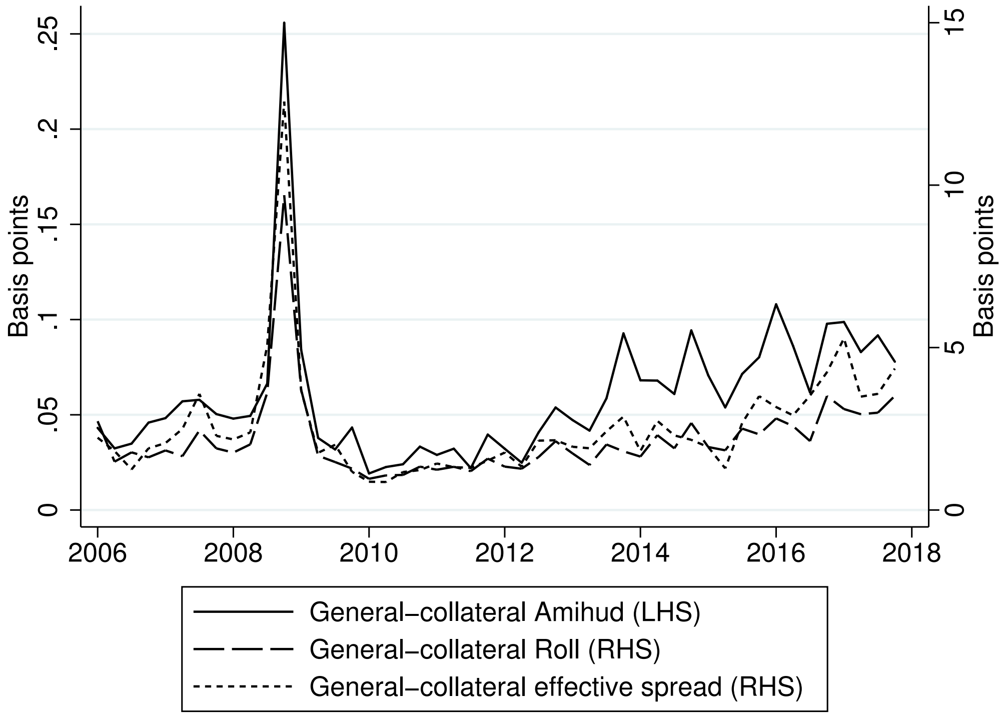
Notes: The solid line shows the total number of gilt repo trades transacted through BrokerTec per year. The dashed line shows the value of the average trade. Annual frequency.
Source: BrokerTec.

Figure 8: Gilt liquidity measures



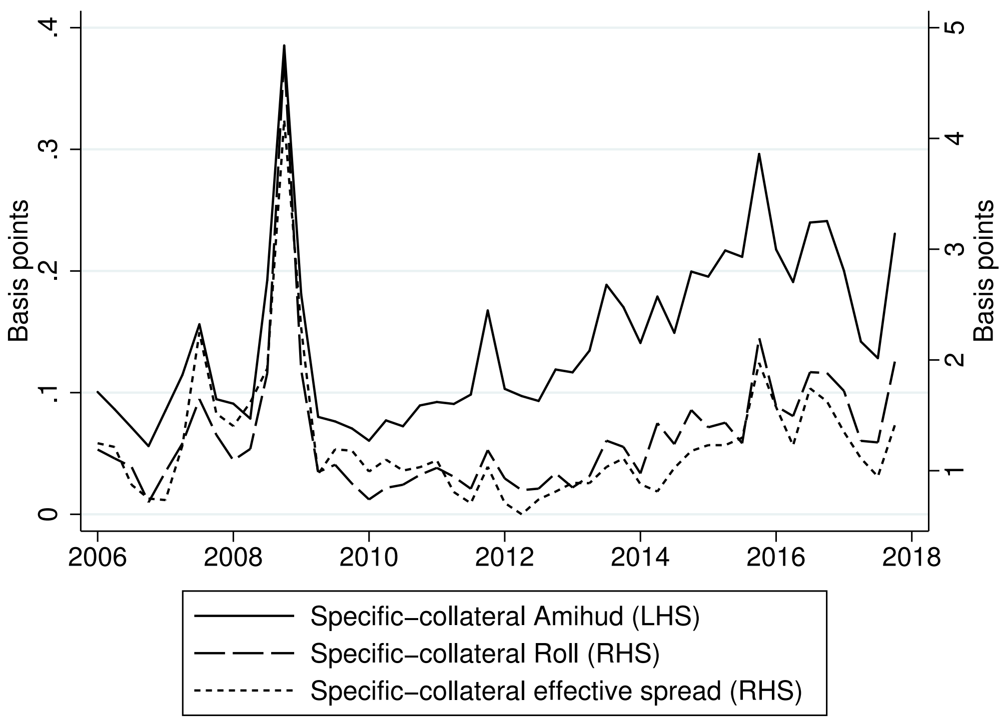
Notes: The chart shows liquidity measures for the gilt market, as defined in Subsection 5.1. Higher values indicate worse liquidity. The units of Amihud, Roll, and round-trip cost are basis points in price space. These measures are constructed at the level of individual gilts, and we show the median across gilts. The units of yield curve noise are basis points in yield space. Quarterly averages.
Sources: Zen dataset, Bank of England, Bloomberg.

Figure 9: General collateral repo liquidity measures



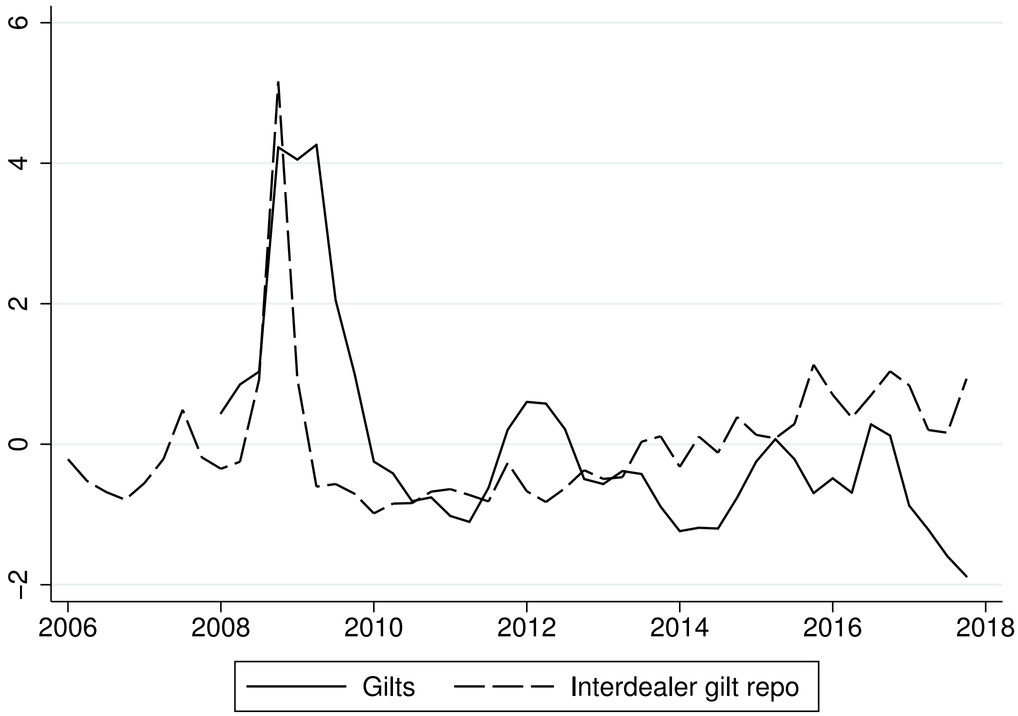
Notes: The chart shows liquidity measures for the general collateral interdealer gilt repo market, as defined in Subsection 5.2. Higher values indicate worse liquidity. For all measures, the units are basis points in repo rate space. The measures are constructed using overnight trades only. Quarterly averages.
Source: BrokerTec.

Figure 10: Specific collateral repo liquidity measures



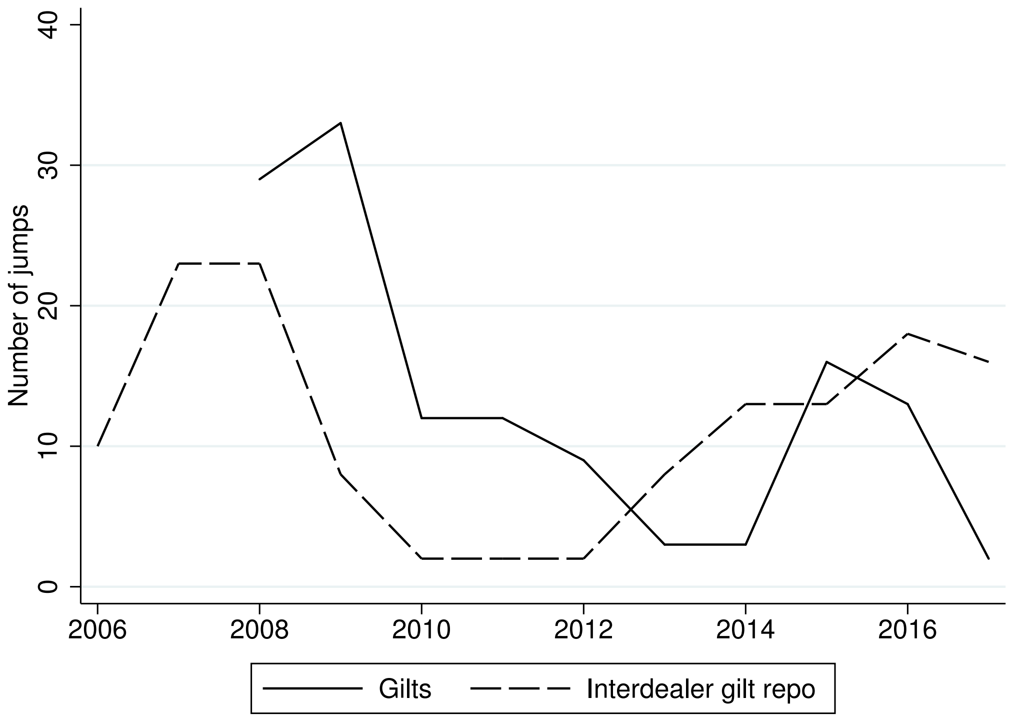
Notes: The chart shows liquidity measures for the specific collateral interdealer gilt repo market, as defined in Subection 5.2. Higher values indicate worse liquidity. For all measures, the units are basis points in repo rate space. The measures are constructed using overnight trades only. The measures are constructed at the level of the underlying security, and we show the median across securities. Quarterly averages.
Source: BrokerTec.

Figure 11: First principal component of liquidity measures



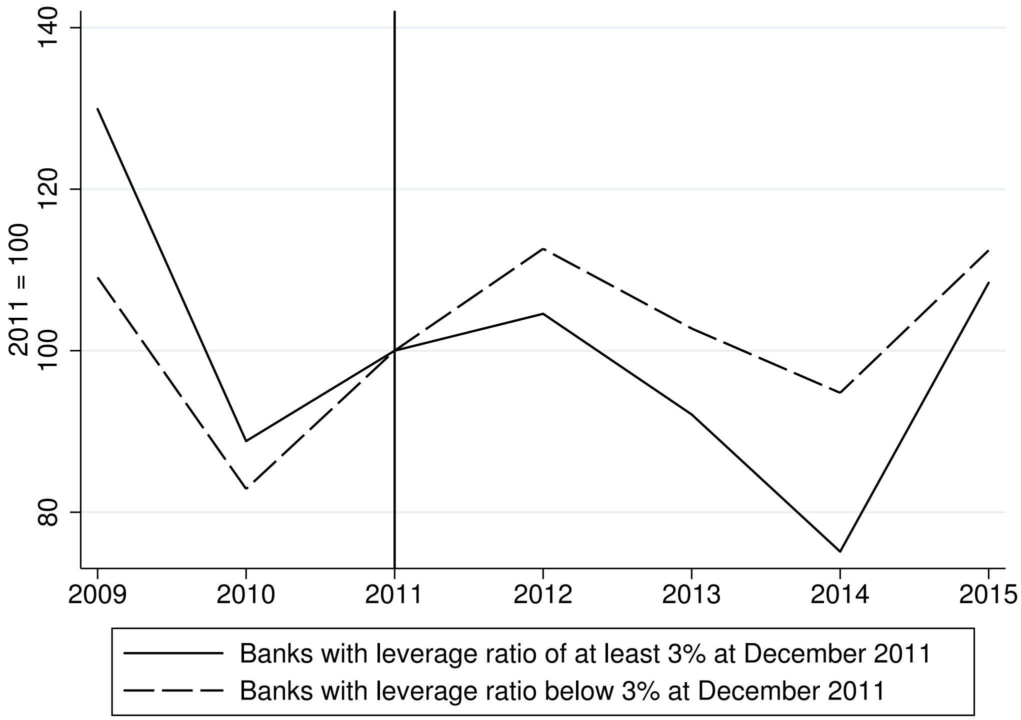
Notes: The chart shows the first principal component of the four gilt liquidity measures in Figure 8 and of the six gilt repo liquidity measures in Figures 9 and 10. The individual liquidity measures are standardized prior to the principal components analysis. Higher values indicate worse liquidity. Quarterly averages.
Sources: Zen dataset, Bank of England, Bloomberg, BrokerTec.

Figure 12: Jumps in liquidity measures



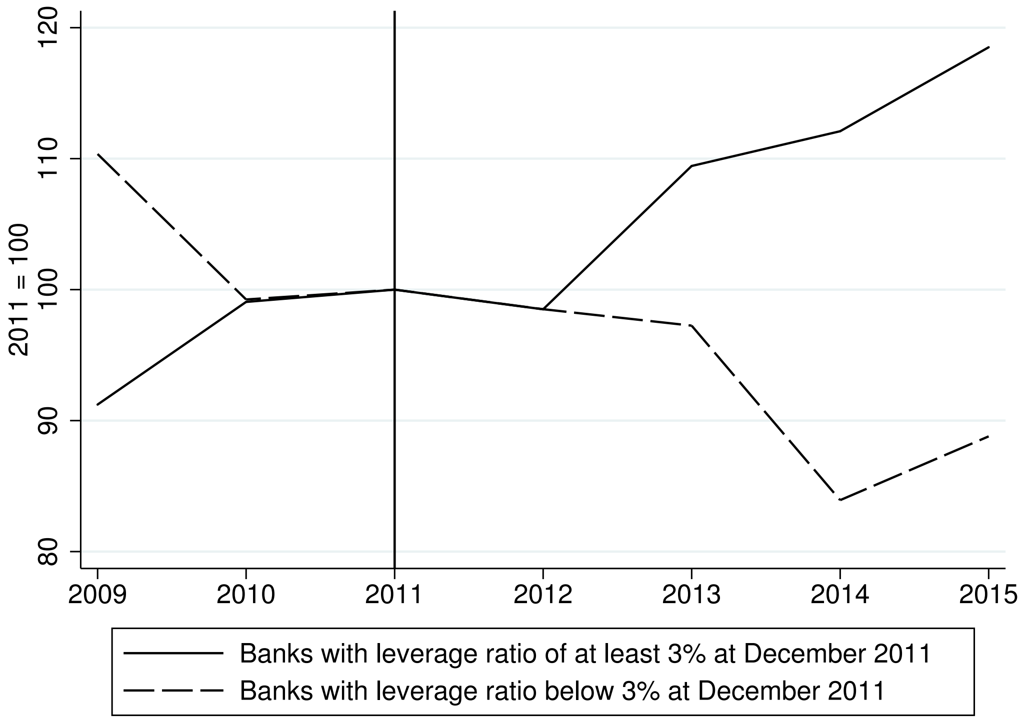
Notes: The chart shows annual sums of the number of upward jumps in the first principal component of the liquidity measures, where a jump is defined to be a one-day increase in the principal component that is at least as large as the standard deviation of the (level of the) principal component over the full sample period. Annual frequency.
Sources: Zen dataset, Bank of England, Bloomberg, BrokerTec.

Figure 13: Gilt round-trip cost, by dealer type



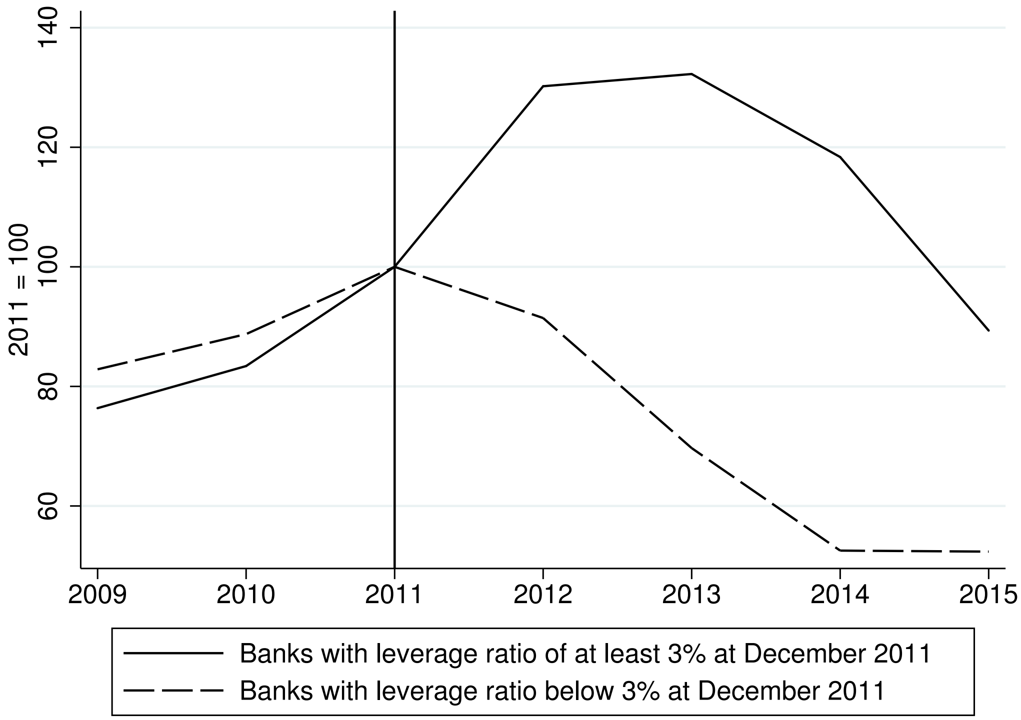
Notes: The chart shows average round-trip cost by dealer type, indexed to 2011. The sample consists of 12 banks (only banks that were GEMMs throughout the sample period are included). Annual frequency.
Source: Zen dataset.

Figure 14: Dealer-to-client volume in the gilt market, by dealer type



Notes: The chart shows average dealer-to-client volume by dealer type, indexed to 2011. The sample consists of 12 banks (only banks that were GEMMs throughout the sample period are included). Annual frequency.
Source: Zen dataset.

Figure 15: Borrowing in the gilt repo market, by dealer type



Notes: The chart shows average borrowing in the gilt repo market, indexed to 2011. The sample consists of 17 banks (only banks that reported Form RSL throughout the sample period are included). Annual frequency.
Source: Form RSL.

Table 1: Leverage ratio timeline

Date	Jurisdiction	Summary
December 16, 2010	BCBS	BCBS proposes a 3% regulatory leverage ratio (disclosure from 2015, minimum requirement from 2018).
December 6, 2011	U.K.	FPC recommends that FSA encourage banks to disclose their leverage ratios not later than the beginning of 2013; FSA implements this by asking large U.K. banks to publish their leverage ratios in their 2012 annual reports and on a bi-annual basis thereafter.
June 7, 2012	U.S.	Proposed rule on new capital framework for large U.S. banks, including draft supplementary leverage ratio.
June 20, 2013	U.K.	Results of capital shortfall exercise published; large U.K. banks with a CET1 leverage ratio below 3% required to submit plans to reach this level.
July 2, 2013	U.S.	Final rule on supplementary leverage ratio (full implementation from 2018), and proposal on enhanced supplementary leverage ratio.
November 29, 2013	U.K.	PRA issues supervisory expectation that eight major U.K. banks and building societies meet a 3% leverage ratio by January 2014.
March 1, 2014	EU	PRA-regulated firms start to report regulatory leverage ratios through COREP on the basis of month-end balance sheets.
April 8, 2014	U.S.	Final rule on enhanced supplementary leverage ratio (full implementation from 2018).
July 11, 2014	U.K.	FPC consultation paper on the design of the U.K. leverage ratio framework; FPC considers applying the framework to all PRA-regulated firms.
October 31, 2014	U.K.	FPC review of the leverage ratio framework published; review recommends that the framework apply only to major U.K. banks and building societies.
July 10, 2015	U.K.	PRA consultation paper on implementing the U.K. leverage ratio framework.
December 1, 2015	U.K.	PRA publishes finalised U.K. leverage ratio framework.
January 1, 2016	U.K.	Large U.K. banks and building societies become subject to a formal minimum regulatory leverage ratio requirement.
January 1, 2018	EU	All PRA-regulated firms become subject to a 3% minimum leverage ratio under CRD IV.

Notes: The table describes key dates in the development of U.K. leverage ratio policy, and selected dates in the development of global, U.S. and European Union leverage ratio policy.

Table 2: Gilt liquidity measures: annual averages and PCA factor loadings

Liquidity measure	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Loading
Amihud	15.4	17.1	10.1	9.5	11.4	9.6	8.1	11.3	10.1	6.9	0.52
Roll	18.2	22.6	11.7	10.9	18.3	14.1	12.1	13.6	15.3	10.4	0.53
Round-trip cost	21.5	27.5	15.2	15.9	17.6	14.6	12.1	16.0	17.8	13.6	0.51
Yield curve noise	9.6	10.9	4.7	4.8	4.0	3.7	3.5	4.4	3.8	2.6	0.44

Notes: The table shows annual averages of the estimated liquidity measures for the gilt market. Higher values indicate worse liquidity. The units of Amihud, Roll, and round-trip cost are basis points in price space. These measures are constructed at the level of individual gilts, and we show the median across gilts. The units of yield curve noise are basis points in yield space. The last column shows the factor loadings of the measures in the first principal component.
Sources: Zen dataset, Bank of England, Bloomberg.

Table 3: Repo liquidity measures: annual averages and PCA factor loadings

Liquidity measure	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Loading
GC Amihud	0.04	0.05	0.11	0.05	0.02	0.03	0.04	0.06	0.07	0.07	0.09	0.09	0.35
GC Roll	1.91	1.96	4.30	2.03	1.11	1.34	1.59	1.74	2.13	2.16	2.75	3.15	0.39
GC effective spread	1.80	2.61	5.59	2.15	1.04	1.39	1.85	2.29	2.25	2.36	3.46	4.20	0.40
SC Amihud	0.08	0.11	0.19	0.10	0.07	0.11	0.10	0.15	0.17	0.23	0.22	0.18	0.49
SC Roll	1.01	1.30	2.24	1.21	0.86	1.00	0.89	1.08	1.30	1.57	1.71	1.57	0.47
SC effective spread	1.02	1.43	2.29	1.41	1.03	0.91	0.72	0.98	0.98	1.44	1.54	1.21	0.33

Notes: The table shows annual averages of the estimated liquidity measures for the inter-dealer gilt repo market. Higher values indicate worse liquidity. For all measures, the units are basis points in repo rate space. The measures are constructed using overnight trades only. The specific collateral measures are constructed at the level of the underlying security, and we show the median across securities. The last column shows the factor loadings of the measures in the first principal component.
Source: BrokerTec.

Table 4: Summary statistics

Variables	(1) N	(2) mean	(3) sd	(4) min	(5) p1	(6) p10	(7) p25	(8) p50	(9) p75	(10) p90	(11) p99	(12) max
Gilt liquidity (standard deviations)	2,008	-0.585	1.000	-2.892	-2.437	-1.681	-1.265	-0.724	-0.0555	0.711	2.526	4.369
Repo liquidity (standard deviations)	2,008	-0.0479	1.000	-1.029	-0.807	-0.617	-0.483	-0.245	0.0856	0.553	3.283	17.63
3m Libor-OIS spread (%)	2,008	0.188	0.135	-0.0186	-0.00430	0.0918	0.105	0.128	0.232	0.423	0.589	0.600
3m GC repo-OIS spread (%)	2,008	0.0474	0.0423	-0.0575	-0.0300	-0.00185	0.0210	0.0410	0.0700	0.108	0.167	0.214
VIX (%)	2,008	0.171	0.0587	0.0914	0.0963	0.115	0.131	0.156	0.191	0.246	0.378	0.458
FTSE 100 (% change)	2,008	0.0221	0.962	-4.667	-2.613	-1.088	-0.467	0.0404	0.539	1.086	2.705	5.161
10y gilt yield (%)	2,008	2.309	0.900	0.623	0.721	1.238	1.633	2.147	2.876	3.720	4.272	4.399
1m10y interest rate implied volatility (%)	2,008	0.766	0.157	0.437	0.476	0.569	0.658	0.758	0.859	0.957	1.224	1.282
U.K. sovereign 5y CDS premium (%)	2,008	0.432	0.232	0.146	0.160	0.189	0.212	0.367	0.619	0.791	0.970	1.049
3m Euro Libor-OIS spread (%)	2,008	0.159	0.191	-0.0545	-0.0249	-0.00114	0.0499	0.103	0.208	0.326	0.881	0.938
10y Italian bond spread (%)	2,008	2.042	1.039	0.693	0.803	1.099	1.336	1.621	2.600	3.676	4.973	5.507
Share of gilts held by ICPFs (%)	2,008	30.18	1.575	28.09	28.09	28.57	29.18	29.89	30.56	32.27	34.90	34.90
Free float (£bn, market value)	2,008	1,029	220.2	594.9	601.0	752.4	898.9	970.6	1,203	1,350	1,415	1,444
Gilt interdealer ratio (%)	2,008	40.78	7.017	7.881	24.05	31.99	36.17	40.78	45.56	49.55	56.93	66.59
APF purchase date indicator	2,008	0.137	0.344	0	0	0	0	0	0	1	1	1
DMO issuance date indicator	2,008	0.218	0.413	0	0	0	0	0	0	1	1	1

Notes: The table shows summary statistics for the variables used in the market-level regressions. The sample period is January 1, 2010 to December 31, 2017, at daily frequency.
Sources: Bloomberg, Bank of England, Zen dataset, BrokerTec, Form RSL, U.K. Debt Management Office, U.K. Office for National Statistics.

Table 5: Market-level gilt regressions (continued on next page)

Variables	(1) Gilt liquidity	(2) Gilt liquidity	(3) Gilt liquidity
2012 indicator	0.418***	0.635***	0.559***
	(0.111)	(0.0967)	(0.0897)
2013 indicator	0.0239	0.525***	0.429***
	(0.0713)	(0.103)	(0.0996)
2014 indicator	-0.205***	0.304***	0.244**
	(0.0673)	(0.0856)	(0.0963)
2015 indicator	0.189**	0.553***	0.618***
	(0.0900)	(0.132)	(0.116)
2016 indicator	0.226**	0.516***	0.681***
	(0.105)	(0.146)	(0.127)
2017 indicator	-0.359***	0.296**	0.258**
	(0.0919)	(0.117)	(0.115)
Month-end indicator	0.443*	0.429*	0.439*
	(0.235)	(0.245)	(0.235)
Month-end and 2014-2017 indicator	-0.445*	-0.490*	-0.441*
	(0.252)	(0.264)	(0.255)
Quarter-end indicator	0.339	0.283	0.305
	(0.258)	(0.248)	(0.230)
Quarter-end and 2012-2017 indicator	-0.645***	-0.683***	-0.595***
	(0.190)	(0.183)	(0.168)
Repo liquidity (standard deviations)		0.0591**	
		(0.0265)	
3m Libor-OIS spread (%)		1.564***	1.194***
		(0.272)	(0.301)
3m GC repo-OIS spread (%)		2.694***	
		(0.869)	
VIX (%)		0.298	
		(0.570)	
FTSE 100 (% change)		-0.00880	
		(0.0226)	
Change in 10y gilt yield (%)		0.809**	
		(0.351)	
1m10y interest rate implied volatility (%)		0.896***	0.926***
		(0.259)	(0.240)
Change in U.K. sovereign 5y CDS premium (%)		2.132	

Table 5: Market-level gilt regressions (continued)

		(1.457)	
Change in 3m Euro Libor-OIS spread (%)		-0.106	
		(1.312)	
Change in 10y Italian bond spread (%)		-0.487**	
		(0.229)	
Change in share of gilts held by ICPFs (%)		-0.0716	
		(0.0475)	
Change in free float (£bn, market value)		0.00372	
		(0.00413)	
Gilt interdealer ratio (%)		-0.0131***	-0.0143***
		(0.00478)	(0.00483)
APF purchase date indicator		-0.0577	
		(0.0520)	
DMO issuance date indicator		-0.0746*	
		(0.0414)	
Constant	-0.316***	-1.337***	-1.065***
	(0.0649)	(0.290)	(0.289)
Observations	2,008	2,008	2,008
R^2	0.380	0.421	0.408
Quarter-end fixed effects	YES	YES	YES
Number of lags of dependent variable	3	3	3
Wald statistic for null hypothesis	52.55***	62.91***	71.43***
that year indicators are jointly zero	(0.00)	(0.00)	(0.00)

Notes: The table shows the results of time series regressions of liquidity in the gilt market. The regression specification is given by equation (1). The regressions are at daily frequency and the sample period is January 1, 2010 to December 31, 2017. Higher values of the dependent variable indicate worse liquidity. Variables are defined in Subsection 6.1. All potentially endogenous regressors are lagged by one day. Quarter-end fixed effects are constrained to sum to zero. HAC standard errors are shown in parentheses. 'Wald statistic for null hypothesis that year indicators are jointly zero' shows the χ^2-statistic from the Wald test that the coefficients on the year indicator variables are all equal to zero, with p-values shown below. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 6: Market-level repo regressions (continued on next page)

Variables	(1) Repo liquidity	(2) Repo liquidity
2012 indicator	0.0300	0.0167
	(0.0404)	(0.0755)
2013 indicator	0.166***	0.217***
	(0.0585)	(0.0802)
2014 indicator	0.206***	0.247***
	(0.0726)	(0.0882)
2015 indicator	0.322***	0.346***
	(0.105)	(0.110)
2016 indicator	0.454***	0.453***
	(0.105)	(0.165)
2017 indicator	0.418***	0.471***
	(0.125)	(0.127)
Month-end indicator	0.526***	0.510***
	(0.164)	(0.162)
Month-end and 2014-2017 indicator	0.639***	0.665***
	(0.229)	(0.227)
Quarter-end indicator	0.372**	0.395**
	(0.162)	(0.160)
Quarter-end and 2012-2017 indicator	2.367***	2.345***
	(0.183)	(0.186)
Gilt liquidity (standard deviations)		0.00299
		(0.0163)
3m Libor-OIS spread (%)		0.231
		(0.313)
3m GC repo-OIS spread (%)		0.561
		(1.317)
VIX (%)		-0.237
		(0.280)
FTSE 100 (% change)		0.0190
		(0.0209)
Change in 10y gilt yield (%)		-0.656
		(0.433)
1m10y interest rate implied volatility (%)		0.0319
		(0.187)
Change in U.K. sovereign 5y CDS premium (%)		0.179

Table 6: Market-level repo regressions (continued)

		(0.526)
Change in 3m Euro Libor-OIS spread (%)		0.0102
		(0.468)
Change in 10y Italian bond spread (%)		0.0851
		(0.114)
Change in share of gilts held by ICPFs (%)		-0.0244
		(0.0329)
Change in free float (£bn, market value)		-0.000471
		(0.00271)
APF purchase date indicator		-0.00150
		(0.0368)
DMO issuance date indicator		-0.0171
		(0.0257)
Constant	-0.295***	-0.370**
	(0.0510)	(0.154)
Observations	2,006	2,006
R^2	0.616	0.618
Quarter-end fixed effects	YES	YES
Number of lags of dependent variable	23	23
Wald statistic for null hypothesis	26.19***	20.05***
that year indicators are jointly zero	(0.00)	(0.00)

Notes: The table shows the results of time series regressions of liquidity in the gilt repo market. The regression specification is given by equation (1). The regressions are at daily frequency and the sample period is January 1, 2010 to December 31, 2017. Higher values of the dependent variable indicate worse liquidity. Variables are defined in Subsection 6.1. All potentially endogenous regressors are lagged by one day. Quarter-end fixed effects are constrained to sum to zero. HAC standard errors are shown in parentheses. 'Wald statistic for null hypothesis that year indicators are jointly zero' shows the χ^2-statistic from the Wald test that the coefficients on the year indicator variables are all equal to zero, with p-values shown below. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 7: Gilt quantile regressions (continued on next page)

Variables	(1) Gilt liquidity 0.5 quantile	(2) Gilt liquidity 0.9 quantile	(3) Gilt liquidity Difference
2012 indicator	0.560***	0.624***	0.0637
	(0.114)	(0.194)	(0.195)
2013 indicator	0.502***	0.703***	0.201
	(0.109)	(0.207)	(0.203)
2014 indicator	0.262***	0.282	0.0193
	(0.0967)	(0.192)	(0.189)
2015 indicator	0.457***	0.930***	0.473*
	(0.113)	(0.274)	(0.262)
2016 indicator	0.477***	1.023***	0.547*
	(0.133)	(0.339)	(0.327)
2017 indicator	0.252*	0.443*	0.192
	(0.129)	(0.262)	(0.254)
Month-end indicator	0.114	0.165	0.0511
	(0.217)	(1.023)	(0.992)
Month-end and 2014-2017 indicator	-0.0835	-0.293	-0.210
	(0.278)	(1.027)	(1.011)
Quarter-end indicator	0.730	0.369	-0.361
	(0.474)	(1.064)	(1.089)
Quarter-end and 2012-2017 indicator	-0.886*	-0.774	0.112
	(0.522)	(1.079)	(1.131)
Repo liquidity (standard deviations)	0.0465	0.0344	-0.0121
	(0.0349)	(0.0552)	(0.0565)
3m Libor-OIS spread (%)	1.531***	1.709***	0.178
	(0.315)	(0.529)	(0.542)
3m GC repo-OIS spread (%)	2.725***	1.260	-1.465
	(0.872)	(1.648)	(1.603)
VIX (%)	-0.446	3.037**	3.483**
	(0.592)	(1.538)	(1.404)
FTSE 100 (% change)	-0.0194	0.0393	0.0587
	(0.0275)	(0.0657)	(0.0631)
Change in 10y gilt yield (%)	0.318	1.080	0.761
	(0.500)	(1.111)	(1.067)
1m10y interest rate implied volatility (%)	0.907***	0.818*	-0.0889
	(0.234)	(0.476)	(0.479)

Table 7: Gilt quantile regressions (continued)

Change in U.K. sovereign 5y CDS premium (%)	2.074	1.926	-0.148
	(1.438)	(3.431)	(3.161)
Change in 3m Euro Libor-OIS spread (%)	0.342	1.435	1.093
	(1.956)	(2.510)	(2.753)
Change in 10y Italian bond spread (%)	-0.666**	-0.325	0.341
	(0.301)	(0.771)	(0.722)
Change in share of gilts held by ICPFs (%)	-0.0774*	-0.0706	0.00683
	(0.0409)	(0.0781)	(0.0783)
Change in free float (£bn, market value)	0.00430	1.84e-05	-0.00428
	(0.00408)	(0.00626)	(0.00611)
Gilt interdealer ratio (%)	-0.0129***	-0.0125	0.000451
	(0.00465)	(0.00915)	(0.00930)
APF purchase date indicator	-0.0607	0.0735	0.134
	(0.0604)	(0.149)	(0.144)
DMO issuance date indicator	-0.0342	-0.212**	-0.177*
	(0.0456)	(0.0916)	(0.0906)
Constant	-1.304***	-0.844	0.460
	(0.280)	(0.563)	(0.559)
Observations	2,008	2,008	2,008
Pseudo-R^2	0.257	0.246	n/a
Quarter-end fixed effects	NO	NO	NO
Number of lags of dependent variable	3	3	3
Wald statistic for null hypothesis	7.40***	3.61***	0.84
that year indicators are jointly zero	(0.00)	(0.00)	(0.54)

Notes: The table shows the results of time series quantile regressions of liquidity in the gilt market. The regression specification is given by equation (1). The regressions are at daily frequency and the sample period is January 1, 2010 to December 31, 2017. Higher values of the dependent variable indicate worse liquidity. Variables are defined in Subsection 6.1. All potentially endogenous regressors are lagged by one day. Bootstrapped standard errors are shown in parentheses. Column (1) shows the results from the conditional median regression, column (2) shows the results from the conditional 0.9 quantile regression, and column (3) shows the estimated difference between the coefficients from the two regressions. 'Wald statistic for null hypothesis that year indicators are jointly zero' shows the F-statistic from the Wald test that the coefficients on the year indicator variables are all equal to zero, with p-values shown below. In column (3), the null hypothesis is that the coefficients from the 0.9 quantile regression are equal to the coefficients from the median regression. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 8: Repo quantile regressions (continued on next page)

Variables	(1) Repo liquidity 0.5 quantile	(2) Repo liquidity 0.9 quantile	(3) Repo liquidity Difference
2012 indicator	0.000497	0.0456	0.0451
	(0.0277)	(0.0717)	(0.0696)
2013 indicator	0.0982***	0.114	0.0160
	(0.0315)	(0.0759)	(0.0726)
2014 indicator	0.122***	0.262***	0.140
	(0.0390)	(0.0908)	(0.0873)
2015 indicator	0.212***	0.0912	-0.120
	(0.0524)	(0.117)	(0.114)
2016 indicator	0.256***	0.293*	0.0372
	(0.0720)	(0.173)	(0.167)
2017 indicator	0.194***	0.510***	0.316**
	(0.0515)	(0.148)	(0.143)
Month-end indicator	0.192*	1.414**	1.222**
	(0.114)	(0.586)	(0.548)
Month-end and 2014-2017 indicator	1.053***	-0.138	-1.191
	(0.235)	(0.794)	(0.752)
Quarter-end indicator	0.574	0.536	-0.0374
	(0.368)	(0.839)	(0.782)
Quarter-end and 2012-2017 indicator	0.887	3.684**	2.797*
	(0.819)	(1.538)	(1.466)
Gilt liquidity (standard deviations)	0.0103	-0.0238	-0.0341*
	(0.00812)	(0.0197)	(0.0187)
3m Libor-OIS spread (%)	0.0199	0.221	0.201
	(0.0935)	(0.253)	(0.241)
3m GC repo-OIS spread (%)	0.381	1.669*	1.288
	(0.409)	(0.930)	(0.905)
VIX (%)	-0.119	-0.0699	0.0496
	(0.167)	(0.333)	(0.327)
FTSE 100 (% change)	-0.00685	-0.0134	-0.00651
	(0.00827)	(0.0198)	(0.0190)
Change in 10y gilt yield (%)	-0.276	0.153	0.428
	(0.176)	(0.412)	(0.380)
1m10y interest rate implied volatility (%)	0.0561	0.118	0.0623
	(0.0714)	(0.166)	(0.156)

Table 8: Repo quantile regressions (continued)

Change in U.K. sovereign 5y CDS premium (%)	-0.149	0.290	0.439
	(0.432)	(0.863)	(0.836)
Change in 3m Euro Libor-OIS spread (%)	0.0160	-0.595	-0.611
	(0.351)	(0.596)	(0.635)
Change in 10y Italian bond spread (%)	-0.0208	0.119	0.140
	(0.0746)	(0.167)	(0.164)
Change in share of gilts held by ICPFs (%)	0.0255*	0.000764	-0.0248
	(0.0143)	(0.0302)	(0.0296)
Change in free float (£bn, market value)	-0.00116	-0.00123	-7.11e-05
	(0.00118)	(0.00293)	(0.00286)
APF purchase date indicator	0.0266	-0.00279	-0.0293
	(0.0240)	(0.0612)	(0.0598)
DMO issuance date indicator	0.0114	0.0184	0.00700
	(0.0171)	(0.0350)	(0.0341)
Constant	-0.321***	0.0190	0.340**
	(0.0717)	(0.165)	(0.154)
Observations	2,006	2,006	2,006
Pseudo-R^2	0.314	0.472	n/a
Quarter-end fixed effects	NO	NO	NO
Number of lags of dependent variable	23	23	23
Wald statistic for null hypothesis	3.64***	3.19***	2.55**
that year indicators are jointly zero	(0.00)	(0.00)	(0.02)

Notes: The table shows the results of time series quantile regressions of liquidity in the gilt repo market. The regression specification is given by equation (1). The regressions are at daily frequency and the sample period is January 1, 2010 to December 31, 2017. Higher values of the dependent variable indicate worse liquidity. Variables are defined in Subsection 6.1. All potentially endogenous regressors are lagged by one day. Bootstrapped standard errors are shown in parentheses. Column (1) shows the results from the conditional median regression, column (2) shows the results from the conditional 0.9 quantile regression, and column (3) shows the estimated difference between the coefficients from the two regressions. 'Wald statistic for null hypothesis that year indicators are jointly zero' shows the F-statistic from the Wald test that the coefficients on the year indicator variables are all equal to zero, with p-values shown below. In column (3), the null hypothesis is that the coefficients from the 0.9 quantile regression are equal to the coefficients from the median regression. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 9: Sizes and market shares of groups of dealers

	Gilt market		Gilt repo market	
	Number of dealers	Market share	Number of dealers	Market share
$LargeUK$	5	40%	7	60%
$SubsidiaryUS$	5	30%	4	23%
$OtherUK$	6	29%	8	18%

Notes: The table shows the size and market shares of different groups of dealers over the sample period 2008:Q1 to 2017:Q4. $LargeUK$ refers to the group of banks that were subject to the FSA's implementation of the FPC's December 2011 recommendation on disclosure, the PRA's November 2013 supervisory expectation that banks meet a 3% leverage ratio, and the formal introduction of the U.K.'s leverage ratio framework in January 2016. $SubsidiaryUS$ refers to U.K. subsidiaries of U.S. banks. $OtherUK$ refers to smaller U.K. banks and to the U.K. subsidiaries of (non-U.S.) foreign banks.

Table 10: Dealer-level panel regression results: gilt market

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Round-trip cost (basis points)					Log(Trading volume with clients)				
$Dec2011\_Constrained$	0.897	0.388				-0.139	0.0510			
	(2.107)	(1.309)				(0.235)	(0.0668)			
$-Dec2011\_PTLR$			-0.351					0.0415*		
			(0.272)					(0.0228)		
$Treated$				-1.576**					0.167**	
				(0.718)					(0.0620)	
$-PTLR$				0.112					-0.0392	
				(0.536)					(0.0365)	
$Jan2016\_Treated$					-0.752					0.0443
					(1.750)					(0.104)
Observations	458	420	420	420	240	458	420	420	420	242
R^2	0.459	0.565	0.570	0.569	0.564	0.722	0.921	0.923	0.923	0.974
Time fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Dealer fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Country controls	NO	YES	YES	YES	YES	NO	YES	YES	YES	YES
Dealer controls	NO	YES	YES	YES	YES	NO	YES	YES	YES	YES
Frequency	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly
Number of dealers	16	16	16	16	16	16	16	16	16	16

Notes: The table shows the results of panel regressions of dealer-level liquidity provision in the gilt market. The regressions are at quarterly frequency. For columns (1)-(4) and (6)-(9), the sample period is 2008:Q1 to 2015:Q4. For columns (5) and (10), the sample period is 2014:Q1 to 2017:Q4. The regression specification is given by equation (2). In columns (1)-(5), $LiquidityProvision$ is measured as round-trip cost estimated at the dealer level (higher values indicate less liquidity provision). In columns (6)-(10), $LiquidityProvision$ is measured as the log of the dealer's trading volume with clients (higher values indicate more liquidity provision). $Dec2011\_Constrained$ is defined in equation (3). $Dec2011\_PTLR$ is defined in equation (4). $Treated$ and $PTLR$ are defined in equation (5). $Jan2016\_Treated$ is defined in equation (6). Country controls are the GDP growth rate and equity index growth rate in the country where the dealer has its main headquarters. Dealer controls are the first lag of liquidity provision; log of total assets; return on assets; the share of assets that are recorded as being in the trading book; the share of assets that are cash or government bonds; and the risk-weighted capital ratio. The sample consists of U.K. banks and U.K. subsidiaries of foreign banks. Standard errors (double-clustered at the dealer and time levels) are shown in parentheses. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 11: Dealer-level panel regression results: repo market

	(1)	(2)	(3)	(4)	(5)
Variables			Log(Repo borrowing)		
$Dec2011\_Constrained$	-0.651	-0.200			
	(0.777)	(0.123)			
$-Dec2011\_PTLR$			-0.0296		
			(0.0311)		
$Treated$				0.122	
				(0.0961)	
$-PTLR$				-0.00726	
				(0.0249)	
$Jan2016\_Treated$					0.0779
					(0.161)
Observations	558	496	496	496	268
R^2	0.852	0.959	0.959	0.959	0.978
Time fixed effects	YES	YES	YES	YES	YES
Dealer fixed effects	YES	YES	YES	YES	YES
Country controls	NO	YES	YES	YES	YES
Dealer controls	NO	YES	YES	YES	YES
Frequency	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly
Number of dealers	19	19	19	19	19

Notes: The table shows the results of panel regressions of dealer-level liquidity provision in the gilt repo market. The regressions are at quarterly frequency. For columns (1)-(4), the sample period is 2008:Q1 to 2015:Q4. For column (5), the sample period is 2014:Q1 to 2017:Q4. The regression specification is given by equation (2). $LiquidityProvision$ is measured as the log of total repo borrowing (higher values indicate more liquidity provision). $Dec2011\_Constrained$ is defined in equation (3). $Dec2011\_PTLR$ is defined in equation (4). $Treated$ and $PTLR$ are defined in equation (5). $Jan2016\_Treated$ is defined in equation (6). Country controls are the GDP growth rate and equity index growth rate in the country where the dealer has its main headquarters. Dealer controls are the first lag of liquidity provision; log of total assets; return on assets; the share of assets that are recorded as being in the trading book; the share of assets that are cash or government bonds; and the risk-weighted capital ratio. The sample consists of U.K. banks and U.K. subsidiaries of foreign banks. Standard errors (double-clustered at the dealer and time levels) are shown in parentheses. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

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